SPARROW

Sensor **P**ackage for **A**dvanced **R**econnaissance and **R**obust **O**perational **W**orkflows

Group 20

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Chapter 1 - Executive Summary

Throughout the years, drones have emerged as versatile tools used in a wide range of applications. One of the most impactful uses of drones is their role in search and rescue operations. These missions require a well-coordinated system that combines drones with a robust base station to aid in search and rescue efforts. To address this challenge, a team of engineering students at the University of Central Florida have introduced an innovative solution: a base station that integrates with autonomous drones, designed specifically to streamline search and rescue operations by scouting areas and locating individuals in need.

At the heart of our solution is SPARROW, a central controller and communication hub that utilizes advanced networking capabilities to maintain a continuous data stream between drones and the base station. SPARROW is the core of a system that integrates drones and a base station to enable real-time communication, image processing, and data transfer. The system provides live camera feeds from drones, analyzes the data, and transmits actionable insight back to the base station.

SPARROW works in tandem with a fleet of SOAR drones, creating a synchronized system that significantly enhances the coverage of larger areas. Developed in collaboration with other University of Central Florida engineering students, SPARROW has equipped SOAR with a Sensor Package designed for obstacle and human detection. These drones capture camera and sensor data, which SPARROW then analyzes to detect individuals.

Overall, this integration of SPARROW with SOAR drones represents an advancement in search and rescue operations. This system not only improves response time but allows companies to perform the critical search and rescue operations in a wide array of various environments.

This document outlines the design process for SPARROW, beginning with the motivation and background that inspired this project. It continues with the research and part selections associated with this project as well as the reasoning behind our selections, highlighting the factors that influenced our choices. We then address the standards and constraints that had to be considered throughout our design process, followed by the schematics that illustrate how our components will be implemented into our final design. The document then covers the fabrication and testing phases, describing the methods we used to build and evaluate our design. We also include the administrative details of our project such as our initial budget, bill of materials, work distribution, and project milestones. This document then concludes with a summary of our findings and reflections on the project's outcomes, offering recommendations for future improvements.

Chapter 2 – Project Description

2.1 Project Motivation and Background

Search and rescue operations have long been a critical response to many emergency situations. Traditionally carried out by human teams, these operations have seen significant advancements with the integration of drone technology. Drones offer a distinct advantage for search and rescue applications, as they are capable of providing an aerial perspective that enhances situational awareness as well as facilitates more effective search for individuals in need.

To address the challenges of traditional methods and to improve the safety and efficiency of these operations, SPARROW presents an innovative solution that establishes communication between drones and a base station controller, enabling drones to scan affected areas and transmit real-time data back to the base station for analysis. By leveraging this aerial data, SPARROW enhances the safety and efficiency of search and rescue efforts.

A key feature of SPARROW is its integration of advanced computer vision technology, which allows it to process visual data in real time. This capability allows the system to detect any individuals in need and display critical information directly onto the controller's interface. By automating the identification process, SPARROW accelerates the assessment phase, ensuring quicker responses while also reducing the risk to human responders by minimizing the need to physically inspect these areas.

This integration of computer vision into drone-based applications represents a progressive approach to search and rescue operations. SPARROW's design, which combines the strengths of drones and base station controllers, allows for rapid, data-driven decision-making during search and rescue operations. This system not only streamlines these operations, but ultimately promises to minimize disruptions caused by emergencies, offering a reliable and efficient method of saving lives in challenging environments.

2.2 Current Technologies and Existing Projects

DJI RC Pro

The DJI RC Pro is a drone controller designed and manufactured by DJI, a leading technology company based in Shenzhen, China. Renowned for producing a wide array of unmanned aerial vehicles (UAVs) used extensively in aerial photography, surveying, and other applications, DJI has become synonymous with innovation and quality in the drone industry. The DJI RC Pro stands out as a versatile and high-performance controller, engineered to be compatible with and control a broad range of DJI's drone products. Our group must consider the design decisions of an industry leader such as DJI so that we may produce a competitive product that attempts to improve areas where the DJI RC Pro is lacking.

One of the standout features of the DJI RC Pro is its advanced communication capabilities. It employs four 2T4R high-gain antenna systems, in combination with O3+ video transmission technology. This combination allows the controller to send and receive information from distances exceeding 15 kilometers, ensuring strong connectivity even in challenging environments. The transmission system operates with a latency of 120 milliseconds, providing real-time control and feedback essential for precision flying. Additionally, the controller supports video transmission at a resolution of 1080p/60fps, ensuring clear and detailed visuals for the operator.

Incorporating a lithium-ion battery with 5000 mAh at 7.2 V of capacity, the DJI RC Pro is provided with a rated power of 12 W. The controller is designed for quick recharging, requiring only 1.5 hours to reach full capacity when using a 15 V USB charger. Once fully charged, the DJI RC Pro can operate continuously for up to 3 hours before running out of battery.

It is because of the DJI RC Pro’s elegance and performance that has made it an industry standard, widely regarded for its ability to support a diverse range of drones while maintaining high-resolution video transmission with minimal latency. This reliability is crucial for professionals who depend on accurate and timely data from their drones and is even more crucial during emergency responses.

However, while the DJI RC Pro excels in many areas, there is always room for improvement and specialization to meet specific needs. This is where SPARROW comes into play. SPARROW aims to build upon the strong foundation provided by the DJI RC Pro, addressing areas where enhancements are necessary. One key focus is implementing AI systems to automate and accelerate the search and rescue process.

Another difference is that SPARROW will emphasize enhancing the autonomous capabilities of the drone system. This includes a camera array and sensors integrated in a package that is attached to SOAR that enables the drone to detect personnel autonomously using computer vision. Such capabilities are particularly critical in search and rescue scenarios, where quick and efficient detection is essential for ensuring safe recovery. By improving these aspects, SPARROW aims to create a drone controller and system that is not only reliable but also highly specialized for critical tasks in challenging environments.

HSE Carrier Ground Control Station (C-GCS)

The Carrier Ground Control Station (C-GCS) is an advanced control unit developed and produced by Homeland Surveillance & Electronics (HSE), a UAV technology company based in Florida, United States. HSE is known for its innovation in drone technology, specializing in the production of UAVs and drone controllers primarily used by first responders and the agricultural industry. The company’s commitment to creating reliable and efficient UAV solutions has made it a trusted name among professionals who depend on aerial technology for their critical operations. It is important for our group to consider the design decisions of a specialized product such as the HSE C-GCS so that we may improve our product.

The C-GCS stands out as a versatile and powerful ground control station, fully compatible with all HSE drones. This compatibility ensures seamless integration and operation, allowing users to efficiently manage and control their UAVs from a single interface. In addition to supporting HSE's drones, the C-GCS is designed to be easily integrated with other third-party UAV platforms. This flexibility is crucial for users who operate a diverse fleet of drones from different manufacturers, providing a unified control system that simplifies operations and enhances efficiency.

One of the key features of the C-GCS is its advanced communication capabilities. It employs an RFD900 and a TBS Crossfire, two high-performance communication systems that enable the control station to send and receive information at distances exceeding 15 kilometers. This long-range capability is essential for operations that require extensive coverage, such as search and rescue missions, large-scale agricultural monitoring, and post-natural disaster responses.

The C-GCS is powered by a 4S lithium-ion battery with a capacity of 5200 mAh, providing ample power for extended operations. For users who require longer operational periods, the C-GCS offers an optional configuration that allows two batteries to be run in parallel, effectively doubling the capacity to 10400 mAh. This flexibility in power options ensures that the control station can meet the demands of various missions, from short, intensive tasks to prolonged, continuous operations.

The durability and reliability of the C-GCS make it a dependable tool for professionals working in demanding environments. HSE has built the control station to withstand harsh conditions, ensuring that it remains operational even in challenging weather and terrain. This robustness is particularly important for first responders who often operate in extreme conditions and for agricultural users who need reliable equipment to manage their fields effectively.

However, similarly to the DJI RC Pro, the C-GCS, despite its numerous advantages, is still lacking in a few areas where SPARROW seeks to improve. We impliment a mesh network to expand its effective operational range at the cost of higher latency. This makes SPARROW better suited for autonomous, drone fleet surveying of an area, allowing it to quickly search a large area and detect personnel in a fraction of the time a single drone would take.

Summary

Examining currently available commercial technologies and past projects relevant to our current product provides valuable insights into our project's potential direction. Understanding existing solutions not only helps us set practical constraints and requirements but also informs us about the areas where we can innovate and improve.

In the case of our current project, we are focusing on two key examples: the DJI RC Pro and the HSE Carrier Ground Control Station (C-GCS). These products highlight different strengths and areas for improvement that are pertinent to our development goals.

The DJI RC Pro serves as a prime example of an industry standard. By analyzing its design, we learned several things about implementing an effective communication system, which would allow our controller to send information to the drone fleet at distances much further than we initially expected at the start of this project. Additionally, we also recognized some areas we could improve upon, such as the DJI RC Pro’s autonomous capabilities. By implementing a detection algorithm utilizing AI, the autonomous capabilities of SPARROW have dramatically increased.

The HSE C-GCS serves as a prime example of a specialized product, similar to our own. We recognized several design choices in the C-GCS that would allow SPARROW to fulfill its intended purpose at a much higher capacity. One such design choice is its power storage and management system. We intend for SPARROW to have a very high battery life when compared to other products that share a similar purpose. Furthermore, we also want SPARROW to be extremely sturdy so that it can handle even the roughest conditions and still be reliable and efficient. The C-GCS utilizes a sturdy case that allows for larger batteries while still keeping the controller safe from any hazards at the cost of both size and weight.

In conclusion, studying the DJI RC Pro and the HSE C-GCS has provided our group several insights into how we should proceed with our research and has given us a direction to move forward. We should pay special attention to our antenna array as there seems to be the most technical variance between the two products. We should also ensure our autonomous capabilities are sufficient so that our project can effectively meet its goals. By integrating these insights into our design process, we can create a product that not only meets but exceeds several current industry standards, providing innovative solutions for drone control and operations in challenging environments.

2.3 Goals and Objectives

The central goal of this project is to develop a drone control station capable of seamlessly managing communication with a drone's sensor package, specifically designed for search and rescue operations. This system, SPARROW, is designed to identify individuals in need of assistance and transmit the video feedback to the base station controller to alert the users. Our project's design focuses on achieving several key goals and objectives, with additional stretch goals aimed at enhancing the system's functionality.

Overall Goals

- **Communication**: SPARROW must establish and maintain reliable communication between the drone and base station to ensure uninterrupted operation.
- **Human Detection**: SPARROW must accurately identify any humans in need of help within the operational area.

Objectives

- **Data Transmission**: Seamlessly transmit data to the drone for effective deployment and operation.
- **Data Reception**: Receive data from the drone, including their findings and operational status.
- **Image Display**: Provide an image feed from the drones' cameras to allow monitoring and immediate assessment of the situation.
- **Automatic Search and Rescue Detection**: Utilize advanced computer vision technology to automatically detect individuals in need of assistance without requiring direct human intervention.

Stretch Goals

- **Automated Drone Recall:** Ensure that the drone fleet can be automatically recalled when the battery levels of either the drone fleet or the controller reaches critical levels.
- **Base Station Charging:** Achieve a system where the base station has a charging station where the drone can autonomously come down and recharge its battery.
- **Payload Deployment:** Achieve a system where the drone package would have room to carry a payload that can be developed in the scene for injured humans spotted in the wild.
- **User Interface:** Maximize user interactivity and ease of operation by incorporating a touchscreen display.

Hardware - Basic Goals

The core functionality of SPARROW revolves around allowing seamless bi-directional data transmission with the SOAR drones. To achieve this, SPARROW must be equipped with some form of antenna, which is essential to issue commands to the drones and to transfer data between the base station and the drones. Converting electronic signals into electromagnetic waves that establish communication links between transmitters and receivers across free space, the antenna is one of the most crucial components for SPARROW.

In any wireless communication system, the antenna plays a pivotal role in maintaining seamless connectivity. For our project, it's important to select an option that is capable of operating effectively over long distances. This capability would not only ensure robust communication but enhance safety by allowing remote control from safer, more secure locations.

Additionally, SPARROW must support a high-resolution display to manage and monitor live image streams from the drones. The display should provide an intuitive interface, allowing users to seamlessly switch between camera feeds, including the regular and infrared views. Furthermore, incorporating a feature that displays the GPS locations of each drone in the fleet would greatly enhance situational awareness, aiding in real-time tracking and efficient coordination.

Power management is another critical aspect of the SPARROW design. SPARROW will be equipped with a battery array designed to last twice as long as the drone's operational time. This redundancy ensures uninterrupted performance during extended missions.

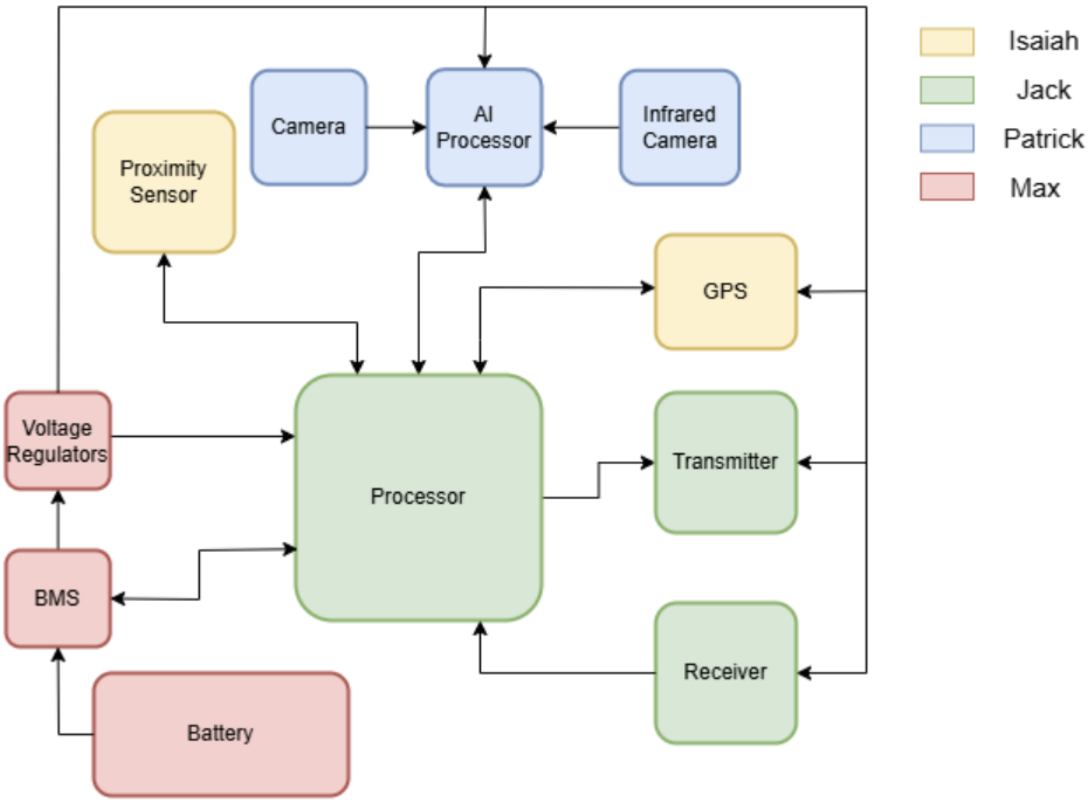


Figure 2.1. *Sensor Package Hardware Block Diagram by Authors*

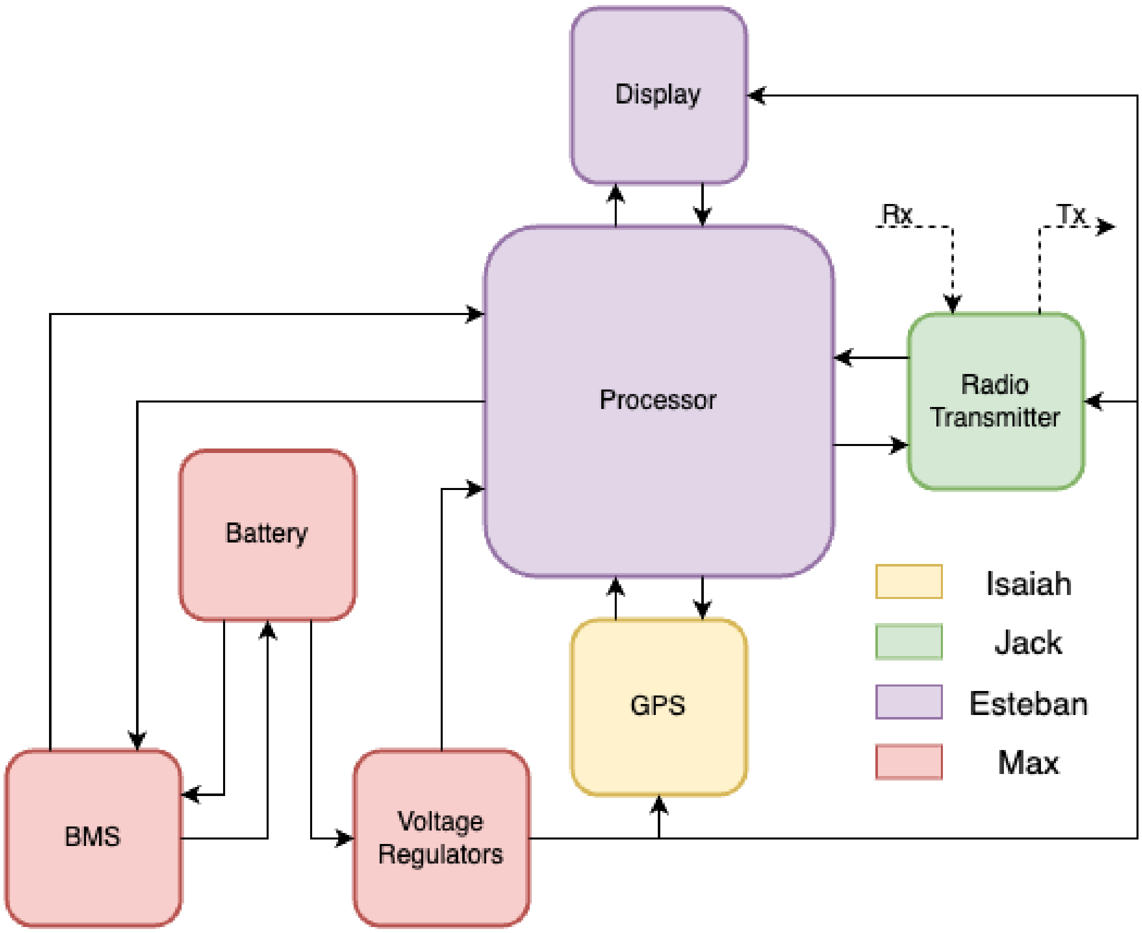


Figure 2.2. *Base Station Hardware Block Diagram by Authors*

Stretch Goal - Base Station Charging

Integrating an autonomous charging station in our system would significantly enhance the efficiency and sustainability of the drone operations. By utilizing wireless charging technology, the drones would be able to recharge their batteries immediately upon landing, minimizing damage to any physical connectors and preventing overcharging through built-in mechanisms.

The drones could utilize their already existing navigation system which incorporates GPS, LiDAR, radar, and computer vision to execute precise landings at the charging station. As a drone approaches its battery limit, it could autonomously navigate back to the base station, initiating the charging process upon landing. Real-time updates on the battery status could be displayed on a dashboard accessible through the base station, ensuring operators have complete oversight.

To further enhance its functionality, the charging station could also feature sensors that monitor the overall health of the charging station, alerting operators to any potential maintenance needs. These alerts would allow for proactive upkeep, ensuring consistent reliability and reducing downtime. Additionally, the base station could incorporate renewable energy sources, such as solar panels, to power the charging station, creating a more sustainable system.

Stretch Goal - Extended Battery Life

Enhancing the battery life of the controller would significantly increase its utility, allowing it to operate for extended periods without requiring frequent recharging. This improvement would be particularly valuable in scenarios where uninterrupted use is critical, such as during prolonged missions or in remote locations where charging options are limited.

To achieve extended battery life, several strategies could be employed. The design could incorporate higher-capacity batteries or more batteries while ensuring compatibility with the controller's compact form factor. Advanced power management techniques, such as dynamic power scaling, could optimize energy consumption based on usage patterns, conserving power during low-demand operations.

Additionally, integrating solar panels or other renewable energy sources into the controller's housing could provide supplementary charging during daylight hours, further reducing downtime. The implementation of energy-efficient components, such as low-power displays and processors, would also contribute to prolonging battery life without compromising functionality.

Stretch Goal - Payload Deployment

Implementing a system where the drones could carry a payload, such as medical equipment, would require careful optimization of the drone's overall weight. This feature, though, would allow the drones to deliver essential supplies to anyone in need, providing immediate assistance before rescue teams arrive.

In order for such a situation to be feasible, the sensors, cameras, and other components integrated onto the drone must be designed to minimize weight without sacrificing performance. Lightweight alternatives could be utilized to reduce the overall weight of the drone. Additionally, the drone's frame and structural elements must also be optimized to maintain structural integrity while still managing to keep the system as light as possible. The payload system must be carefully designed to conform to these limitations of the drone. It must account for the combined weight of the payload and the drone and the payload compartment must also be secure and easily deployable, allowing individuals on the ground to retrieve the supplies with ease.

Stretch Goals - User Interface

Maximizing user interactivity and ease of operation through the use of a touchscreen display could greatly improve upon SPARROW's design. A touchscreen interface simplifies system management, enabling operators to interact directly with the base station. This design choice enhances the overall efficiency and usability of the system, reducing the learning curve and streamlining operations during critical search and rescue missions.

The touchscreen display would serve as the primary interface between the operator and the drone system. Its interface can be customized to provide quick access to essential functions, such as monitoring drone status, and viewing live image feeds. Features like swipe, tap, and pinch-to-zoom gestures allow for efficient navigation through camera views and maps, enabling the operator to remain focused on the task at hand without fumbling through complex controls.

Software Goals

The primary software goal of this project is to develop a network system enabling real-time communication between an autonomous drone tasked with recognizing humans in the field and signaling humans in need of help. The communication will ensure that drones can dynamically share critical data such as video feed and the thermal footage and in order to prevent collisions and optimize coverage, our package will implement autonomous flight software communication to establish connection with the base station. By leveraging this communication framework, the drone will be able to collaboratively identify and report human recognition for efficient and safe inspection processes for a search and rescue operation. The system will include emergency landing and return-to-home protocols, ensuring reliable operation even in challenging environments.

In addition to the network that will be implemented, a main part of the project revolves around the image recognition capabilities to enhance the drones ability to identify and analyze humans in need of help. Using a high-resolution camera and an advanced image processing algorithm, the drones will capture and process real-time images of the scenario to determine whether there is a need for rescue. The image recognition software will be trained to detect humans and automatically report these situations back to the control center with its location. The goal is to significantly improve the speed of human detection, enabling quicker response times and reducing the risk of humans being left outside and unrescued for an extended amount of period.

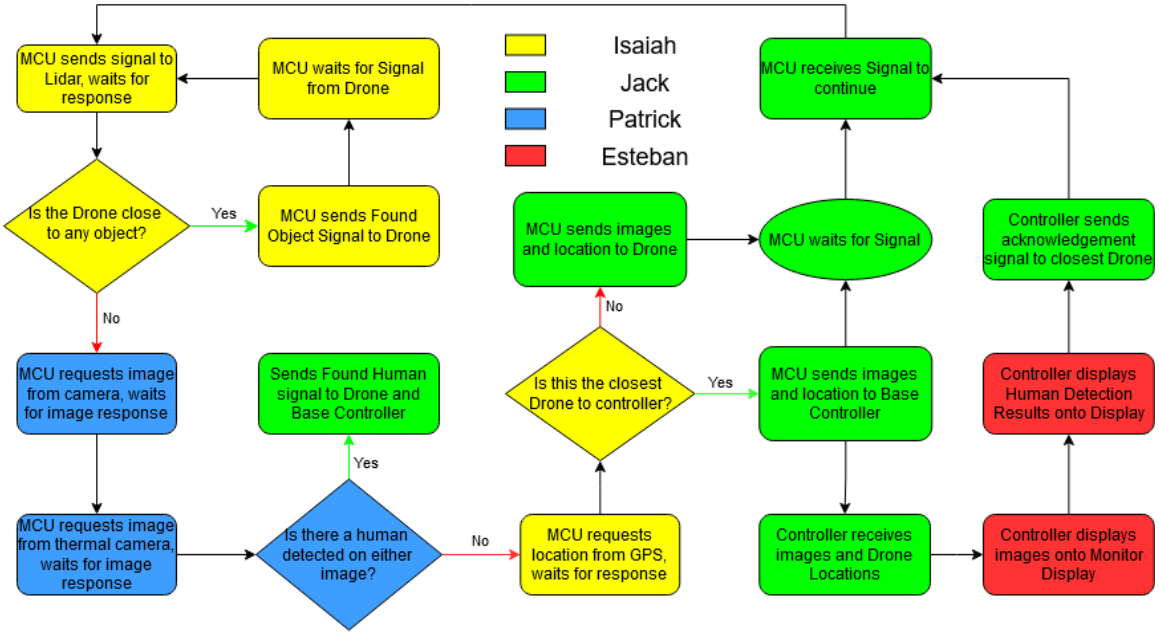


Figure 2.3. *Software Flowchart by Authors*

2.4 Expected Specifications

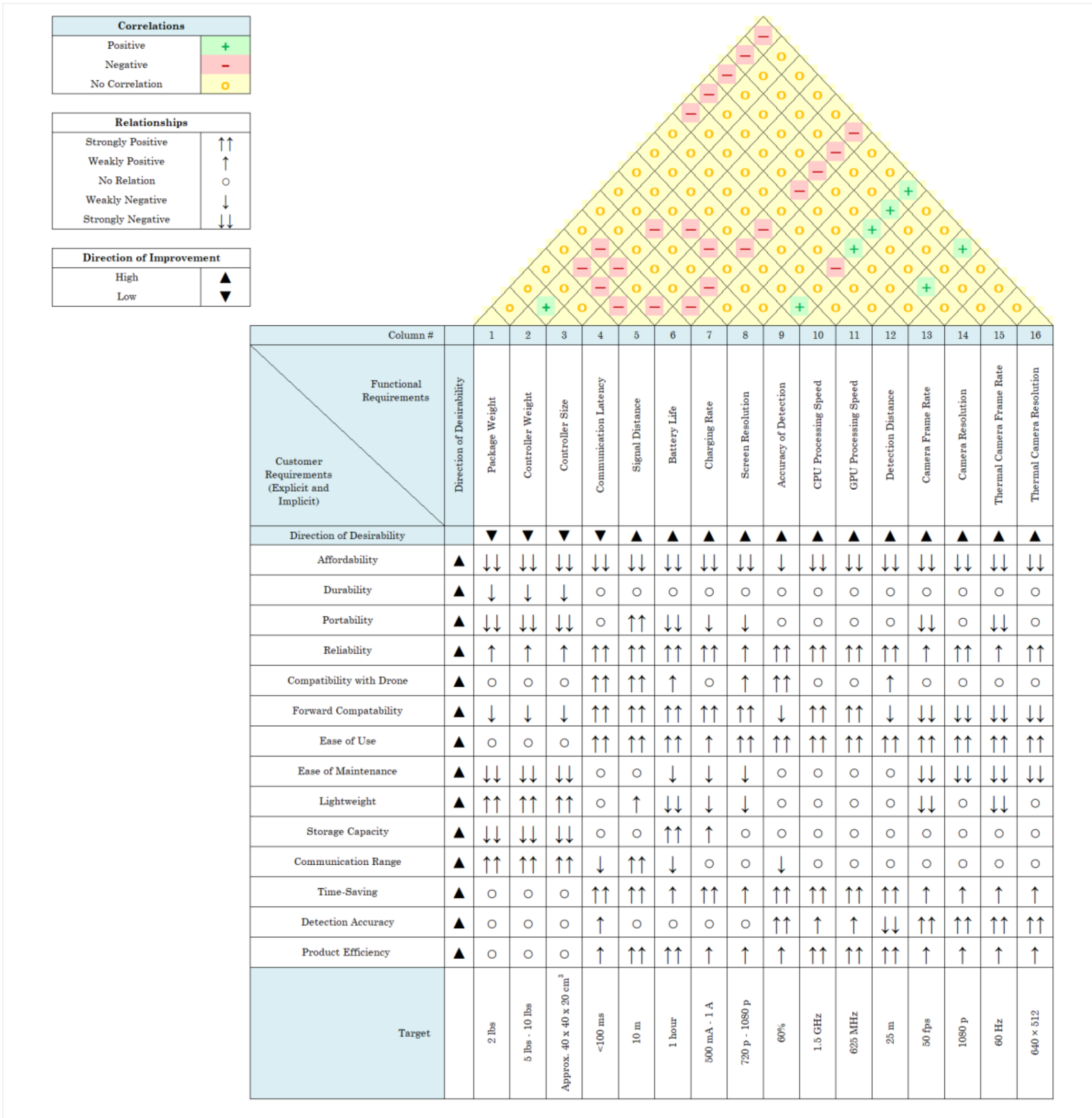
Keeping in mind our goals and objectives for this project, we defined the following specifications to assist in our design process:

Table 2.1. *Expected specifications of SPARROW by Authors*

Physical Qualities	
Maximum Total Weight	2 kg
Minimum Size	40x40x20 cm^3
Communication System	
Minimum Range	12 m
Minimum Data Rate	50 kbps
Maximum Latency	100 ms
Video Reception	
Maximum Range	5 mi

Data Rate	10 Mbps
Display	
Minimum Resolution	720p
Minimum Size	5 in
Maximum Size	13 in
Minimum Refresh Rate	60 Hz
Maximum Response Time	5 ms
Minimum Brightness	400 nits
Video Processing	
Clock Speed	1.5 GHz
Flash Memory	2 MB
RAM	8 GB
Operating Voltage	5 V
Detection Accuracy	60%
Data Throughput	500 Mbps
Power System	
Battery Life	≥ 1 hour
Voltage Output	3.3 V and 12 V
Maximum Current Draw	5 A
Minimum Power	81 W

2.5 House of Quality



Column #		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Functional Requirements / Customer Requirements (Explicit and Implicit)	Direction of Desirability	Package Weight	Controller Weight	Controller Size	Communication Latency	Signal Distance	Battery Life	Charging Rate	Screen Resolution	Accuracy of Detection	CPU Processing Speed	GPU Processing Speed	Detection Distance	Camera Frame Rate	Camera Resolution	Thermal Camera Frame Rate	Thermal Camera Resolution
Direction of Desirability		▼	▼	▼	▼	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
Affordability	▲	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓
Durability	▲	↓	↓	↓	○	○	○	○	○	○	○	○	○	○	○	○	○
Portability	▲	↓↓	↓↓	↓↓	○	↑↑	↓↓	↓	↓	○	○	○	○	↓↓	○	↓↓	○
Reliability	▲	↑	↑	↑	↑↑	↑↑	↑↑	↑↑	↑	↑↑	↑↑	↑↑	↑↑	↑	↑↑	↑	↑↑
Compatibility with Drone	▲	○	○	○	↑↑	↑↑	↑	○	↑	↑↑	○	○	↑	○	○	○	○
Forward Compatability	▲	↓	↓	↓	↑↑	↑↑	↑↑	↑↑	↑↑	↓	↑↑	↑↑	↓	↓↓	↓↓	↓↓	↓↓
Ease of Use	▲	○	○	○	↑↑	↑↑	↑↑	↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑
Ease of Maintenance	▲	↓↓	↓↓	↓↓	○	○	↓	↓	↓	○	○	○	○	↓↓	↓↓	↓↓	↓↓
Lightweight	▲	↑↑	↑↑	↑↑	○	↑	↓↓	↓	↓	○	○	○	○	↓↓	○	↓↓	○
Storage Capacity	▲	↓↓	↓↓	↓↓	○	○	↑↑	↑	○	○	○	○	○	○	○	○	○
Communication Range	▲	↑↑	↑↑	↑↑	↓	↑↑	↓	○	○	↓	○	○	○	○	○	○	○
Time-Saving	▲	○	○	○	↑↑	↑↑	↑	↑↑	↑	↑↑	↑↑	↑↑	↑↑	↑	↑	↑	↑
Detection Accuracy	▲	○	○	○	↑	○	○	○	○	↑↑	↑	↑	↓↓	↑↑	↑↑	↑↑	↑↑
Product Efficiency	▲	○	○	○	↑	↑↑	↑↑	↑	↑	↑	↑↑	↑↑	↑↑	↑	↑	↑	↑
Target		2 lbs	5 lbs - 10 lbs	Approx. 40 x 40 x 20 cm^3	<100 ms	10 m	1 hour	500 mA - 1 A	720 p - 1080 p	60%	1.5 GHz	625 MHz	25 m	50 fps	1080 p	60 Hz	640 × 512

Figure 2.4. *House of Quality*
by Authors

Chapter 3 – Research and Investigation

3.1 Proximity Sensor

The proximity sensor plays a crucial role in a drone's object avoidance system, primarily designed to detect obstacles in its path and prevent collisions that could lead to catastrophic failures. For the proximity sensor to be effective, it must have an appropriate range and detection speed, allowing the drone enough time to react, regardless of its speed.

Another important factor would be ease of integration. The proximity sensor we choose should utilize a standard communication protocol such as I2C, SPI, or UART to ensure seamless communication with the drone and facilitates high data transmission speeds necessary for real-time responses.

The field of view (FOV) of the sensor is also significant. A wider FOV allows a single sensor to monitor a larger area, reducing the number of sensors needed. This reduces the footprint of the sensors on the drone as well as minimizing the costs and power consumption.

Power consumption itself is a major factor to consider when selecting a sensor since it will operate on battery power. Low-energy sensors can significantly extend flight time, making them practical for long-duration missions. Additionally, the accuracy of the sensor is essential, particularly when considering the variety of environments that the drones could be operating in. The sensors must be able to provide reliable reading when faced with interferences such as rain or snow or any potential changes in lighting.

Overall, selecting the right proximity sensor technology involves balancing range, speed, efficiency, power consumption, and accuracy. We also have to make sure our sensor is reliable and adaptable for different scenarios.

Ultrasonic Sensor

Ultrasonic sensors present a cost-effective and low-power option for object avoidance by utilizing sound waves and timers to measure the distance to nearby objects. These sensors are widely available and utilize standard communication protocols that can operate at speeds sufficient for object detection. However, these sensors can only measure distances of up to 50 feet in ideal conditions.

Despite their affordability and low power requirements, ultrasonic sensors may not be the best choice for object avoidance in this particular application due to the various environmental challenges we could encounter and the low range raises concerns about their reliability and effectiveness in our design.

To address these limitations, it may be beneficial to explore alternative sensing technologies. LiDAR sensors, for instance, offer higher accuracy and faster detection times, making them more suitable for dynamic environments, although they typically come at a higher cost and consume more power. RADAR sensors, on the other hand, are less affected by environmental conditions like rain or fog, functioning well at longer ranges, though they may be bulkier and more expensive. Ultimately, exploring sensors that deliver enhanced reliability in a variety of conditions and faster response times is essential.

LiDAR

LiDAR technology offers a compelling alternative for object avoidance on the drone, despite its higher cost and power consumption compared to ultrasonic sensors. By using light instead of sound, LiDAR significantly enhances both the range and speed of object detection, capable of identifying distances up to 200 meters, whereas ultrasonic sensors max out at around 50 feet.

One of the key advantages of LiDAR is its ability to generate a detailed 2D image of the drone's entire surroundings, as opposed to only covering one side like ultrasonic sensors. While rain can affect the accuracy of LiDAR readings, the rapid speed at which it sends out light pulses mitigates this issue. In most cases though, rain droplets are unlikely to obstruct LiDAR's detection capabilities significantly.

However, one of the challenges with LiDAR is the presence of high ambient light conditions. Excessive natural light can interfere with the detection process, as the light pulses may lose energy when bouncing off objects, making them indistinguishable from surrounding ambient light.

Recent advancements have also led to the availability of boards that facilitate easy communication with LiDAR sensors using standard protocols that are sufficiently fast for object avoidance applications. While LiDAR sensors can be more expensive and larger than their alternatives, their superior detection speed and accuracy position them as a strong choice for effective object detection.

Radar

Radar is another viable option for object detection, partially due to its cost-effectiveness. Additionally, one of its significant advantages is its ability to detect objects reliably in rainy conditions, making it well-suited for various environments. Radar systems typically offer a substantially larger detection range, although this comes with a decrease in resolution as the range increases.

Boards equipped to communicate using standard protocols for quick object avoidance are readily available, facilitating integration into existing systems. However, it's important to note that while radar offers greater range, it does not match the accuracy or level of detail provided by LiDAR.

Overall, radar serves as a lower-frequency alternative to LiDAR, allowing for effective object detection even in adverse conditions, though at the cost of resolution and detection speed. Its lower price point compared to LiDAR, combined with the ability to fit into more compact boards, makes radar an attractive choice for proximity sensing in drone applications.

Overall, while radar may not offer the same level of detail as LiDAR, its robustness in various weather conditions and ease of integration make it a practical option for effective object detection.

Table 3.1. *Comparison of proximity sensor technologies by Authors*

Criteria	LiDAR	RADAR	Ultrasonic Sensor

Environmental Robustness	Moderate	Good	Bad
Detection Speed	Good	Good	Bad
Detection Accuracy	Good	Moderate	Bad
Detection Range	Good	Good	Bad
Ease of Data Transfer	Good	Good	Good
Power Consumption	Moderate	Moderate	Good
Size	Moderate	Good	Bad
Price	Moderate	Good	Good

Proximity Sensor Technology Selection

Based on the performance of each proximity sensor, we selected to use LiDAR since it met the specific requirements for SPARROW. LiDAR is reliable, accurate, and has a satisfactory detection range and speed that will meet the needs of SPARROW. LiDAR is often used in industry as well, as it supports the downsides of each respective sensing technology, further validating its effectiveness. While ultrasonic sensors were initially considered due to their low cost and ease of implementation, they were ultimately not selected because of their lower detection range, accuracy, and speed.

The criteria used to determine the proximity sensor for SPARROW were price, size, weight, detection accuracy, detection speed, detection range, standard protocol compatibility, and environmental robustness. Among these factors, size and weight are a major concern as drones have limited payload capabilities. Excess weight not only affects the ability to carry any additional sensors, but also impacts the power consumption. As the drone carries more weight, the motors will have to generate more force in order to keep the drone in the air, increasing the power draw from the batteries. This would significantly decrease the flight time, thus decreasing the effectiveness of the product.

Standard protocol compatibility is another important factor, as it determines the ease of integration onto the main board. This would make it simpler for the software team to implement, allowing for easier optimization of the system as a whole.

Price is also an important consideration; finding a cost-effective solution without compromising any of the other criteria. Together, these criteria form the foundation for selecting the most suitable proximity sensor for SPARROW, ensuring that they satisfy the requirements of our project without compromising performance.

RPLIDAR C1

The RPLIDAR C1 presents a viable choice for the LiDAR sensor on SPARROW. It offers a full 360-degree field of view with a maximum detection range of 12 meters. The LiDAR sensor performs a full 360-degree scan at a rate of up to 10 Hz, generating 1,400 samples per cycle. With a distance resolution of approximately 0.2 cm, it demonstrates exceptional accuracy. The RPLIDAR C1 sensor operates effectively in various lighting conditions, though it shouldn't be directly facing the sun. The sensor also has resistance to ambient light, increasing its effectiveness in non-ideal environments.

Communication with the RPLIDAR C1 is straightforward as the sensor utilizes UART, making it easy to interface with a microcontroller. Additionally, it comes with an existing software library, simplifying the implementation process. The RPLIDAR C1 is housed in a protective plastic enclosure, protecting it from environmental factors. Furthermore, the connector has a plastic locking mechanism to ensure safety during flight.

Functionally, the RPLIDAR C1 meets all of the requirements for SPARROW's LiDAR sensor, enabling swift and accurate detection of objects in the surrounding area. However, there are notable drawbacks to consider, including size, weight, power consumption, and cost. The dimensions of this sensor are relatively large, measuring 96.8 x 70.3 x 55 mm. It operates at 5 volts and draws an average current of 450 mA, meaning that the device consumes 2.25 watts of power. Additionally, the sensor is relatively heavy, weighing 170 grams, largely due to the motor required for spinning and achieving a full 360-degree view. The price is around $100.

Overall, the RPLIDAR C1 sacrifices size, weight, power consumption, and cost for high performance. Despite its significant drawbacks, it remains a strong competitor for SPARROW's LiDAR sensor due to its impressive capabilities.

TFmini Plus

The TFmini Plus, is a small, lightweight, and durable LiDAR sensor that presents itself to be a compelling option for SPARROW's LiDAR sensor. Unlike the RPLIDAR A1, the sensor does not offer 360-degree sensing, resulting in significantly lower size, weight, and power consumption since it operates without a motor. This limitation, though, means that it can only detect objects in one direction.

Despite this drawback, the TFmini Plus is relatively accurate, with a detection range of up to 12 meters, and a distance resolution of 1 cm. It has a sample rate of 1,000 samples per second, which is notably lower making it significantly slower than the RPLIDAR A1. However, the TFmini Plus is resistant to ambient light, functioning effectively in conditions up to 70 klux. For reference the ambient light on a sunny day is up to 25 klux making the TFmini Plus more than suitable for various weather conditions.

The TFmini can communicate using either I2C or UART, making it easily interfaceable with a microcontroller. While the user manual provides details on the serial packet contents, there is no pre-existing library available for quick implementation. Functionally, although the TFmini Plus lacks 360-degree sensing and is slower than the RPLIDAR A1, it remains a solid choice due to its straightforward software interface and strong ambient light immunity.

From a structural standpoint, the TFmini Plus is strong, featuring an IP65-rated casing that provides resistance to dust and relative waterproofing, which means that the casing can withstand rain, but shouldn't be dunked underwater. The sensor also uses very little power, with the maximum power consumption only being around 700 mW and less than 100 mW when operating in low-power mode.

With dimensions of 35 x 18.5 x 21 mm and a weight of just 12 grams, the TFmini Plus is exceptionally compact and lightweight, making it ideal for drones that have strict size and weight constraints. Additionally, at a price point of $52.90, it is considerably cheaper than the RPLIDAR A1.

Overall, while the TFmini Plus can only detect in one direction, its speed, resolution, and detection distance meet SPARROW's requirements. Additionally, its compact size, low power consumption, and cost-effectiveness make it a strong candidate for the LiDAR sensor in SPARROW.

LDROBOT D300

The LDROBOT D300 sensor is another viable option for the SPARROW's LiDAR sensor. The D300 provides 360-degree sensing with a detection range of up to 12 meters. It provides an impressive 4,500 data points at a rate 13 Hz, enabling rapid and accurate mapping of obstacles surrounding the drone. With an IP-65 rated housing, the D300 is designed to resist external elements such as dust and water.

The sensor communicates its data using UART, providing a straightforward interface where the microcontroller functions primarily as a receiver of the data packets. The motor that controls the rotation of the LiDAR sensor can operate independently, eliminating the need for a PWM signal, although the option still remains available. Additionally, the D300 has ambient light resistance up to 30 klux, ensuring effective operation even on sunny days.

In terms of specification, the D300 outperforms the RPLIDAR A1, with a faster cycle rate and higher points per cycle. The D300's typical operating current is 180mA at 5 V, making its power draw only 900 mW. While this is higher than the TFmini, it is significantly lower than the RPLIDAR A1, which had a higher power requirement due to its motor.

The D300 is compact, being 38.59 x 38.59 x 33.50mm, making it significantly smaller than the RPLIDAR A1 and only slightly larger than the TFmini. With a weight of 47 grams, it is much lighter than the RPLIDAR A1, which is advantageous for drone integration.

The primary drawback of the D300 is its cost. The price of the D300 LiDAR kit is $120, making it more expensive than the RPLIDAR A1 and the TFmini. However, due to its functional capabilities, and its lighter weight and smaller size, the D300 is a good choice for the LiDAR sensor for SPARROW. Its overall performance and suitability for the operational environment make it an attractive option for ensuring effective object avoidance.

Table 3.2. *Comparison of LiDAR products by Authors*

Criteria	RPLIDAR C1	TFmini Plus	LDROBOT D300
Size	55.6 x 55.6 x 41.3 mm	35 x 18.5 x 21 mm	38.59 x 38.59 x 33.5 mm
Weight	110 g	12 g	47 g
Detection Resolution	15 mm	1 cm	15 mm
Detection Speed	5000 points per sample 10 samples per second	1000 samples per second	4500 points per sample 13 samples per second
Detection Range	12 m	12 m	12 m
Environmental Protection	IP-65	IP-65	IP-65
Protocol	UART	I2C UART	UART
Power Consumption	1.15 W	700 mW	900 mW
Ambient Light Immunity	40 klux	70 klux	30 klux
Price	$69	$52.90	$120

LiDAR Part Selection Choice

The RPLIDAR C1 was selected for the LiDAR sensor of SPARROW due to its 360-degree sensing capability, fast sample speed, adequate power consumption, compact size, and lightweight design. The importance of the 360-degree sensing cannot be overstated, as it allows the drone to detect objects in all directions simultaneously, essential for safely navigating in a three-dimensional space. A single-direction sensor would leave the drone blind to potential obstacles in other directions, necessitating multiple sensors to achieve full coverage, which would increase costs, power consumption, weight, and overall size.

The TFmini Plus was ultimately deemed unsuitable for SPARROW due to its single-direction sensing capability. Although the LDROBOT D300 offered adequate detection speed, resolution, and range, the size, power consumption, inferior ambient light immunity, the RPLIDAR offers similar specs, for almost half the price.

Ultimately, the LDROBOT D300 served as a great choice due to its impressive performance, but ultimately the RPLIDAR C1 won us over due to its very reasonable price point. This decision was driven by the RPLIDAR's capability to still meet the demands of the drone's operational environment while ensuring effective and reliable object detection.

3.2 Heat Detection

Heat detection technology plays a crucial role in search and rescue operations, providing critical support in locating individuals in emergency situations. By sensing the infrared radiation emitted by warm bodies and other heat sources, integrating some form of heat detection technology would help identify any individuals in remote and challenging environments.

Fundamentally, heat detection systems capture infrared radiation, which exists on the electromagnetic spectrum just beyond visible light. Although human eyes are unable to perceive this radiation, specialized sensors can detect this radiation and convert it into images by assigning colors to different temperatures, allowing the operators of our system to spot individuals or any heat sources that could indicate life.

In the context of search and rescue operations, integrating heat detection technology would significantly improve response times. Drones equipped with advanced heat detection technology could efficiently cover much larger areas in various environmental conditions to ensure that targets are identified properly.

For effective heat detection from drones, several key factors must be considered. First, the system should be capable of detecting the higher temperatures that indicate living beings. Additionally, the ability to detect heat signatures from a considerable distance is essential, since the drones will operate at varying altitudes and need to provide clear imagery from those heights.

Furthermore, the chosen heat detection technology must be lightweight and compact, allowing for easy integration onto the drone without compromising flight stability or flight time. A higher resolution is also necessary to distinguish between smaller temperature variations, as it would allow for more precise identification of hotspots.

Overall, heat detection technology is an essential component for search and rescue operations. By utilizing drones equipped with infrared sensing capabilities, rescue teams could proactively monitor environments to detect potential survivors. By ensuring that the technology we choose meets the specifications listed above, this approach to search and rescue operations assists in locating individuals and promotes a swift response time.

Multispectral Imaging

Multispectral imaging is one of the technologies that can be used in our system, as it is able to detect heat in addition to capturing images across various wavelengths of the electromagnetic spectrum. Derived from spectroscopy and optics, multispectral imaging uses many sensors to gather information at different wavelengths. This allows it to capture data not only in the visible light spectrum, but also in wavelengths invisible to the naked eye, such as infrared and thermal radiation.

Practically speaking, the drone would use this technology to capture data and then transmit the data to the base station, where specialized software would process the multispectral images. While it may appear to be advantageous to obtain a camera capable of capturing a wide range of wavelengths at a high resolution, the cost of this advanced technology can be very expensive, often costing thousands of dollars.

Additionally, for the purposes of SPARROW, capturing data across multiple wavelengths may not be necessary. Since the primary purpose of SPARROW is to detect heat signatures that could indicate the presence of survivors, a camera that only detects infrared radiation may be more effective, as well as more cost-efficient. By avoiding collecting any unnecessary data, SPARROW can meet its objectives without the added complexity and expense of multispectral imaging.

Thermal Imaging

Thermal imaging could play a crucial role in SPARROW by helping identify heat signatures, which is essential for detecting survivors. Since this technology would be attached to a drone, it would be important to select the right thermal camera capable of producing high-quality thermal images.

There are several factors we would have to consider when choosing a thermal camera for this project. First, the camera should be able to communicate seamlessly with the drone’s processor. This communication should allow the processor to request image data from the camera, process it, and relay the information to the rescue team in real-time.

Another parameter to consider is the resolution of the camera. A higher resolution will result in clearer images, making it easier to identify individuals or heat sources in the surrounding environment. Additionally, the camera’s frame rate (FPS) is important, as a higher FPS provides smoother, more detailed imagery, which could greatly improve the detection accuracy.

Physical characteristics like size and weight would also have to be considered. A bulkier or heavier camera could negatively impact the drone's flight stability and performance. Since the drone would also operate on battery power, the camera's energy consumption is another important factor to consider since a camera that uses too much power could reduce the drone's operational time, limiting its effectiveness.

Finally, cost is another important consideration. While better specifications like high resolution and high frame rate are desirable, they significantly increase the price. Balancing the technical needs of the project with our budget constraints will be crucial in selecting the right thermal camera for SPARROW.

Table 3.3. *Comparison of heat detection technologies by Authors*

Property	Multispectral Imaging	Thermal Imaging
Detection Basis	Multiple Spectrums	Infrared Radiation
Output Images	Multi-band Images (Shows various Spectral Bands)	Heat Maps (Shows Temperature Variations)
Environment Perception	Works through fog/rain/smoke	Susceptible to fog/smoke/rain
Cost	High	Medium

Heat Detection Technology Selection

For this project, we have decided to use thermal imaging for heat detection, based on several key factors. Thermal imaging provides the infrared detection necessary for identifying heat sources. While multispectral imaging is capable of detecting additional wavelengths, this extra functionality is unnecessary for our project.

The main advantage that multispectral cameras have is the added benefit of operating in various environmental conditions, like fog or rain. However, the cost difference between multispectral imaging cameras and thermal cameras is so significant, it is not justifiable for our project. Since SPARROW focuses primarily on detecting heat signatures to locate survivors, thermal imaging provides a more cost-effective solution while still satisfying the operational needs of the project.

AMG8833

The AMG8833 thermal camera is a low-cost, surface-mounted camera that provides an 8x8 pixel resolution, 10 frames per second, and a thermal detection range of 0 °C (32 °F) to 80 °C (176 °F). While its affordability is its most attractive feature, the camera's performance is highly limited. The 64-pixel resolution is insufficient for our purposes, especially when it comes to detecting heat signatures from a distance, which is critical for search and rescue operations.

Despite its low cost and minimal power consumption, the AMG8833 sacrifices performance in areas that are critical for successful operation of our project. These limitations make it less suitable for SPARROW, as a higher resolution is necessary. As a result, the AMG8833 may not be the choice for our thermal imaging needs.

MLX90640

The next thermal camera we're considering is the MLX90640, which offers both advantages and disadvantages when integrated with a processor. One of its key strengths is its improved resolution of 32x24 pixels, which is adequate for our project. Additionally, the MLX90640 features an adjustable frame rate, which can be tailored to meet our requirements.

A standout feature of the MLX90640 is the option to select different fields of view (FOV). Depending on the operational circumstances, a wider FOV might be beneficial for gathering thermal data from higher altitudes during search and rescue operations. Additionally, the camera can operate in temperatures ranging from -40 °C (-40 °F) to 85 °C (185 °F) and offers a thermal detection range of -40 °C (-40 °F) to 300 °C (572 °F). This range makes it more than capable of identifying heat sources, far exceeding the temperature threshold needed to detect humans in various environments.

However, the MLX90640 does come with some trade-offs. Its higher price and increased power consumption are notable considerations given our budget and power limitations. Nevertheless, the MLX90640 appears to be a strong contender for SPARROW, offering excellent capabilities that align more with our goals.

MLX90641

The next thermal camera to consider is the MLX90641, which offers its own unique traits while maintaining similarities to the MLX90640. With a resolution of only 16x12 pixels, the MLX90641 offers a lower resolution than the MLX90640, but still provides a significant improvement from the AMG8833. This resolution is sufficient for our project's needs and balances performance and cost.

Like the MLX90640, the MLX90641 features an adjustable frame rate and a wide thermal detection range of -40 °C to 300 °C. A notable improvement with the MLX90641 is its higher operating temperature range, from -40 °C to 125 °C, allowing it to withstand harsher conditions, but the practical impact may be limited by the drone's operational constraints.

Overall, the MLX90641 serves as the middle ground between the AMG8833 and the MLX90640 in terms of price, power consumption, and performance. Its balance of features makes it a viable option for SPARROW, offering sufficient capabilities while keeping costs and power consumption down.

Boson Longwave Infrared (LWIR) OEM Module 320

The final thermal camera we're considering is the Boson Longwave Infrared (LWIR) OEM thermal camera by FLIR. This powerful camera stands out with its impressive specifications, offering a choice between 320x256 or 640x512 pixel resolution. This high resolution is incredibly beneficial for capturing detailed thermal images, making it ideal for search and rescue operations where detecting small details in the environment can be crucial.

Additionally, the Boson LWIR OEM thermal camera boasts a wide temperature range of up to 140 °C or up to 500 °C. This range makes it particularly well-suited for the purpose of SPARROW. Despite its lower operating temperature range of -40 °C to 80 °C, it remains more than capable of detecting humans in typical outdoor environments.

One significant consideration is the high cost of the Boson LWIR OEM, as it sits on the premium end of the market. However, given its advanced capabilities and incredible performance, the Boson LWIR OEM thermal camera is a top contender for SPARROW. It offers detailed thermal imaging that could greatly enhance our search and rescue efforts by providing accurate and high-resolution scans of the environment.

Table 3.4. *Thermal camera product selection*
by Authors

	AMG8833	**MLX90640**	**MLX90641**	**Boson LWIR OEM Module 320**
Resolution	8x8 pixels	32x24 pixels	16x12 pixels	320x256 pixels or 640x512 pixels
FPS	10	0.5 - 32 (Programmable)	0.5 - 32 (Programmable)	60 Hz, 30 Hz, or 9 Hz
Size	25.6mm x 25.3mm	28mm x 16mm	28mm x 16 mm	21mm x 21mm x 11mm
Range of Thermal Detection	0°C to 80°C	-40°C to 300°C	-40°C to 300°C	Up to 140 °C or Up to 500 °C
Field of View	45°x 45°	55°x 35° or 110°x 70°	55°x 35° or 110°x 70°	92°x 74°

Current Consumption	4.5 mA	23 mA	12 mA	152 mA
Cost	$44.95	$54.99	$44.99	$1,959.00

Thermal Camera Product Choice

When it comes to choosing the thermal camera for our product, the Boson LWIR OEM thermal camera stands out as the top option, despite the high cost, which our sponsor Lockheed Martin generously offered to cover. The performance the Boson LWIR OEM offers is unmatched when compared to other products. Even with the lower resolution of 320x256 pixels, it provides 100 times the pixel count of the second best option. This higher resolution allows for much more detailed thermal detection, which is crucial for search and rescue operations.

While the Boson LWIR OEM has the highest power consumption among the thermal cameras we considered, its higher resolution and wide temperature detection range justify this trade-off. This higher resolution ensures that we can capture the best possible details of the environment.

Another big advantage is its ability to achieve 60 frames per second, much higher than the other products are able to offer. This higher frame rate results in smoother video, allowing us to capture cleaner and more detailed footage of the surrounding environment, The 60 Hz capability would also be ideal for any scenarios where we may want to analyze the environment in slow motion.

Overall, the Boson LWIR OEM thermal camera is the best option for SPARROW. Its superior resolution, frame rate, and thermal detection capabilities make it an invaluable asset for search and rescue operations. Thanks to our sponsor for covering the cost, we can afford this high-performance camera without worrying about the price, making it a clear winner for our project.

3.3 Visible Light Detection

Visible light detection plays a critical role in SPARROW's operations by allowing us to capture images and video of the environment using the wavelengths of light within the visible light spectrum (400 to 700 nanometers), which the human eye can naturally perceive. By using a camera, SPARROW can reproduce what is seen from the drone's perspective in real-time.

The camera is essential for SPARROW as it provides visual data that helps the operators identify and locate individuals in need of rescue. High-quality video footage is critical for ensuring successful operations, which is why we must carefully review the camera's specifications. High resolution is necessary because it allows for more precise observation and detection of important visual cues. Similarly, the camera's frame rate is important because higher frame rates produce smoother footage, which is essential for accurate real-time assessments, especially when the drone is moving.

Since the drone will be operating at varying altitudes, the camera must be capable of delivering clear footage from a distance. This requires us to carefully consider the camera's range and zoom capabilities, ensuring it can capture high-quality footage even at higher elevations. At the same time, physical characteristics such as the camera's size, weight, and power consumption must be managed to avoid compromising flight stability or flight time.

By selecting a camera that meets these specifications, SPARROW will allow human operators to safely and efficiently inspect areas from a distance, identifying any environmental hazards, as well as anyone in need of rescue, without putting personnel at risk.

Digital

Digital cameras play a key role in SPARROW's search and rescue operations by providing high-resolution images and videos for navigation. These cameras rely on visual data to determine the distance and position of objects, allowing for precise navigation and obstacle detection. They work by using a sensor that converts the light into electric signals, which are then processed into digital images or video. These visuals can then be transmitted in real time to the base station, allowing for quick analysis.

One of the main advantages of digital cameras is their simplicity. Additionally, digital cameras are well-established in the general market, meaning that they're user-friendly and require very minimal setup. This simplicity allows us to focus more time on other critical aspects of the project, such as transferring the data. Digital cameras also typically offer superior image quality with faster frame rates, higher resolution, and zoom capabilities that provide operators with the necessary visual clarity needed to inspect areas from a considerable distance.

However, there are trade-offs. While high frame rates and resolutions are desirable, they often come with higher costs, requiring us to carefully consider our budget. Another limitation is the camera's relatively narrow field of view, which means that if an operator needs to revisit a specific area, both the drone and the camera need to be repositioned, which can be time-consuming and impact operational efficiency. Balancing cost, quality, and the camera's operational limitations will be crucial in selecting the best digital camera for SPARROW.

Omnidirectional

Omnidirectional cameras offer distinct advantages over traditional digital cameras by capturing a full 360-degree view in a single shot. Using either multiple lenses or a single lens with a wide field of view, these cameras provide complete spatial awareness by covering all directions. This makes them particularly useful for SPARROW's search and rescue operations, as they could detect people in need as well as obstacles from any angle.

This panoramic view makes them ideal for our application for extensive spatial awareness considering this could be operated in dynamic and unpredictable environments, allowing operators at the base station to fully understand the surroundings without requiring the drone to reorient itself or the need for any additional cameras.

However, omnidirectional cameras also have their limitations. The most significant drawback is the increased power consumption and computational resources needed to process and stitch together the large volume of visual data the camera generates. This additional power demand could reduce the drone's flight time, both due to the energy required and the heavier hardware these cameras typically entail. Additionally, the complexity of the camera can be an obstacle itself. These cameras often require more detailed setup and calibration as well as specialized software to stitch, record, and stream the footage. This complexity introduces a learning curve, which could consume valuable time and resources.

Despite these challenges, the panoramic capabilities of omnidirectional cameras make them a strong contender for enhancing SPARROW's situational awareness. Careful consideration of the trade-offs in power efficiency, hardware, and learning time will be essential in determining the best fit for our project.

Wireless Network

Wireless network cameras, or Internet Protocol (IP) cameras, offer a significant advantage for SPARROW by streaming real-time video footage directly to a central processing unit. These cameras could integrate with the drone's onboard network, allowing the video feeds to be transmitted to a remote operator or processing server for efficient real-time monitoring and analysis. By offloading the data processing to a remote location rather than the drone's microcontroller unit, IP cameras could help reduce the drone's onboard load and conserve power, making them ideal for a project like SPARROW, which requires long-distance transmission and constant monitoring.

However, wireless network cameras also come with specific challenges. The primary issue is their reliance on network infrastructure, which can lead to latency issues or connectivity issues, especially in environments with poor network coverage or high interference, which could significantly degrade the quality of the video feed. Additionally, the range of the IP cameras must be taken into consideration, since there's a risk that the drone may not be able to transmit the footage if it operates too far from the base station. In such cases, network range extenders may be needed to ensure stable connection over long distances.

Table 3.5. *Comparison of visible light detection technologies by Authors*

	Digital	**Omni-Directional**	**Wireless Network**
Connectivity	Physical Connection	Physical Connection or Network	Network

Ease of Use	High	Low	Moderate
Field of View	Moderate	High	Moderate
Resolution	High	Moderate	Moderate
FPS	High	Moderate	High
Power Consumption	Moderate	High	Moderate
Size	Moderate	High	Moderate
Price	Moderate	High	Moderate

Visible Light Detection Technology Selection

When selecting a camera for SPARROW, several critical factors must be considered. The first is usability, both in terms of physical connectivity and ease of setup and operation. These factors directly impact how we can stream live footage to the base station. Next, we need to consider the specifications of the camera, including field of view (FOV), resolution, and frames per second (FPS), as these greatly influence the clarity of the footage and its effectiveness in monitoring and analysis. Insufficient FOV, low resolution, or lower FPS could lead to missed details in critical situations.

Beyond image quality, power consumption, size, and cost are key considerations. Power consumption affects the battery life of the drone, while size and weight influence the drone's design and overall performance. Cost is another important factor, given our $2,000 budget.

After evaluating various options, we've decided that digital cameras are the best fit for SPARROW. While omnidirectional cameras offer the widest FOV and wireless network cameras supply the highest FPS under stable conditions, digital cameras offer a balanced performance across all these critical areas. Additionally, the physical connection of a digital camera ensures reliability and high uptime, making them more stable for video streaming, which is critical for the transmission of data to the base station. In contrast, omnidirectional cameras can be difficult to interpret due to their 360-degree view, and IP cameras may struggle with connection instability.

Additionally, clear and easily interpretable footage is essential for the human operators at the base station. Complications such as poor connection in IP cameras or the complex view of omnidirectional cameras could hinder effective decision-making. Digital cameras, with their ease of use and stable physical connections, provide the clarity and consistency required for SPARROW's operations.

Before selecting a specific digital camera model, it's important to consider some of the available connection types such as Ethernet, USB, and coaxial. Each of these offers unique advantages and disadvantages that can affect the camera's performance and usability. Understanding these differences is essential to making an informed decision. Selecting the right connection type is crucial for ensuring that the digital camera aligns with SPARROW's performance and operational requirements.

Ethernet

Ethernet cameras offer high-speed data transmission and stable connections, making them an excellent choice for real-time video streaming and high-resolution imaging. These cameras typically support resolutions up to 4K and frame rates up to 60 FPS, and can perform well in various lighting conditions. A significant advantage of these cameras is their Power over Ethernet (PoE) capability, which allows the camera to receive both power and data through a single cable. This can simplify the drone's wiring setup by reducing the number of cables required onboard.

However, Ethernet cameras also come with certain challenges. The added weight and complexity of Ethernet cabling can negatively impact the drone's aerodynamics and overall flight performance. These cameras tend to be bulkier, which could limit the drone's maneuverability and increase power consumption. Additionally, setting up an Ethernet camera requires a deeper understanding of networking and configuration, adding technical complexity to the project. While Ethernet cameras provide exceptional reliability and data quality, they are generally more expensive, and the necessary networking equipment further increases the investment.

If we consider an Ethernet camera for SPARROW, it's crucial to balance the enhanced performance and stability against the potential downsides, such as the increased weight, complexity, and cost. These factors must be considered to determine if Ethernet cameras are the best fit for SPARROW.

USB

USB cameras are a popular choice for drone applications due to their ease of use, affordability, and wide range of specifications. These cameras typically offer resolutions from 720p to 4K and frame rates up to 60 FPS. Many USB cameras also feature autofocus, low-light enhancement, and wide-angle lenses, which make them versatile in various environments. Their straightforward connection to a drone's onboard computer or controller via a USB port simplifies installation, and their compatibility with popular operating systems and software makes integration with custom applications easy.

However, USB cameras come with certain limitations. One key issue is their reliance on a stable USB connection, which can be susceptible to disconnections or signal interference, especially in the high-vibration environment of a drone. USB cameras also tend to consume considerable power and processing resources, which can negatively affect the drone's battery life and overall performance. Additionally, the relatively short range of USB cables can restrict camera placement, limiting flexibility. While USB cameras are generally affordable, higher-end models with advanced features can still be quite expensive, potentially increasing the overall cost of the project.

Balancing these advantages and disadvantages is essential when selecting the right USB camera for SPARROW. Careful consideration of factors like power consumption, connection stability, and overall cost will help determine if a USB camera meets the specific needs of SPARROW.

Coaxial Cables

Coaxial cameras, commonly used in surveillance systems, are a potential option for SPARROW due to their ability to deliver high-definition resolutions, often up to 1080p, as well as their reliability over long distances without significant signal degradation. The use of coaxial cables enable stable, consistent connections, which is critical for real-time video transmission.

However, using coaxial cameras on drones presents several challenges. One major drawback is the weight and rigidity of coaxial cables, which can negatively impact the drone's flight dynamics and the overall operational efficiency. The bulkiness of the cables alongside their connectors makes installation more complicated compared to lighter, more flexible solutions like USB or Ethernet cameras. Additionally, coaxial cameras often require extra equipment, such as baluns or converters, to integrate with digital systems, which can add to the complexity and overall cost of the project.

Despite these challenges, coaxial cameras could still be a viable option for applications that require long-distance signal transmission and minimal latency, provided that the drone's design can accommodate the added weight and bulk. Careful evaluation of these trade-offs is necessary to determine whether coaxial cameras are the best fit for SPARROW's specific needs.

Table 3.6. *Comparison of digital camera technologies*
by Authors

	Ethernet	**USB**	**Coaxial Cables**
Reliability	Moderate	Low	High
Ease of Use	Moderate	High	Low

Resolution	High	Moderate	Low
FPS	High	High	Low
Camera Range	Very Low	Moderate	High
Field of View	Moderate	Moderate	Low
Power Consumption	Moderate	Low	Moderate
Size/Weight	Moderate	Low	High
Cost	Moderate	Low	Moderate

Camera Technology Selection

We have decided that a USB camera is the best option for our purposes. These cameras offer excellent ease of use and provide reasonable video resolution, power consumption, range, and size. Their affordability allows us to keep replacement cameras on hand, which is an important consideration. Additionally, the higher frame rates are valuable, as a reliable video feed from the camera is essential for SPARROW. While there may be some concerns regarding their reliability, the low cost makes it possible to replace them if necessary. For these reasons, we are choosing to move forward with a USB camera.

GXIVision S2M05

The GXIVision S2M05 camera offers a resolution of 1600x1200, which is equivalent to 1080p. However, it features an aspect ratio of 4:3 instead of the more common 16:9. Although the data sheet did not specify the camera's horizontal field of view (FOV), our calculations estimate it to be approximately 179°. This camera also has a fixed focus and consistently captures videos at 60 frames per second.

With an impressive operating temperature range of -30°C to 70°C and compact dimensions of 38 × 38 × 16 mm, the camera consumes 1 W of power when operational.

Despite its strong performance in terms of FOV, temperature range, and power consumption, the GXIVision S2M05 camera is relatively expensive, priced at $68.88 before shipping. While the higher cost and the non-standard aspect ratio may pose some challenges, we believe these drawbacks can be managed to meet our specific needs.

ELP-SUSB1080P01-LC1100

The ELP-SUSB1080P01-LC1100 camera offers a resolution of 1080p and operates at a framerate of 50 frames per second. It features a horizontal FOV of 70° and has a fixed focus. Although the data sheet did not specify the depth of the camera, it is expected to be negligible. This camera operates within a temperature range of 0°C and 70°C, with dimensions of 38 × 38 mm for both height and width.

With a power consumption of approximately 1.1 W, the camera can operate efficiently for extended periods. Priced at $60.90 before shipping, this camera presents itself as a very reasonable option for SPARROW.

The primary drawback of this camera is its lower field of view compared to some alternative options. However, considering its solid resolution, competitive framerate, compact dimensions, efficient power draw, and operating temperature range, the ELP-SUSB1080P01-LC1100 is a well-rounded choice for the needs of our project.

Arducam B0433

The Arducam B0433 has a range of standard resolutions, including 480p, 720p, 1080p, and 4K. However, these resolutions come with a lower frame rate of 30 frames per second and a horizontal FOV of 110°. With a power draw of about 1.5 W, it is on the higher end of power consumption. This camera operates effectively within a temperature range of -20°C to 70°C and has dimensions of 38 × 38 × 16 mm.

One notable consideration for the Arducam B0433 is its manual focus feature. While this allows for customizable adjustments to the camera's focus, it also introduces the risk of becoming unfocused due to potentially changing weather conditions. However, priced at $59.99, it is the cheapest option among the cameras we've considered.

Ultimately, while the manual focus presents a potential challenge, the wide range of resolutions, wide operating temperature range, and competitive cost make the Arducam B0433 an appealing choice for SPARROW.

EMEET C970L

The EMEET C970L webcam offers a full HD resolution of 1080p at a consistent frame rate of 60 frames per second. It features an adjustable horizontal field of view between 75° and 90°. The camera includes an autofocus system to maintain image clarity during movement and integrates a built-in ring light with three adjustable brightness levels to enhance video quality in low-light conditions. Its operating temperature range is not officially documented, but the camera is designed for reliable indoor use. While C970L has a compact rectangular form factor and supports USB plug-and-play connectivity, making it compatible with Linux and our computer vision libraries. Its slightly higher price and lack of outdoor durability may limit certain use cases.

Table 3.7. *Comparison of USB cameras*
by Authors

	GXVision	ELP	Arducam	EMEET C970L
Max Resolution	1600x1200	1920x1080	3840x2160	1920x1080
Aspect Ratio	4:3	16:9	16:9	16:9
Focus Type	Fixed	Fixed	Manual	Fixed
Operating Temperature	-30°C-70°C	0°C-70°C	-20°C-70°C	Not Found
Max Frame Rate	60	50	15	60
Operating Voltage	5 V ± 5%	5 V ± 5%	5 V ± 5%	5 V ± 5%
Horizontal Field of View	179.6°	70°	110°	90°
Maximum Operating Current	200 mA	220 mA	300 mA	500 mA
Size	38 x 38 x 16 mm	38 x 38 mm	38 x 38 x 16 mm	1.73" x 4.72" x 2.09"
Cost	$68.88	$60.90	$59.99	$48.99

USB Camera Part Selection Choice

After evaluating all four camera options, we determined that the EMEET C970L best meets SPARROW's needs. It provides a strong balance between resolution, frame rate, field of view, and user-focused features. The 1080p resolution at 60 frames per second ensures high-quality video capture, while the adjustable field of view and built-in ring light allow for flexible and reliable imaging in varied lighting conditions. Its plug-and-play functionality and integrated privacy mode also add practical value during field deployment.

Although the Arducam B0433 offered a competitive price and multiple resolution options, its manual focus raised concerns about maintaining image clarity under dynamic conditions. Similarly, the GXIVision S2M05 provided a wider field of view and strong thermal performance, but its non-standard aspect ratio and higher price limited its appeal. The ELP-SUSB1080P01-LC1100 remained a solid contender with low power consumption and a fixed focus, but its narrower FOV restricted situational awareness compared to the C970L.

Ultimately, the EMEET C970L was selected as the best camera option for SPARROW, offering a well-rounded combination of performance, versatility, and ease of use for our visual light detection tasks.

3.4 Global Positioning System (GPS)

The Global Positioning System (GPS) is an advanced satellite-based navigation system that allows users to determine their precise location anywhere on Earth. This sophisticated system operates by triangulating signals received from a network of 31 satellites that are continuously orbiting our planet. These satellites are strategically positioned to ensure comprehensive coverage and reliable signal transmission. Each satellite continuously broadcasts signals to GPS receivers located on the ground or in various devices.

When a GPS receiver picks up signals from multiple satellites, it calculates the distance to each satellite based on the time it takes for the signals to travel. By analyzing this information, the receiver can accurately triangulate its precise geographical location. This process enables users to pinpoint their location with remarkable accuracy, often within a few meters, regardless of their environment.

For our project, the integration of GPS technology is particularly important because the SPARROW drones must have a reliable means of determining their location in relation to IRIS. This capability is essential for their autonomous navigation, allowing them to return to a designated point with just the push of a button.

CD-PA1616S

The PA1616S GPS module is built around the advanced MT3339 chipset, achieving an impressive sensitivity of -165 dBm. This high sensitivity ensures a quick Time-to-First Fix (TTFF) of up to 60 seconds for cold starts, allowing for accurate positioning even in low-signal conditions.

With a low power consumption of only around 75 mW, the PA1616S is particularly well-suited for power-sensitive devices, enabling extended operating times for portable applications. Priced under $25, it offers a compelling combination of advanced features and robust performance, making it ideal for various uses, including drones, automotive navigation, and outdoor equipment.

Additionally, its compact design facilitates easy integration into existing systems, enhancing usability across multiple platforms. Overall, the PA1616S GPS module delivers exceptional performance and value, positioning it as an excellent choice for accurate location data in drones and other applications.

NEO-M8U

The NEO-M8U GPS module features the u-blox NEO-M8U chipset, providing exceptional sensitivity of up to -160 dBm. This high sensitivity ensures a rapid Time-to-First Fix (TTFF) of just 30 seconds for cold starts, enabling ultra-accurate positioning even in challenging environments with low signal reception and high velocity.

With a typical supply voltage of 3.3 V and current between 20mA and 25mA, the NEO-M8U only requires between 66 and 75 mW, so the NEO-M8U is well-suited for power-sensitive applications, allowing for extended operating times in portable devices. While it is priced higher than the CD-PA1616S, the NEO-M8U justifies this cost with its advanced features and robust performance.

This module is ideal for various applications, including drones, automotive navigation, and outdoor equipment. Additionally, its compact design facilitates easy integration into existing systems, enhancing its usability across multiple platforms.

NEO-M9N

The NEO-M9N GPS module features a 72-channel u-blox M9 engine, delivering impressive performance and accuracy. With a sensitivity of -167 dBm, it achieves a Time-to-First Fix (TTFF) of approximately 26 seconds for cold starts, providing continuous navigation capabilities even in challenging environments.

Designed for low power consumption, the NEO-M9N typically operates at around 60 mW, making it an ideal choice for power-sensitive applications such as drones, automotive systems, and portable devices. This efficiency enables extended operating times without compromising performance.

Reasonably priced, the NEO-M9N offers advanced features and robust capabilities suitable for various applications. Its ability to receive signals from multiple GNSS constellations—including GPS, GLONASS, BeiDou, and Galileo—ensures reliable positioning with an accuracy of approximately 2 meters. Furthermore, the compact design of the NEO-M9N allows for seamless integration into existing systems, enhancing usability across multiple platforms.

Overall, the NEO-M9N GPS module delivers exceptional performance and value, making it an excellent choice for accurate location data. With its advanced technology and low power requirements, it stands out as a dependable solution for a wide range of applications.

ZED-F9R

The ZED-F9R GPS module features a high-performance u-blox F9 engine, delivering impressive accuracy and reliability. With a sensitivity of -160 dBm, it achieves a Time-to-First Fix (TTFF) of approximately 15 seconds for cold starts, providing continuous navigation capabilities even in challenging environments.

However, the ZED-F9R typically operates at around 210 mW, which may pose a challenge for power-sensitive or battery-powered applications like ours. Despite this limitation, the module offers advanced features and robust capabilities suitable for various uses. Its ability to receive signals from multiple GNSS constellations (GPS, GLONASS, BeiDou, and Galileo) ensures reliable positioning with an accuracy of about 1 centimeter when paired with RTK (Real-Time Kinematic) positioning. Furthermore, the compact design of the ZED-F9R facilitates seamless integration, enhancing usability across multiple platforms.

While the ZED-F9R GPS module delivers exceptional performance, its higher power demands and steep price point make it an unlikely solution for our specific needs.

SAM-M8Q-0-10

The SAM-M8Q-0-10 GPS Module is a highly advanced and versatile GPS solution designed for a range of applications that require fast and accurate positioning. Powered by the SAM-M8Q chipset, the module supports up to 72 GNSS channels, offering excellent tracking performance even in challenging environments like dense urban areas or under foliage.

With a sensitivity of -167 dBm, the SAM-M8Q-0-10 can maintain a strong signal in difficult conditions. Its update rate of up to 18 Hz ensures real-time accuracy, making it suitable for applications that demand quick and precise positioning data. Furthermore, the module supports multiple GNSS systems, including GPS, GLONASS, Galileo, and BeiDou, enhancing the reliability and accuracy of location data across different regions.

Although the module lacks a built-in antenna, it supports the use of external antennas, offering flexibility to optimize performance based on their specific needs and environments. Its low power consumption and small size make it an excellent choice for any projects requiring energy efficiency and minimal space.

Additionally, the SAM-M8Q-0-10 is priced competitively and is compatible with both Raspberry Pi and Arduino through UART and I2C interfaces, making it ideal for prototyping and small-scale deployment. Its combination of advanced features and adaptability make it a strong contender for various GPS-based applications.

Table 3.8. *Comparison of GPS modules by Authors*

Criteria	PA1616S	NEO-M8U	NEO-M9N	ZED-F9R	SAM-M8Q
Update Rate	<10 Hz	<30 Hz	<25 Hz	<30 Hz	<18 Hz
Sensitivity	-165 dBm	-160 dBm	-167 dBm	-160 dBm	-167 dBm
Accuracy	3 meters	2.5 meters	2 meters	0.01 meters	2.5 meters
Interfaces	I2C, UART	I2C, SPI, UART, USB	I2C, SPI, UART, USB	I2C, SPI, UART, USB	I2C, UART
Average Power Consumption	~66 mW	~69 mW	~84 mW	~210 mW	~69 mW

Operating Voltage	3.0 V - 4.3 V	2.7 V - 3.6 V	2.7 V - 3.6 V	2.7 V - 3.6 V	3.3 V - 5 V
Cost	$24.95	$60.00	$27.00	$149.00	$31.50

GPS Module Selection

The SAM-M8Q-0-10 GPS Module stands as the best choice for drone projects focused on achieving long-range, reliable navigation. Its multi-GNSS support, which includes GPS, GLONASS, Galileo, and BeiDou systems, gives it access to a broader range of satellites, improving accuracy and signal reliability, especially in environments with potential signal obstructions. This makes it superior to some alternatives, which typically have less comprehensive satellite support.

With its high sensitivity of -167 dBm, the SAM-M8Q is capable of picking up weaker signals more effectively, which is crucial for maintaining connectivity in any remote or obstructed areas. Additionally, its high update rate of up to 18 Hz ensures precise, real-time positioning data, which is essential for drones that need to make rapid adjustments during flight.

Another significant advantage is its compatibility with external antennas, which can further extend its range, making it the optimal choice for drones operating over long distances. Overall, its combination of multi-GNSS support, high sensitivity, fast update rate, and external antenna compatibility makes the SAM-M8Q-0-10 the optimal choice for drone applications where extended range and signal reliability are critical.

3.5 Displays

The display will be an important part of the SPARROW. Incorporating displays into the controller setup for a fleet of drones is crucial for effective monitoring and management. Displays allow users to view real-time images and video feeds sent from the drones, providing immediate visual confirmation of detected power line faults. Additionally, the ability to see pinned locations on a map interface helps operators track the exact positions of the drones and the identified faults, enhancing situational awareness and decision-making. This allows the user to see images that were sent from the drone and the ability to see pinned locations. The goal of the display is to have a decent refresh rate and the ability to be readable in sunlight.

A key consideration for the display is its refresh rate, which must be high enough to ensure a fluid rendering of live video feeds. The responsiveness is important for timely reaction to potential issues that will arise when the drones navigate remote or hard-to-reach areas. In addition, the display needs to be easily readable in various lighting conditions, including direct sunlight, as the controller might be used in an outdoor environment.

One thing that could enhance the interactivity of the controller would be having a touchscreen. This could allow operators to quickly navigate through maps, zoom in on specific areas, and interact with pins dropped by the drones directly. Overall, selecting a display that combines high resolution, readability, responsiveness, durability, and cost-effectiveness will contribute significantly to the effectiveness and efficiency of the drone controller system.

LCD

There are three primary LCD displays. TN, IPS, and VA all function similarly but vary with how the liquid crystal is used. TTN (Twisted Nematic) displays are known for their high refresh rates and low prices. The primary advantages of TN displays are their affordability and high refresh rates, making them suitable for applications requiring fast screen updates. However, TN displays have a significant drawback in their limited viewing angles, which can result in color shifting and reduced image quality when viewed from the side.

IPS (In-Plane Switching) displays offer superior color quality and wider viewing angles compared to TN displays. This makes IPS panels ideal for applications where color accuracy and consistency across different viewing angles are critical. The downside of IPS displays is their higher cost, especially when seeking refresh rates comparable to those of TN panels. This higher price can be a limiting factor for budget-conscious projects, but the improved visual experience may justify the expense for professional or demanding applications.

VA (Vertical Alignment) is known for its strong contrast due to the perpendicular liquid crystals. The pros for this option are that they are usually a cheap option (but not always) and excel in contrast. A con is that they are not as popular in the market as compared to the VA and on some ends can be more expensive than the TN. The best LCD option with regard to the price and refresh rate would be to look at the TN LCD displays. A potential drawback of VA displays is their lesser popularity in the market, leading to fewer options and potentially higher prices compared to TN displays. Additionally, VA panels may suffer from slower response times, making them less suitable for high-speed applications.

LED

A misconception about LEDS is that they are also LCDs but not all LCDs are LEDS. One of the advantages of LED displays is the energy efficiency due to the LED consuming less power then than other forms for backlit displays. It is also very lightweight due to the thinness factor. They are also very bright which would be helpful if the device is needed in sunlight and is ideal for portable devices. The cons for LED displays is the limited color accuracy which could limit the clear image seen from the IR camera on the drone when it sends over images. LED displays are not the cheapest displays out there and could be more expensive than other options we have when looking at screen sizes.

Another significant advantage of LED displays is their brightness, which makes them highly suitable for use in sunlight or other bright environments. This is particularly important for outdoor applications or situations where the controller needs to be used in various lighting conditions. The high brightness ensures that the display remains readable and effective even in direct sunlight.

However, there are some drawbacks to LED displays. One of the primary cons is their limited color accuracy, which might affect the clarity of images, especially when viewing detailed data from IR cameras on drones. This could limit the effectiveness of identifying power line faults from the transmitted images. Additionally, LED displays tend to be more expensive than other types of displays, which could be a consideration when managing project budgets. The cost can increase significantly with larger screen sizes, making them less cost-effective for extensive display needs.

While LED displays offer numerous benefits such as energy efficiency, lightweight design, and high brightness, they also come with limitations in color accuracy and potentially higher costs. Choosing the right display type involves balancing these factors against the specific requirements of the project, ensuring that the display meets the functional and budgetary needs.

OLED

OLED displays do not rely on liquid crystals like LCDs do since they use technology that uses diodes that allow for the best image quality for a display. The pros for OLED displays are that it also excels in contrast like the VA LCD display does. Notable cons for OLEDs are the prices for these displays since they are more expensive than LED options. OLEDs are also known for having burn-in issues with static images, which we could potentially face if we use this option for the project.

Another benefit of OLED displays is their faster response time compared to other display technologies, providing smoother motion rendering and reducing blurring in fast-moving images. Additionally, OLEDs offer wider viewing angles without significant color distortion, ensuring that the display remains clear and consistent from various perspectives. This feature is particularly useful for collaborative environments where multiple users may need to view the screen simultaneously.

However, there are notable cons associated with OLED displays. One significant drawback is the cost. OLEDs are generally more expensive than LED options, which could impact the project's budget, especially when considering larger screen sizes. Another issue is the potential for burn-in, where static images can leave permanent marks on the screen over time. This could be a concern for our project if the display frequently shows static elements, such as maps or control interfaces, for extended periods.

While OLED displays offer unparalleled image quality, contrast, and viewing angles, they come with higher costs and the risk of burn-in. Careful consideration is needed to determine whether the benefits outweigh these drawbacks, depending on the specific requirements and budget constraints of the project.

Table 3.9. *Comparison of display types*
by Authors

	IPS LCD	**VA LCD**	**TN LCD**	**LED**	**OLED**

Refresh Rate	Moderate	Moderate	High	High	Very High
Viewing Angles	Wide	Moderate	Limited	Wide	Very Wide
Color Quality	High	High	Moderate	Moderate	Excellent
Power Usage	Moderate	Moderate	Moderate	Low	Moderate
Cost	High	Moderate to High	Low	Moderate to High	Very High
Durability	High	High	High	Moderate	Moderate
Response Time	Moderate	Slow	Fast	Fast	Fast

Display Technology Selection

The IPS LCD (In-Plane Switching Liquid Crystal Display) is a type of display technology known for its accurate color reproduction and wide viewing angles of up to 178 degrees. Unlike other LCD types, IPS panels maintain consistent color and clarity when viewed from different angles, making them ideal for real-time applications like drone monitoring, where visibility from multiple perspectives is crucial. Additionally, IPS LCDs offer good brightness and contrast, ensuring clear visibility in various lighting conditions.

We chose IPS LCD for our project because it offers the best balance of color fidelity, clarity, and reliable performance. Its capability to handle fast-changing data while maintaining color accuracy makes it the most suitable display for real-time drone operations, where users need to monitor video feeds, sensor data, and other visual elements simultaneously. Additionally, IPS LCDs are widely available, cost-effective, and compatible with embedded systems, ensuring that our display solution meets both performance and budgetary needs.

In selecting the display for SPARROW, several factors were essential to achieving optimal performance, usability, and compatibility. Given SPARROW's embedded nature and field-based operational goals, the display had to support clear visibility, power efficiency, durability, and ease of integration within a compact design. After evaluating various options, we selected the HMTECH 7-inch Raspberry Pi Screen, an IPS LCD display known for its color fidelity, reliable performance, and viewing flexibility. This section provides a deeper analysis of the considerations and justifications behind this choice.

HMTECH 7-inch Raspberry Pi Screen

The HMTECH 7-inch display is a compact and highly versatile option, tailored for embedded projects that require portability and ease of integration. With its 800x480 IPS panel, this screen offers vivid colors and a wide 178° viewing angle, ensuring that visuals remain clear even when viewed from the side. It’s plug-and-play, connecting seamlessly to devices through HDMI and USB, which minimizes setup time and makes it user-friendly for those working with Raspberry Pi, Arduino, or similar DIY systems. Its lightweight and compact design is a strong advantage for portable or space-constrained applications, as it allows users to embed the display within tight setups or transport it with ease. While the resolution is modest compared to larger screens, this 7-inch display prioritizes functionality, compactness, and affordability, making it an ideal candidate for embedded environments.

The HMTECH 7-inch display was chosen based on its capacity to meet the demanding requirements of an embedded, real-time control system. The IPS panel technology allows for a wide viewing angle of up to 178°, preserving color consistency and image clarity even when viewed from varied perspectives—a vital feature in drone operations where the controller may be monitored by multiple users. With a resolution of 800x480, the display offers adequate clarity for real-time data monitoring without taxing the system’s power resources. Compared to higher-resolution alternatives, the HMTECH’s balanced resolution optimizes visual quality and energy consumption, ensuring SPARROW’s efficiency in extended operations.

In terms of compatibility, the HMTECH’s plug-and-play functionality with HDMI and USB connectivity simplifies setup and integration with the Raspberry Pi platform, which serves as SPARROW’s control hub. This connectivity allows for rapid deployment and troubleshooting, reducing setup complexity in the field and aligning with the project’s goal of practical usability in dynamic settings.

Faytech Lapscreen 12.5-inch Full HD Portable Monitor

The Faytech Lapscreen is a 12.5-inch Full HD monitor that brings a professional touch to portable displays. With its 1920x1080 resolution, the screen provides sharp, detailed visuals, which makes it suitable for both work and multimedia tasks. Weighing just 350-400 grams and featuring an ultra-slim profile, this display is perfect for users needing a secondary screen while on the go. It offers USB-C and HDMI connectivity, allowing easy integration with modern laptops, tablets, and some embedded systems, although it’s not explicitly designed for embedded projects. With a 178° viewing angle, the screen delivers consistent color accuracy and clarity from multiple perspectives, enhancing usability in various lighting conditions. Its lightweight build and high resolution make it a versatile option for users who value portability and image quality, especially for tasks that benefit from a larger viewing area than smaller embedded screens provide.

15.6-inch Full HD IPS Monitor with AMD FreeSync

This 15.6-inch Full HD monitor offers a larger screen size that caters to users who prioritize a broader visual field and extended comfort during prolonged use. The display is equipped with an IPS panel, ensuring a wide viewing angle and eye-care technology to reduce eye strain over time. With features like AMD FreeSync, this monitor minimizes stuttering and screen tearing, delivering smoother visuals, which is advantageous for gaming, multimedia, and even professional use. It includes two USB-C ports and a mini-HDMI port, allowing it to connect with a range of devices like laptops, game consoles, and mobile devices. However, its size and features make it less portable and less suited for dedicated embedded projects. It shines as a general-purpose monitor that can adapt to various needs, but its larger size and power requirements make it more appropriate for desktop or stationary setups.

75Hz Refresh Rate Monitor with Built-in Speakers

This monitor is designed with a 75Hz refresh rate, built-in speakers, and Adaptive Sync technology, making it an ideal choice for gaming, work, and general multimedia consumption. The higher refresh rate offers a smoother experience, which is especially beneficial for fast-moving visuals, while Adaptive Sync helps eliminate screen tearing, enhancing overall visual quality. It features HDMI and VGA connectivity options, ensuring compatibility with both modern and older devices, making it a versatile addition to home or office setups. The inclusion of built-in speakers and a security lock adds value for users who need an all-in-one solution for desktop applications. However, this monitor's design is oriented more toward general-purpose and desktop use rather than embedded projects. Its larger form factor and desktop-centric features make it less practical for compact, embedded systems where portability and low power consumption are priorities.

Display Product Selection

Several critical factors were weighed during the display selection process:

- **Portability and Integration**: The HMTECH's compact form factor was a significant advantage over larger options such as the Faytech Lapscreen (12.5 inches) and the 15.6-inch Full HD monitor. Its small, lightweight build supports SPARROW's portable design, making it ideal for embedded applications that require minimal weight and space.

- **Power Efficiency and Durability**: With SPARROW intended for potentially rugged environments, the durability and low power requirements of the HMTECH display were decisive factors. While larger displays offer higher resolutions, they also consume more power and typically require larger protective enclosures, which would not align with SPARROW's embedded and field-ready design goals. The HMTECH's energy-efficient IPS panel minimizes strain on SPARROW's power supply, ensuring prolonged operational capability during critical missions.

- **Usability in Varied Lighting Conditions**: The IPS technology in the HMTECH display supports visibility under different lighting conditions, a necessity for outdoor field operations. The screen's wide viewing angle and vibrant color display allow operators to view data clearly from multiple angles, ensuring real-time monitoring accuracy. Larger displays, while offering more screen space, lacked the compactness and field adaptability required for SPARROW's applications.

- **Cost-Effectiveness and Compatibility with Embedded Systems**: The HMTECH 7-inch display's affordability and compatibility with Raspberry Pi and Arduino platforms make it the most practical choice for this project. Higher-end displays, while providing added features like AMD FreeSync and built-in speakers, were more aligned with general-purpose or stationary desktop setups, adding unnecessary cost and power consumption for an embedded controller application. By selecting the HMTECH, the project remained within budget, allowing for efficient allocation of resources to other critical system components.

This compact 7-inch display is designed for embedded projects, making it highly suitable for Raspberry Pi, Arduino, or other DIY systems. It features an IPS panel with 800x480 resolution, offering vibrant colors and wide 178° viewing angles. It's plug-and-play, connecting easily via HDMI and USB. Its lightweight build makes it perfect for portable setups. Although the resolution is lower than larger monitors, it's the best fit for embedded applications where integration, portability, and cost are priorities.

The Faytech Lapscreen offers a 12.5-inch Full HD (1920x1080) display, making it a versatile option for both work and leisure. It's extremely lightweight, weighing just 350-400 grams, and has a slim profile, making it ideal for travel or secondary screen use. It supports USB-C and HDMI connectivity, and its 178° viewing angle provides clear visuals from various positions. While it's not specifically made for embedded projects, it's well-suited for users needing a compact second screen with high resolution.

This monitor features a 15.6-inch Full HD IPS display, making it a larger option for users who prioritize screen size. It offers a wide viewing angle, eye-care technology, and supports AMD FreeSync to minimize stutter, making it comfortable for extended use. It has two USB-C ports and a mini-HDMI port, simplifying connectivity with various devices. It's a great choice for laptops, consoles, or smartphones, offering versatility for those who need a larger screen. However, it's less focused on embedded projects, making it more suitable for general-purpose use.

This monitor stands out with its 75Hz refresh rate, built-in speakers, and support for Adaptive Sync, which reduces screen tearing. It offers HDMI and VGA ports, making it compatible with older devices as well. The built-in speakers and security lock make it ideal for gaming, work, or general desktop use. Its larger size and focus on desktop setups make it less portable and less optimal for embedded applications.

The display is an important aspect of this project and needs to be tailored for travel purposes, since it could be used in any terrain. The options that came across were a 15.6" travel monitor, a 15.6" portable monitor, and a 12.5" Non-touch Portable monitor. The team is looking for a compact design and lightweight build that makes it easy to integrate into any set up. It is a full IPS LCD panel that provides clear visuals, which is ideal for monitoring and analyzing data in embedded systems like a Raspberry Pi or Arduino. Its versatility and focus on embedded applications make it a good choice for this project.

While each monitor offers distinct benefits, the HMTECH 7-inch Raspberry Pi Screen is the most suitable for embedded projects. It combines portability, ease of use, and compatibility with Raspberry Pi and similar devices, making it the best fit for integration into DIY and embedded setups. The other monitors offer higher resolutions and wider compatibility but are more geared toward general use, travel, or gaming setups rather than embedded systems.

Given the specific requirements of our project, the HMTECH 7-inch Raspberry Pi Screen stands out as the optimal choice for embedded applications. Its compact design, plug-and-play functionality, and lightweight build make it well-suited for portable setups where space and power efficiency are key considerations. The display's 800x480 resolution, while modest compared to other options, is sufficient for data monitoring and visual feedback in embedded systems, especially when paired with devices like the Raspberry Pi or Arduino.

Although the Faytech Lapscreen offers a higher resolution and is excellent for general portability, it's better suited as a secondary monitor for tasks that demand more screen real estate. The larger 15.6-inch options, including the monitor with AMD FreeSync and the one with a 75Hz refresh rate, provide versatile connectivity and a comfortable viewing experience for extended use, but they fall short in terms of portability and energy efficiency for embedded setups.

After evaluating several monitor options for the SPARROW ground station, I initially considered various 7-inch and larger displays for their portability and compact size. At first, I opted for a non-touch 7" display, assuming the touchscreen functionality wouldn't be essential due to our system's reliance on a keyboard and mouse. However, as the project evolved, it became clear that a touchscreen would add significant usability benefits, especially in field conditions where simplicity and speed are critical.

The decision to switch to the official 7-inch Raspberry Pi touchscreen display was made after hands-on testing and feedback. Although the dimensions and resolution of the new monitor were nearly identical to the original, the touchscreen feature became a game-changer. It allowed for a more intuitive, streamlined user experience, operators could now quickly toggle camera views and interact with controls through the touchscreen.

3.6 Processor

At the core of our project, the processor would be responsible for handling many parts of our project from taking data from the cameras to sending that data via a communication protocol to the base station while also maintaining the autonomous flight system within the drones of our project. Tasked with such heavy duties, the processor that would be selected for this project would have to handle a variety of tasks in order to satisfy our project needs.

Microcontrollers are essential for our project because they serve as the central processing unit that manages all onboard systems of the drone and the base station. The microcontroller's ability to handle multitasking, real-time processing, and efficient power management is crucial for the reliability and effectiveness of the drone in search and rescue scenarios. With the right microcontroller, our drones can perform complex tasks autonomously, providing rapid and accurate assessments of critical infrastructure, thus aiding in swift and informed decision-making during recovery efforts.

On the other hand, FPGA (Field Programmable Gate Array) is another option to serve as the processor of our project since it is able to achieve similar results while opening to become more complex if we choose so. Regardless, the battle for the processor of our project lies between FPGA and MCU, with both having to account for their power consumption and capabilities for our project.

FPGA

Field Programmable Gate Arrays (FPGAs) are highly flexible and reconfigurable integrated circuits that allow developers to customize hardware functionality according to specific application needs. FPGAs consist of an array of programmable logic blocks and interconnects that can be reconfigured to implement virtually any digital circuit. This adaptability makes FPGAs particularly valuable in fields requiring high parallel processing capabilities, such as signal processing, hardware acceleration, and custom hardware solutions. With FPGAs, developers can achieve hardware-level performance optimization, making them ideal for applications where real-time processing, low latency, and high throughput are critical.

FPGAs are often employed in telecommunications, aerospace, defense, automotive, and data center applications, providing a solid platform for rapid prototyping and iterative development. However, the complexity of FPGA programming, often requiring hardware description languages like VHDL or Verilog, along with higher power consumption compared to microcontrollers (MCUs), are key considerations. Despite these challenges, FPGAs remain an indispensable tool for projects seeking unparalleled flexibility and performance in their designs. Although FPGA allows for more advanced features for our project, there are significant drawbacks such as high power consumption and complexity in programming that must be taken into account selecting FPGAs as our processor choice of technology.

For the SPARROW project, leveraging an FPGA could enable advanced real-time image processing and object detection algorithms, which are essential for identifying humans in search and rescue scenarios. The parallel processing capabilities of FPGAs would allow for efficient handling of high-resolution video streams and complex computations, such as feature extraction or neural network inference, directly on hardware. This can significantly reduce latency and enhance the responsiveness of the system compared to traditional CPU or GPU-based solutions. However, these advantages must be weighed against the additional development time and expertise required for FPGA programming, as well as the potential need for specialized tools and workflows. While FPGAs provide unmatched flexibility and performance, their practical implementation in SPARROW would depend on the project's resource constraints and the expertise of the development team.

MCU

Microcontroller Units (MCUs) are compact, integrated circuits designed to manage specific control-oriented tasks within embedded systems. An MCU typically includes a central processing unit (CPU), memory (both RAM and Flash), and various peripherals, all on a single chip. This integration enables MCUs to perform real-time operations efficiently, making them ideal for a wide range of applications, from simple home appliances and consumer electronics to complex automotive and industrial control systems. MCUs are prized for their low power consumption, cost-effectiveness, and ease of use, often programmed using high-level languages like C or C++.

MCUs play a critical role in the Internet of Things (IoT), where they are used to collect data from sensors, control actuators, and communicate with other devices. Their ability to operate in low-power modes is crucial for battery-powered devices. Additionally, the wide availability of development boards and ecosystems, such as Arduino and STM32, simplifies prototyping and accelerates the development process. Despite their limited processing power, MCUs provide sufficient computational capability for numerous applications, balancing performance with energy efficiency and cost. At the end of the day, MCUs provide a simple component to function as our processor due its ease of use in embedded systems while also allowing for many peripherals on a single board, which can be crucial in allowing our drone to contain all the components and be managed through the singular processor unit.

For the SPARROW project, an MCU offers an excellent balance between functionality and efficiency, enabling seamless integration of essential components such as thermal cameras, GPS modules, and communication interfaces for real-time telemetry and video transmission. Its low power consumption is particularly advantageous for extending drone flight times, which is critical in search and rescue missions where operational endurance is paramount. Additionally, the vast ecosystem of libraries and development tools available for popular MCU families simplifies implementation and allows for rapid debugging and iteration, reducing development time. While MCUs may not match the raw computational power of FPGAs, their ease of use, reliability, and cost-effectiveness make them an ideal choice for SPARROW's embedded system, ensuring that the drone operates efficiently while maintaining simplicity in hardware and software design.

Table 3.10. *Comparison of MCU and FPGA*
by Authors

	MCU	**FPGA**
Processing Power	Moderate; suitable for simple control tasks	High; excels in parallel processing for complex tasks

Architecture	Fixed, integrated with CPU, memory, and peripherals	Reconfigurable logic blocks and interconnects
Programming	Easier; uses languages like C, C++, Assembly	Complex; uses hardware description languages (HDL)
Performance	Limited; not ideal for intensive computational tasks	High; can accelerate AI algorithms and handle large data sets efficiently
Power Consumption	Low; optimized for energy efficiency	Higher; varies based on configuration
Cost	Generally lower; cost-effective for simple applications	Higher initial cost; offers better performance for complex tasks
Flexibility	Limited; fixed functionality	High; can be updated and reconfigured for different tasks
Latency	Higher latency for complex computations	Low latency, ideal for real-time processing
Use Case Suitability	Best for simple, low-power, and cost-sensitive applications	Best for high-performance, flexible, and complex applications

Processor Technology Selection

After thorough consideration, the processor technology of choice that we are going with would be the MCU as our project incorporates various peripherals that would naturally come with many MCUs in the market. From sensors to cameras to wireless communications, we would like our embedded system to be solid and able to maintain the ability to manage all the components. There are many MCU boards that are equipped to handle wireless communications and also ones that have the ability to run an entire operating system on them. While FPGAs can be better at real time processing alongside parallel processing, the complexity of programming such technology is undesirable alongside the high power consumption as with our drone, we would like the best out of the battery and would prefer to not let the drone die down fast after being sent out. Overall, we went with the MCU as our processor technology of choice since it is capable of offering various peripheral support for our components on top of being able to have low power consumption, low cost, and less complexity in terms of programming.

ESP32-WROOM-32

The ESP32-WROOM-32 MCU stands out as a highly integrated and versatile solution tailored for a diverse array of IoT applications. Powered by a dual-core 32-bit LX6 microprocessor, it boasts incredible processing capabilities suitable for demanding tasks. Integrated Wi-Fi and Bluetooth functionalities enable wireless communication, essential for applications requiring real-time data transmission and remote control. With 4 MB of flash memory, it offers ample storage capacity for firmware and applications, while supporting multiple communication interfaces such as SPI, UART, and I2C. Its low power consumption makes it particularly suitable for battery-operated devices like drones. Coupled with extensive library support and a strong developer community, the ESP32-WROOM-32 excels in delivering performance, connectivity, and energy efficiency, making it an excellent choice for embedded systems and IoT projects alike, including scenarios like post-disaster drone missions aimed at detecting power line faults and transformer heating. Overall, with all these aspects in mind, the ESP32 serves as a decent choice for our drone project as it offers a ton of capabilities that is suitable for allowing our drone to succeed in its goals.

ESP32-S2

The ESP32-S2 is a single-core microcontroller designed for IoT applications, notable for its enhanced security features and efficient power management. Powered by a single-core 32-bit LX7 microprocessor, it offers a balance between performance and power consumption. The ESP32-S2 includes integrated Wi-Fi capabilities but lacks Bluetooth, making it ideal for applications focused solely on wireless networking. It features 320 KB of SRAM and 128 KB of ROM, providing sufficient memory for firmware and applications. The microcontroller supports various communication interfaces such as SPI, UART, and I2C, along with ADC capabilities for analog sensor integration. With hardware-based security features like hardware encryption and secure boot, the ESP32-S2 ensures data integrity and device authenticity, making it suitable for secure IoT deployments. Overall, the ESP32-S2 is well-suited for applications requiring reliable wireless connectivity and robust security measures, offering a cost-effective solution for IoT projects, including sensor networks and smart devices. Nevertheless, the ESP32-S2 offers sufficient abilities and makes for another solid choice of the MCU for our drone project.

STM32H743ZI

The STM32H743ZI microcontroller represents a high-performance solution based on the ARM Cortex-M7 core, capable of operating at speeds up to 480 MHz. Through the combination of 1 MB RAM and 2 MB flash memory, this microcontroller offers substantial resources crucial for demanding applications, including autonomous drone systems. This microcontroller excels in real-time processing and control tasks as it supports comprehensive peripherals such as SPI, UART, I2C, and Ethernet interfaces. These features facilitate integration of diverse sensors and communication protocols essential for applications such as thermal and regular camera data processing, as well as solid communication with ground stations. The STM32H743ZI also features integrated ADC and DAC converters, enhancing its ability to accurately sample and process analog signals from sensors. Overall, from the advanced features, coupled with moderate power consumption, ensures a reliable performance while maintaining the high performance necessary for our project, makes the STM32H743ZI an optimal choice for SPARROW and its goals, thus this microcontroller should not be neglected is in consideration as the main processor for our drone.

STM32F103C8T6

The STM32F103C8T6 is a slightly less capable microcontroller compared to the STM32H743ZI, but this comes with certain advantages. Among the microcontrollers considered, the STM32F103C8T6 features the lowest processor speed and the smallest amount of RAM, making it less suitable for high-performance tasks. However, its 64 KB of Flash Memory provides sufficient storage for smaller applications while maintaining a lower power consumption profile, making it an excellent choice for energy-efficient systems. The STM32F103C8T6 supports a range of peripherals, including UART, SPI, I2C, PWM, and ADC, ensuring compatibility with many sensors and communication modules if needed. This microcontroller's 12-bit ADC and PWM outputs enable reliable analog signal processing and motor control capabilities. While it lacks the advanced processing power and feature set of higher-end microcontrollers, its simplicity and efficiency make it a practical option for less demanding tasks. For SPARROW, the STM32F103C8T6 could serve well as a secondary or support microcontroller in the base station, handling basic data processing and communication tasks. Its slower processor speed and lightweight nature make it more suited for stationary operations like managing received data rather than being deployed onboard a drone.

Raspberry Pi 4 Model B

The Raspberry Pi 4 Model B stands out as an excellent choice for a drone project focused on tasks such as thermal imaging, powerline fault detection, and mesh network communication. Powered by a quad-core ARM Cortex-A72 processor running at 1.5 GHz and available with up to 8 GB of LPDDR4 RAM, it offers robust performance for real-time data processing and multitasking. Its Gigabit Ethernet port ensures fast and reliable wired networking, crucial for stable communication with ground stations and high-speed data transfer during drone operations. In terms of connectivity, the Raspberry Pi 4 includes multiple USB 3.0 and USB 2.0 ports, an HDMI port for display connectivity, and GPIO pins for interfacing with sensors and peripherals. Dual-band 802.11ac Wi-Fi and Bluetooth 5.0 support provide additional wireless connectivity options, facilitating communication with other devices and enabling flexible deployment scenarios. Overall, the Raspberry Pi 4 Model B combines powerful processing capabilities with comprehensive connectivity, making it a versatile platform for developing and deploying sophisticated drone systems that require advanced data processing, communication, and control functionalities.

Raspberry Pi 3 Model B+

The Raspberry Pi 3 Model B+ is a versatile single-board computer ideally suited for drone projects requiring reliable performance and connectivity. Powered by a quad-core ARM Cortex-A53 processor running at 1.4 GHz and 1 GB of LPDDR2 RAM, it provides sufficient processing power for tasks such as image processing from thermal and regular cameras, sensor data fusion, and control algorithms. The board includes built-in 2.4 GHz and 5 GHz 802.11ac Wi-Fi and Bluetooth 4.2/BLE for wireless communication, enabling connectivity with ground stations and other devices. It features a 10/100 Ethernet port for stable wired networking, essential for high-speed data transfer and robust communication during drone operations. With HDMI output and multiple USB ports, the Raspberry Pi 3 Model B+ offers versatility in peripheral connectivity, supporting various sensors, cameras, and other peripherals required for drone applications. Overall, its compact size, computational capability, and connectivity options make it a reliable MCU for developing and deploying drone systems with advanced functionality and communication capabilities, especially for our drone.

Jetson Nano

The Jetson Nano is a highly capable edge computing platform, well-suited for drone and base station applications that demand substantial processing power and advanced AI functionality. Powered by a quad-core ARM Cortex-A57 processor and a 128-core NVIDIA Maxwell GPU, it delivers impressive performance for real-time tasks such as image recognition, sensor data fusion, and autonomous navigation. With 4 GB of LPDDR4 RAM, the Jetson Nano supports the execution of deep learning models and complex algorithms, making it ideal for environments where quick decision-making and high-throughput data handling are essential. In terms of connectivity, the Jetson Nano offers a versatile array of interfaces, including SPI, I2C, UART, USB 3.0, Gigabit Ethernet, and CSI camera input, allowing it to integrate seamlessly with a wide variety of sensors, cameras, and other peripherals. Its support for MIPI and high-bandwidth video inputs makes it particularly effective for tasks involving thermal and optical imaging. Despite its powerful capabilities, the Jetson Nano maintains a compact form factor and energy-efficient profile, making it suitable for onboard drone applications where space and power are limited.

Additionally, its ability to run full Linux operating systems and support major AI frameworks like TensorFlow, PyTorch, and OpenCV provides developers with a flexible and familiar environment for rapid prototyping and deployment. Overall, the Jetson Nano is a robust, scalable solution for SPARROW, enabling it to process data from multiple sources and perform real-time image recognition and analytics throughout the drone's expedition.

Jetson AGX Orin Developer Kit

The Jetson Orin is an excellent choice for our search and rescue drone project, which also includes a base station controller. It features an 12-core Arm Cortex-A78AE CPU and an NVIDIA Ampere GPU, providing incredible computational power for tasks such as AI-based object detection, autonomous flight control, and real-time video streaming. The integrated Wi-Fi, Bluetooth, and Ethernet connections ensure stable communication between the drone and the base station. With 8 GB of RAM and 16 GB eMMC storage, it can efficiently manage complex applications like search algorithms and obstacle detection. Its low power consumption makes it viable for both mobile drone operations and base station tasks, while the AI capabilities allow for advanced functions like facial recognition and environmental sensing during rescue missions. The Jetson Orin's performance, versatility, and connectivity make it an ideal solution for search and rescue applications where reliability and real-time decision-making are essential.

Table 3.11. *Comparison of MCU products - Part 1*
by Authors

Criteria	ESP32-WROOM-32	ESP32-S2	STM32H743ZI	STM32F103C8T6
Processor	Dual-core Tensilica LX6	Xtensa LX7	ARM Cortex-M7	ARM Cortex-M3
Clock Speed	Up to 240 MHz	Up to 240 MHz	Up to 480 MHz	Up to 72 MHz
RAM	520 KB	320 KB	1 MB	20 KB
Flash Memory	4 MB	4 MB	2 MB	64 KB
Connectivity	Bluetooth Wi-Fi	Bluetooth Wi-Fi	CAN USB	CAN USB
UART	Yes	Yes	Yes	Yes
I2C	Yes	Yes	Yes	Yes
SPI	Yes	Yes	Yes	Yes

PWM	Yes	Yes	Yes	Yes
ADC	Yes	Yes	Yes	Yes
DAC	Yes	Yes	Yes	No
Power Consumption	Low	Low	Moderate	Low

Table 3.12. *Comparison of MCU products - Part 2*
by Authors

Criteria	**Raspberry Pi 4 Model B**	**Raspberry Pi 3 Model B+**	**Jetson Nano**	**Jetson Orin AGX Developer Kit**
Processor	Broadcom BCM2711	Broadcom BCM2837B0	Quad-core ARM Cortex-A57	8-core ARM Cortex-A78AE
Clock Speed	Up to 1.5 GHz	Up to 1.4 GHz	Up to 1.43 GHz	Up to 2.2 GHz
RAM	1 GB - 8 GB	1 GB	4 GB	32 GB
Flash Memory	None	None	None	64 GB
Connectivity	Bluetooth Ethernet Wi-Fi	Bluetooth Wi-Fi	Ethernet	Bluetooth Ethernet Wi-Fi
UART	Yes	Yes	Yes	Yes
I2C	Yes	Yes	Yes	Yes
SPI	Yes	Yes	Yes	Yes

PWM	Yes	Yes	Yes	Yes
ADC	Yes	Yes	None	None
DAC	Yes	Yes	None	None
Power Consumption	Moderate/High	Moderate/High	Low/Moderate	Moderate/High

Processor Product Selection

For the processor of choice for SPARROW, we have decided on Jetson Orin AGX Developer Kit as it provides a powerful source for our project. It comes with incredible computing power and with the ability to run AI on it, we can use it to leverage our abilities to use robot vision and detect humans more easily inside the images through the use of robot vision. When applying various applications and tasks on the processor, the Jetson Orin has 64 GB of RAM alongside 16 GB of Flash Memory in conjunction with a 1.5 GHz clock speed, which allows it to significantly perform various tasks for SPARROW, especially with the footage obtaining part of the human detection algorithm. Additionally, the Jetson Orin can efficiently run convolutional neural networks (CNNs) and machine learning models specifically trained to identify human shapes, postures, and features within varied environments, which is crucial for projects that rely on detecting humans in challenging or obstructed visuals. For the human detection criteria, the Jetson Orin can process data from high-resolution cameras or thermal sensors and use deep learning models to distinguish humans from other objects, even in low-light or high-noise environments. This capability is further enhanced by its ability to perform on-device inference, which is critical for applications that require low-latency responses, such as real-time search and rescue operations. Although it does consume more power than other MCUs for this project, the Jetson Orin has incredible AI capabilities which pushes it over the edge and while it does cost more to purchase, thankfully, our sponsor Lockheed Martin is able to provide us with the Jetson Orin so we are able to use such powerful MCU for the AI detection portion of our project.

While the drones in the air may not be able to fit the heavy Jetson Orin onto them for the image processing and human detection on board, the Jetson Nano comes into play for this situation. The Jetson Nano serves as mini Jetson Orins on the board and will be taking data feed from the cameras on the drone before applying human detection algorithm on them and then sending them over to the radio modem where the image data would be transmitted alongside flight data down towards the base station where the Jetson Orin would process everything.

While the Jetson Orin AGX is selected for its AI capabilities for SPARROW, we are also choosing to select the STM32F103C8T6 microcontroller to be alongside the Jetson Orin AGX. The STM32F103C8T6 is chosen as the companion to the Jetson Orin AGX as the Jetson Orin AGX is meant to be constantly handling image processing and the AI parts of our project whereas the STM32F103C8T6 will be handling the other operations of SPARROW at the ground base station such as power controlling. Although this microcontroller may be weaker in terms of power wise when compared to other microcontrollers that were compared for SPARROW, the STM32F103C8T6 comes with its own benefit of the low power consumption alongside significant memory to handle power controls and other smaller functionality of the SPARROW base station while letting the Jetson Orin AGX handle all the other harder computing tasks within SPARROW.

3.7 Battery Management System

A Battery Management System (BMS) is an important component to ensure the safe, reliable, and efficient operation of the battery pack. Batteries are sensitive to operating conditions, requiring precise monitoring of parameters like voltage, current, and temperature to prevent damage or hazardous situations. A BMS acts as a safeguard, providing protection mechanisms against overvoltage, undervoltage, and overcurrent conditions, which are essential for maintaining the health and longevity of the battery cells.

The inclusion of a BMS in our design ensures the battery operates within its safe limits. Overcharging a cell can lead to thermal runaway, potentially causing fires or explosions, while over-discharging can result in permanent damage to the battery chemistry. By integrating features such as overvoltage and undervoltage protection, the BMS helps to prevent these risks, making the system inherently safer and more reliable for both the end user and the application.

Another vital role of the BMS is in optimizing the performance and lifespan of the battery pack. Through voltage sensing and cell balancing, the BMS ensures that all cells in the pack are charged and discharged evenly. This prevents imbalances that can reduce the overall capacity of the battery or lead to premature failure of individual cells. For our project, where efficiency and long-term reliability are paramount, these capabilities are indispensable.

Temperature monitoring is another critical feature provided by the BMS. Cells are sensitive to extreme temperatures, which can degrade their performance or cause safety hazards. The BMS's ability to detect and mitigate temperature variations ensures that the battery operates within its optimal temperature range, protecting the cells and the surrounding system components.

BQ76925

The BQ76925 is an analog front-end (AFE) designed for battery management systems, particularly for 3 to 6 series-connected lithium-ion cells. It provides key features for monitoring, protecting, and controlling a battery pack. Its core functionality includes cell voltage monitoring, cell current monitoring, temperature measurement, and cell balancing. The device is controlled via an I2C interface, ensuring seamless communication with a host controller.

The BQ76925 includes a built-in 3.3 V regulator and a comparator for overcurrent monitoring. This comparator can generate alerts for potential faults or wake up the host system. Additionally, the device supports external thermistors for temperature measurement, offering a biasing output that can be toggled to reduce power consumption. In terms of power efficiency, the BQ76925 has several operational modes, including a low-power sleep mode consuming 1.5 µA, making it suitable for energy-sensitive applications.

Cell balancing is achieved through integrated FETs, which are host-controlled to balance individual cell voltages, with current limited to 50 mA. The device also features protections against overvoltage, undervoltage, and current imbalances, ensuring enhanced safety and reliability of the battery system. Its design includes an optional CRC for error detection in communication and operates within a wide voltage range of 4.2 V to 26.4 V.

The BQ76925's thermal and electrical characteristics make it adaptable to demanding applications. It is available in two package options (TSSOP and QFN), offering different thermal resistance and footprint benefits for various design needs. This makes the BQ76925 an excellent choice for applications requiring efficient and safe management of lithium-ion batteries, such as in portable electronics, electric vehicles, and energy storage systems.

BQ76920

The BQ76920 is a battery monitor designed by Texas Instruments to support up to 5-series cell lithium-ion or lithium iron phosphate battery packs, typically handling voltages around 18V. It is part of the BQ769x0 family, which includes the BQ76925. The BQ76920 integrates several battery management functions, including monitoring individual cell voltages, battery pack temperature, and current. It uses a highly efficient I2C interface, enabling a host controller to manage charge/discharge cycles, enforce protections, and perform cell balancing for optimal battery performance.

This device includes integrated A/D converters for digital measurement of system parameters, eliminating the need for external circuitry for voltage and temperature monitoring. It also offers safety features, such as overcurrent, overvoltage, and undervoltage protection, through its control of charge and discharge FETs. These capabilities make it a suitable choice for portable electronics, power tools, and energy storage systems requiring precise and reliable battery management.

To minimize power consumption, the BQ76920 supports a SHIP mode, placing the battery pack into an ultra-low-power state. This feature is ideal for conserving energy during storage or periods of inactivity. The device's compact design and robust functionality enable it to meet the demands of high-performance battery management applications in a wide range of industries.

AD7280WBSTZ-RL

The AD7280WBSTZ-RL is an advanced lithium-ion battery monitoring IC designed by Analog Devices. It is engineered for high-precision monitoring in applications like hybrid and electric vehicles, battery backup systems, and power tools. This IC enables the monitoring of up to six stacked battery cells and features a high-accuracy ADC with a resolution of 12 bits. Its design includes an internal reference with ±3 ppm/°C stability and a cell voltage accuracy of ±1.6 mV, ensuring reliable operation under various conditions.

The device offers a fast ADC conversion time of 1 μs per channel, making it capable of monitoring up to 48 cells when used in a daisy-chain configuration. It also supports auxiliary ADC inputs for additional monitoring tasks. A built-in voltage regulator, high input impedance, and robust CRC error protection enhance the IC's performance in critical systems. It includes features for cell balancing, and its SPI-compatible interface simplifies integration into complex designs.

This IC is well-suited for automotive environments, as it operates over a temperature range of −40°C to +105°C and supports a wide input voltage range of 8 V to 30 V. Its high level of integration and performance make it a reliable choice for demanding battery management applications.

L9961

The L9961 is a battery management IC from STMicroelectronics, specifically designed for industrial applications and use with their other products such as the STM32F103C8T6. It supports configurations of up to five cells and is designed to monitor and balance individual cell voltages while ensuring comprehensive protection mechanisms. The IC integrates a high-precision 12-bit ADC for voltage and temperature measurements, as well as a 16-bit current-sensing amplifier that facilitates coulomb counting for estimating the battery's state of charge (SOC) and state of health (SOH). Its integrated MOSFETs enable efficient cell balancing, while pre-drivers for both high-side and low-side protection enhance safety features.

The L9961 is particularly focused on safety, incorporating advanced diagnostic capabilities, fault detection systems, and protection features such as overvoltage, undervoltage, and overcurrent monitoring. Additionally, it offers a fuse driver for critical fault scenarios and an internal non-volatile memory (NVM) for safety-relevant configuration storage. The L9961's low power consumption and functionality make it ideal for applications like power tools, drones, medical devices, and other portable or semi-portable systems.

The device supports an ecosystem that includes software packages and evaluation kits, allowing for quick implementation and testing. Its configurable features, combined with support for I2C communication, streamline integration into battery management systems while reducing the need for external components, ultimately lowering design complexity and cost.

Table 3.13. *Comparison of BMS products*
by Authors

Criteria	BQ76925	BQ76920	AD7280WB STZ-RL	L9961
Input Voltage (V)	4.2 - 26.4	4.2 - 26.4	4.5 - 18	4.3 - 25
Communication Interface	I2C	I2C	SPI	I2C
Number of Cells	3 - 6	3 - 5	3 - 6	3-5
Voltage Sensing	Yes	Yes	Yes	Yes
Current Sensing	Yes	Yes	Yes	Yes
Temperature Sensing	Yes	Yes	Yes	Yes
Cell Balancing	Yes	Yes	No	Yes
Overvoltage Protection	Yes	Yes	Yes	Yes
Undervoltage Protection	Yes	Yes	Yes	Yes
Short-Circuit Protection	Yes	Yes	Yes	Yes
Internal Voltage Reference	Yes	Yes	No	Yes
Price	$0.86	$1.46	$15.37	$2.41

BMS Product Selection

After analyzing the BMS products, the L9961 emerged as the most suitable choice for our project's specifications. Its ability to support up to five lithium-ion cells and its integrated 12-bit ADC for precise voltage and temperature monitoring make it highly compatible with our application's requirements. The integrated 16-bit current-sensing amplifier enables accurate state-of-charge (SOC) and state-of-health (SOH) estimations, enhancing the battery pack's operational reliability. The L9961 also features embedded MOSFETs for efficient cell balancing, which is critical for extending battery life and maintaining performance consistency.

The L9961 offers several protection features, including overvoltage, undervoltage, and overcurrent monitoring, along with a fuse driver for managing critical fault conditions. Its configurable high-side and low-side pre-drivers simplify circuit design while ensuring safety and flexibility. Additionally, the IC is designed for low power consumption, supporting extended operation in low-power states. Importantly, the L9961 is directly compatible with the STM32F103C8T6 processor used in our design, ensuring seamless integration and communication through its I²C interface. This compatibility eliminates the need for additional interface adaptations, streamlining development and reducing potential design complexities.

While other options like the BQ76925 and AD7280WBSTZ-RL offer comparable cell monitoring and protection features, the L9961's direct compatibility with our processor make it a more suitable choice. The BQ76925, although efficient, lacks this level of integration and processor-specific support. Likewise, while the AD7280WBSTZ-RL provides an SPI interface for faster communication, it omits cell balancing features, which are vital for ensuring long-term battery health in our application. Overall, the L9961's comprehensive feature set, combined with its compatibility and flexibility, makes it the best choice for our battery management system.

3.8 Voltage Regulator

Ensuring a stable and consistent voltage supply is critical to the performance and longevity of the drone controller's and components. The drone controller houses numerous electrical elements, each with specific voltage requirements. These components, ranging from sensors to communication modules and microcontrollers, rely on a steady input voltage to function correctly. Variations in voltage can lead to performance inconsistencies, malfunctions, or even irreversible damage to sensitive components. This is where the voltage regulator plays a pivotal role.

Voltage regulators maintain a constant voltage level, regardless of changes in input voltage or load conditions. In the context of our project, where various components within the drone and its control systems operate at different voltage levels, the regulator ensures that each component receives the appropriate power. Without a voltage regulator, the components would be exposed to the full, often fluctuating, voltage supplied by the battery or power source. These fluctuations can arise from the dynamic operation of the drone, which may cause voltage spikes or drops due to sudden demands for power.

Additionally, the voltage regulator also serves to protect the battery. Drone controllers typically use high-capacity, rechargeable lithium-ion or lithium-polymer batteries, which are highly efficient but sensitive to over-voltage conditions. If the battery supplies too much voltage to the controller's electronic systems, it can shorten the battery's lifespan, cause overheating, or in extreme cases, result in a fire hazard. The voltage regulator ensures that the battery's output is moderated and kept within safe operating limits, thus extending the life of both the battery and the electronic components it powers.

Overall, the voltage regulator is an essential safeguard in the power management system. By maintaining stable voltage levels, it not only ensures optimal performance of the drone’s critical components but also enhances their longevity. This protection extends to the power source, preventing damage and reducing the risk of dangerous conditions such as overheating. In summary, the voltage regulator is a key factor in maintaining the reliability and safety of the PCB, making it a vital component for both the performance and durability of the entire system.

The two most common types of voltage regulators are linear regulators and switching regulators. Each has distinct advantages and are suited to specific scenarios.

Linear Voltage Regulator

A linear voltage regulator maintains a stable output by continuously adjusting the resistance within the regulator to match the load demand. It operates by dissipating excess energy as heat, ensuring the output voltage remains steady regardless of input fluctuations. Some advantages of using a linear voltage regulator include: low noise and fast response time; however, linear voltage regulators usually have poor thermal management and have low efficiency, especially if there is a significant difference between voltage input and output.

Switching Voltage Regulator

A switching voltage regulator converts input voltage to the desired output using high-frequency switching and energy storage components like inductors and capacitors. It alternates between storing energy and releasing it to maintain a consistent output voltage. Some advantages a switching voltage regulator has include: high efficiency and versatility (can handle boosts, bucks, and high currents); however, switching voltage regulators are usually more complex than linear voltage regulators and generate noise caused by electromagnetic interference.

Table 3.14. *Power Tree*
by Authors

Hardware Component	Supply Voltage	Maximum Current Draw	Maximum Power
Jetson AGX Orin Dev Kit	10 V - 20 V	3 A	60 W
HMTECH 7-inch Raspberry Pi Screen	5 V	2 A	10 W
STM32F130C8T6	2 V - 3.6 V	150 mA	540 mW
RFD900x-US	5 V - 5.5 V	60 mA	300 mW
SAM-M8Q-0-10	2.7 V - 3.6 V	10 mA	36 mW
L9961	4.3 V - 25 V	5 µA	125 µW

Voltage Regulator Technology Selection

Because the controller requires 3.3 V and 12 V to operate various components and the power supply will produce more than 12 V at its lowest output, a switching voltage regulator (buck) is the ideal choice. Switching regulators offer high efficiency, which is critical given the significant power demands of components like the display and Jetson Orin. These components require not only steady voltage but also the ability to draw relatively high currents without overheating or draining the battery too quickly.

Because the input voltage coming from the batteries is higher than the three rails, a buck voltage regulator is required to ensure all components receive the required amount of voltage without damage.

The Jetson AGX Orin developer kit includes its own onboard power regulation systems and is capable of supplying a stable 5 V rail for the modem and dispaly. This simplifies the overall power architecture by reducing the need for an external 5 V regulator. By leveraging the Orin's integrated power management, the system can ensure reliable and consistent voltage delivery to components that operate at 5 V, such as USB devices or auxiliary sensors, without additional circuitry. This not only helps reduce the system's complexity and weight, but also contributes to overall power efficiency, as fewer discrete regulators are needed.

AP64501

The AP64501 is a high-efficiency DC/DC buck converter developed by Diodes Incorporated, designed to meet the power needs of systems with medium load requirements. It operates at a switching frequency of 570 kHz and can handle input voltages of up to 40 V, making it versatile for various power management applications. With a continuous output current maximum of 5 A, the AP64501 is well-suited for use in embedded systems, telecommunications equipment, and other electronic devices that require reliable voltage regulation.

Advanced features such as internal soft-start, overcurrent protection (OCP), thermal shutdown, and undervoltage lockout (UVLO) enhance the reliability and safety of the regulator, protecting both the device and the system it powers from fault conditions. Additionally, the AP64501 incorporates pulse skipping mode under light load conditions to improve efficiency and reduce power loss when the full 5 A output is not required.

Overall, the AP64501 offers a dependable solution for systems needing precise voltage regulation without sacrificing energy efficiency. While it excels in power-sensitive environments, its suitability may vary based on specific project requirements, such as input voltage range or load demands. Its design makes it a practical choice for our project.

TPS566247DRLR

The TPS566247DRLR is a high-efficiency, synchronous buck converter from Texas Instruments, designed for precise DC-DC voltage regulation. With an input voltage range of 3 V to 16 V, it can deliver a continuous current of up to 6 A, making it suitable for a variety of low to medium-power applications. Its compact design and robust specifications allow it to integrate seamlessly into power management systems where efficient voltage conversion is critical.

A key feature of the TPS566247DRLR is its Forced Continuous Conduction Mode (FCCM), which ensures a consistent switching frequency across varying load conditions. This steady frequency helps minimize output ripple, ensuring stable performance even under dynamic workloads. The converter’s synchronous operation also enhances efficiency by reducing energy losses, particularly at higher loads, making it ideal for applications such as industrial equipment, embedded systems, and telecommunications hardware.

Despite its high efficiency, some design considerations must be accounted for, such as thermal management, especially in systems with limited airflow. Additionally, while FCCM mode is beneficial for stability, it may slightly reduce efficiency at very light loads compared to pulse-skipping alternatives. Overall, the TPS566247DRLR offers excellent reliability and performance, balancing precision and efficiency.

LM2596

The LM2596 is a widely used step-down (buck) voltage regulator that provides high efficiency and versatility for various applications. Designed by Texas Instruments, this regulator can handle input voltages up to 40 V, making it suitable for a range of power management scenarios. With a continuous output current of up to 3 A, the LM2596 is an excellent choice for projects that demand reliable voltage regulation while ensuring efficient power usage.

One of the notable features of the LM2596 is its built-in thermal shutdown and current limiting capabilities, which provide added protection against overheating and overcurrent situations. This makes it especially valuable in environments where components are sensitive to temperature variations and electrical stresses. The regulator operates with a typical efficiency of around 75-90%, significantly reducing wasted energy and heat generation, which is crucial for battery-powered devices.

In summary, the LM2596 is a reliable and efficient voltage regulator ideal for applications where stable output and thermal management are critical. Its reliability and performance make it a suitable addition to any project requiring precise voltage regulation, especially in systems where power efficiency and component protection are paramount.

Table 3.15. *Comparison of switching voltage regulator (buck) products by Authors*

Criteria	AP64501	TPS566247DRLR	LM2596
Input Voltage (V)	3.8 - 40	3 - 16	4.5 - 40
Output Voltage (V)	0.8 - 39	0.6 - 7	3.3, 5, 12
Maximum Output Current (A)	5	6	3
Price	$3.22	$0.57	$8.63

Voltage Regulator Product Selection

After analyzing the various switching voltage regulator products, the AP64501 emerged as the most suitable choice for our project's specifications. Its wide input voltage range of 3.8 to 40 V accommodates our supply needs. Furthermore, it can output a voltage range of 0.8 to 39 V, allowing it to supply adequate voltage to both the 3.3 V and 12 V rail.

The AP64501 supports a maximum output current of 5 A, which is sufficient for our application requirements. Priced at $3.22, it is rather expensive but the cost is outweighed by its versatility. Its efficiency in switching provides lower heat generation, enhancing reliability and operational longevity.

While the TPS566247DRLR offers a higher maximum output current of 6 A and a lower price point of $0.57, its narrower input voltage range (3 to 16 V) limits its applicability in higher voltage scenarios. The LM2596, on the other hand, presents a broader input voltage range (4.5 to 40 V) but is limited to fixed output voltages (3.3, 5, or 12 V) and does not meet our needs as effectively.

Considering the critical factors of input and output voltage flexibility, maximum output current, and cost, the AP64501 stands out as the best overall choice for our project. Its robust performance characteristics, coupled with its ability to handle a wide range of input and output conditions, make it a reliable and efficient solution for our voltage regulation requirements. Other options, like the TPS566247DRLR and LM2596, may provide certain advantages, but they do not offer the same combination of flexibility, capacity, and efficiency as the AP64501 for our specific application needs.

3.9 Batteries

SPARROW contains a drone and a base station which both require batteries to provide power. SOAR requires one hour of battery lifetime and the controller will need to provide at least twice that battery lifetime at 4.2 V, 5 Ah. A few other considerations are price, weight, size, technology, and charging and discharging requirements.

Another distinction we must make before continuing any further are the two main categories of batteries. Primary batteries, or disposable batteries, are intended for one-time use applications. Once their chemical energy is depleted, they cannot be recharged or reused economically. Primary batteries are convenient for devices where long-term reliability and rechargeability are not necessary. Secondary batteries, or chargeable batteries, are designed to be recharged and used multiple times. They store electrical energy through reversible chemical reactions, allowing them to be refilled with energy once depleted. This characteristic makes them cost-effective and environmentally friendly compared to primary batteries. Secondary batteries are prevalent in devices requiring frequent use and sustained power. For our specifications for this project, secondary batteries will be used by both the drone and drone controller.

Lithium Polymer

Lithium Polymer (LiPo) batteries are a popular choice for drone controllers due to their high energy density and lightweight characteristics. These batteries are constructed using a flexible polymer electrolyte, allowing for a variety of shapes and sizes, which is advantageous for fitting into compact and uniquely shaped devices. LiPo batteries can deliver high power output and maintain a stable voltage, making them ideal for high-performance applications like drones and drone controllers.

However, LiPo batteries require careful handling and charging to prevent potential hazards such as overcharging, which can lead to thermal runaway and battery swelling, and over-discharge, which can permanently damage the cell overheating or swelling. They are more sensitive to physical damage and improper charging practices compared to other battery types. Because of this, LiPo batteries necessitate comprehensive circuit protection mechanisms to prevent these malfunctions. Additionally, circuit protection is crucial to prevent overcurrent, where excessive current flow can cause overheating and compromise battery integrity. Short-circuit conditions pose a significant risk as well; if a short circuit occurs between the battery's external electrodes, it can rapidly discharge the cells to their capacity limit, triggering a rapid increase in temperature and potential fire hazards.

To mitigate these risks, LiPo batteries incorporate built-in protection circuits that monitor voltage levels, current flow, and temperature. These circuits disconnect the battery from the load or charging source in case of abnormal conditions, preventing irreversible damage and ensuring safe operation. Furthermore, proper handling and charging practices, including using designated chargers, are essential to maximize the safety and longevity of

LiPo batteries. Despite these risks, the benefits of high power and lightweight design often outweigh the drawbacks, making LiPo batteries a preferred choice in many modern electronic devices, especially where weight and space are critical considerations.

Lithium Ion

Lithium-ion (Li-ion) batteries are renowned for their high energy density and long lifespan, making them a prevalent choice for a wide range of electronic devices, including drone controllers. These batteries offer reliable performance with lower maintenance requirements compared to other rechargeable batteries. Li-ion batteries maintain a stable voltage and provide consistent power output, which is crucial for the optimal functioning of drones and other high-demand applications.

Li-ion batteries, similarly to Lithium Polymer (LiPo), rely on circuit protection systems to mitigate potential hazards such as overcharging, over-discharge, overcurrent, and short-circuit events. These protections are critical because a short circuit between external electrodes can lead to a rapid and uncontrolled discharge of the battery cells, pushing them to their capacity limit and generating excessive heat. This heat not only poses safety risks but can also compromise the battery's performance and longevity. Circuit protection mechanisms actively monitor the battery's voltage, current, and temperature, ensuring that it operates within safe limits under all conditions. By detecting and responding to abnormalities, these systems play a crucial role in enhancing the reliability, safety, and lifespan of Li-ion batteries.

Although Li-ion batteries are generally heavier and more expensive than Lithium Polymer (LiPo) batteries, they offer improved stability and safety. They are less prone to the risks of overheating and swelling when compared to LiPo batteries, making them a more robust option for various uses. The higher cost is often justified by their durability and efficiency, ensuring a longer operational life and fewer replacements over time. These qualities make Li-ion batteries a good choice if we were to prioritize longevity and reliability.

Lead Acid

Lead-acid batteries have been a longstanding and reliable choice in various industrial and automotive applications, although they are less commonly used in modern drone controllers due to their weight and size. These batteries utilize a liquid electrolyte composed of sulfuric acid, which facilitates the chemical reactions necessary for energy storage and release. Lead-acid batteries are known for their ability to provide high surge currents, making them suitable for applications requiring robust power delivery.

Lead-acid batteries are recognized for their thermal stability. This feature ensures that as temperatures rise, the float voltage automatically decreases. This adjustment is pivotal in maintaining a safe operating distance from the thermal runaway zone, where conditions can escalate dangerously. By reducing the float voltage in higher temperatures, the battery system effectively mitigates the risk of overheating and potential thermal runaway, thereby enhancing overall safety and longevity. This thermal stability characteristic makes lead-acid batteries particularly suitable for applications where predictable and stable performance under varying environmental conditions is paramount, such as in standby power systems and industrial backup solutions.

However, compared to newer technologies like LiPo and Li-ion batteries, lead-acid batteries are significantly heavier, bulkier, and have lower energy density. They also require regular maintenance, including checking electrolyte levels and ensuring proper ventilation to prevent the buildup of hydrogen gas. Despite these drawbacks, lead-acid batteries remain cost-effective and reliable for certain applications where weight and size constraints are less critical, such as stationary power backup systems or industrial equipment.

Table 3.16. *Comparison of battery types by Authors*

	Lithium Polymer	**Lithium-Ion**	**Lead Acid**
Nominal Cell Voltage (V)	2.7 – 3	3.6 – 3.85	2.1
Internal Resistance (mΩ)	2 – 20	250 – 350	5 – 10
Energy Density (Wh/kg)	100 – 265	100 – 265	30 – 50
Rating	3.7 V 2 Ah	3.6 V 2 Ah	12 V 2 Ah
C-Rate (C)	1	1	0.2 - 0.05
Charge/Discharge Efficiency	95%	95 – 98%	50 – 95%
Self-Discharge/ Month	<3%	<3%	<5%
Charge Cycles	300 – 500	300 – 500	600 – 700

Operational Temperature (°C)	-20 – 60	-10 – 50	-35 – 45
Circuit Protection	Yes	Yes	No
Thermally Stable	No	No	Yes
Cost (per Wh)	\$2.31	\$0.94	\$0.70

Battery Technology Selection

After researching the different types of batteries commonly used in the industry, Lithium-ion (Li-ion) batteries appear to be the most suitable selection for the controller's requirements. Li-ion batteries offer a balance of high energy density and long lifespan, which are crucial for the controller's performance. While Lithium Polymer (LiPo) batteries provide a lightweight option with high power output, their sensitivity to physical damage and stringent charging protocols present significant risks while costing over twice as much per Wh stored when compared to Li-Ion batteries. Lead-acid batteries, though reliable and cost-effective in certain applications, are not feasible due to their weight, bulk, and lower energy density, making them impractical for our relatively compact and high-performance needs.

The selection of Li-ion batteries ensures that the power systems will meet the demands of the drone and the other components in the controller while maintaining safety and efficiency. Through the implementation of a circuit protection system, many of the safety concerns surrounding Li-ion batteries can be mitigated. Additionally, Li-ion batteries require lower maintenance which further enhances their suitability, offering a reliable and durable solution. Despite their higher cost compared to other options, the long-term benefits of stability, safety, and longevity justify the investment, making Li-ion batteries the optimal choice for our project.

Sony VTC6

The Sony VTC6 battery stands out for its high capacity and excellent performance, making it a popular choice for applications requiring reliable power sources. With a nominal capacity of 3 Ah and a continuous discharge rating of 15 A, it delivers power output suitable for demanding tasks such as high-drain electronic devices and power tools. This high discharge capability ensures consistent performance under load, providing a dependable energy source for a wide range of applications.

However, the VTC6 battery is relatively more expensive compared to other batteries with lower specifications, which might be a consideration for budget-sensitive projects. Additionally, while it performs well at high discharge rates, its overall lifespan can be affected by frequent deep discharges or improper handling, potentially leading to diminished performance over time.

Overall, the Sony VTC6 battery provides impressive power output and safety features, making it an excellent choice for high-performance applications. Its advanced design and high capacity deliver substantial benefits, though cost and maintenance considerations should be taken into account when selecting it for specific uses.

Samsung INR18650-30Q

The Samsung INR18650-30Q battery is renowned for its impressive performance in various applications. With a capacity of 3000 mAh and a nominal voltage of 3.6 V, it provides a suitable energy source ideal for high-drain devices such as power tools and electric vehicles. This lithium-ion cell offers a high discharge rate, typically handling up to 15 A continuous current, which ensures reliable power delivery for demanding uses.

In terms of cost-effectiveness, the 30Q is competitively priced, making it a popular choice for both consumer and industrial applications. Its balance between capacity and discharge rate offers a good compromise for users who need both high performance and affordability.

However, while the 30Q excels in many areas, it does have some limitations. The battery's capacity, while substantial, may not be sufficient for applications requiring higher energy reserves. Additionally, like all lithium-ion cells, it requires careful handling and proper charging practices to ensure safety and longevity. Without adequate protection circuitry, there is a risk of thermal runaway, which underscores the importance of using quality battery management systems.

Overall, the Samsung INR18650-30Q battery stands out for its high discharge rate and reliable performance, making it a versatile and efficient choice for a wide range of applications. Its reasonable price and solid performance make it an attractive option for users seeking both value and power.

LG MJ1

The LG MJ1 battery stands out due to its impressive capacity and performance when compared to other lithium-ion batteries. With a nominal capacity of 3.5 Ah and a voltage of 3.7 V, it offers a substantial energy density, making it a reliable choice for high-capacity applications such as power tools, electric vehicles, and portable electronics. Its design enables extended operating times, which is particularly advantageous for devices requiring long-lasting power.

In terms of efficiency, the LG MJ1 battery demonstrates a notable discharge rate, providing a stable output even under high current loads. This characteristic is crucial for applications demanding consistent performance, such as electric bikes or other high-drain devices.

Additionally, its robust build contributes to enhanced durability and longevity, offering users a dependable power source.

However, while the LG MJ1 offers these benefits, there are some considerations to keep in mind. The battery's relatively high capacity can result in a larger physical size compared to smaller cells, potentially affecting the design and portability of devices. Additionally, as with many lithium-ion batteries, safety concerns related to thermal management and overcharging exist, necessitating proper battery management systems to mitigate risks.

Overall, the LG MJ1 battery provides a blend of high capacity, reliable discharge rates, and durability, making it a strong candidate for various high-power applications. Its design prioritizes performance and longevity, though users should be aware of the size and safety considerations associated with its use.

Samsung INR21700-40T

The Samsung INR21700-40T battery is a high-performance lithium-ion cell known for its impressive capacity and discharge capabilities. With a nominal capacity of 4 Ah, it supports high-current discharge up to 35 A, making it a solid choice for applications requiring substantial power output, such as in high-performance electric vehicles or power tools. Its energy density allows it to deliver significant power while maintaining a relatively compact form factor, which is beneficial for designs that need both space efficiency and high energy output.

One of the key advantages of the INR21700-40T is its robust performance at high discharge rates. This characteristic ensures reliable power delivery in demanding conditions, enhancing the performance of devices that rely on substantial and consistent energy flow. Additionally, its ability to handle high discharge currents without significant voltage drop contributes to its appeal in high-drain applications, ensuring stable operation even under heavy loads.

However, the INR21700-40T does come with some considerations. While it excels in high discharge applications, it may not be the most cost-effective option for lower power or less demanding uses due to its advanced performance specifications. Additionally, like all lithium-ion batteries, it requires proper handling and safety measures to avoid issues such as thermal runaway or short circuits. Proper battery management systems are necessary to maximize its lifespan and maintain safety.

Overall, the Samsung INR21700-40T battery stands out for its high capacity and strong discharge performance, making it a suitable choice for demanding applications where reliable and powerful energy delivery is critical. Its design offers substantial benefits for high-drain scenarios, although its higher specifications might not always align with more budget-conscious or lower-power needs.

LG INR21700-M50

The LG INR21700-M50 battery is designed to deliver high performance with its notable 5 Ah capacity, offering extended usage times for various devices. With a nominal voltage of

3.6 V and a maximum discharge rate of 5 A, it provides a reliable and stable power source suitable for demanding applications such as high-drain electronic devices, power tools, and electric vehicles. This battery's high energy density allows for longer operational periods between charges, enhancing overall convenience and efficiency.

Utilizing lithium-ion technology, the INR21700-M50 maintains a consistent output and has a relatively low self-discharge rate, ensuring that it retains its charge over extended periods of inactivity. This characteristic makes it ideal for use in devices that require long-term reliability and performance.

Overall, the LG INR21700-M50 battery offers impressive capacity and performance, making it a strong candidate for the controller. Its advanced features and high energy density contribute to its effectiveness in a broad spectrum of uses, although considerations around cost and size may influence its suitability for certain projects.

Table 3.17. *Comparison of Li-ion battery products by Authors*

Criteria	Sony VTC6	Samsung INR18650-30Q	LG MJ1	Samsung INR21700-40T	LG INR21700-M50
Nominal Cell Voltage (V)	3.6	3.6	3.6	3.6	3.6
Energy Density (Wh/kg)	270.4	262.5	300.0	251.5	303.2
Rating	4.2 V 3 Ah	4.2 V 3 Ah	4.2 V 3.5 Ah	4.2 V 4 Ah	4.2 V 5 Ah
Weight (g/per cell)	46.6	48	49	66.8	69.25

Dimensions (mm)	18.5 x 65.2	18.3 x 64.9	18.3 x 65.1	21.1 x 70.4	21.0 x 70.4
Cost (per cell)	$6.00	$5.99	$5.99	$5.99	$4.99

Battery Product Selection

Overall, the LG INR21700-M50 provides the most energy density at the lowest cost per cell, making it a strong candidate for applications that prioritize both performance and cost-efficiency. While it is the heaviest of the five batteries we evaluated, this trade-off is mitigated by its high capacity (5 Ah) and superior energy density of 303.2 Wh/kg, which offers longer runtime and higher power output compared to other options.

Given the demands of our project, the LG INR21700-M50's combination of high energy density, extended usage times, and competitive pricing makes it the best overall choice. Its larger size and weight may require adjustments in design, but the benefits of increased power capacity and energy efficiency outweigh these considerations. Furthermore, the battery's low self-discharge rate and reliable performance under heavy loads make it particularly suitable for high-drain applications, ensuring a consistent energy supply for prolonged periods.

While other batteries, such as the Sony VTC6 or Samsung INR18650-30Q, offer competitive discharge rates and are slightly lighter, they fall short in capacity and energy density when compared to the LG INR21700-M50. For applications requiring more compact or lighter battery options, these alternatives may be worth considering. However, for this project's focus on high energy capacity and efficiency, the LG INR21700-M50 stands out as the optimal selection, offering the best balance between cost, performance, and long-term reliability.

3.10 Wireless Communication Method

Wireless communication methods are crucial to enable real-time data exchange in our system. Without reliable communication techniques, SPARROW would fail to transmit or receive any data that is essential for effective operation, such as GPS locations or video feeds. This data is critical to successfully identify any power line or transformer faults and for proper navigation of the drone. Furthermore, the ability to issue commands to adjust drone flight paths is essential to maintain operational integrity. Utilizing the proper communication techniques would ensure the safe, reliable, and efficient operation of the drone, especially in environments with unknown obstacles and conditions.

Wi-Fi

Wi-Fi is a family of wireless network protocols based on the IEEE 802.11 standard designed to provide wireless access to the internet using radio waves. Typically, it utilizes either the 2.4 GHz or 5 GHz frequency bands, but modern advancements in technology allow access to the 6 GHz frequency band as well. Wi-Fi enables the creation of a local area network, or LAN, which allows devices connected to the same network to communicate wirelessly. One of the main advantages of Wi-Fi is the high-speed data transfer. The current Wi-Fi standard, IEEE 802.11be, or Wi-Fi 7, can achieve a potential maximum data rate of 5.8 Gbps when utilizing 4096 QAM modulation on a 320 MHz channel with 2 spatial streams.

For tasks such as receiving video footage from a drone, where quick responses are crucial, Wi-Fi's high speed is advantageous for real-time communication and streaming. However, Wi-Fi has limitations that must be considered. Its coverage is typically limited to a few hundred feet, which can be problematic when drones move farther away from the base station.

Additionally, Wi-Fi signals are highly vulnerable to interference from other devices and nearby Wi-Fi networks, potentially affecting their reliability. Despite the limitations, solutions such as implementing a mesh network can extend Wi-Fi's utility in drone operations. A mesh network would allow drones to communicate with each other, extending coverage beyond Wi-Fi's typical limits, however the communication range between devices is limited to around 70 meters, meaning this approach may not be ideal for drone applications, where the drones will maintain a much greater distance than 70 meters for the majority of the operation.

Bluetooth

Bluetooth is a wireless technology standard for exchanging data over short distances using radio waves. It operates in the 2.4 GHz frequency band and is widely used for connecting devices such as smartphones, tablets, headphones, and IoT devices. The latest Bluetooth standard, Bluetooth 5.2 boasts data transfer speeds up to 2 Mbps and improved efficiency compared to its predecessors.

One of the main advantages of Bluetooth is its versatility in connecting various devices seamlessly without the need for cables. For a base station designed to manage tasks in real-time, Bluetooth's capability for low-latency communication can be advantageous. However, Bluetooth's range is typically limited to about 10 meters (33 feet) which may pose challenges as the drones move farther away from SPARROW. Additionally, Bluetooth signals can be affected by interference from other wireless devices operating in the same frequency band.

While Bluetooth may not suffice for applications requiring drones to operate over longer distances from the base station and in environments with heavy interference, it remains a viable option for many other applications due to its low power consumption, ease of use, and cost-effectiveness. For applications requiring drones to operate over longer distances or in challenging environments, other technologies may be more suitable due to their extended range capabilities and better resistance to interference.

Radio

Radio is a form of wireless communication that utilizes electromagnetic waves to transmit data across various frequency bands. It operates in a wide range of frequencies, including the MF, HF, VHF, and UHF bands. Unlike Wi-Fi, which has a limited range, radio enables the creation of communication links across much greater distances. This capability makes radio communication particularly beneficial for drone applications since these great distances allow for consistent communication even in remote locations.

However, for a base station controller tasked with receiving video footage from a drone and requiring rapid responses, radio presents some challenges. The data transfer rates are significantly lower than those of Wi-Fi, which can significantly hinder real-time communication. Additionally, radio signals are susceptible to interference from other devices using the same frequency, potentially affecting their reliability. Although this issue is less of an issue than it is with Wi-Fi due to the diversity of available frequencies, it remains a consideration.

To address these problems, implementing other protocols such as APRS or LoRaWAN can enhance the functionality of our communication system. These protocols optimize the use of radio by extending coverage and minimizing the constraints of signal range, ensuring that SPARROW can effectively receive data from drones, even when they are distant from the base station.

While radio alone may not suffice for applications that require drones to operate at further distances from their base station, radio may still be a viable choice in scenarios where maintaining consistent communication links between SOAR and SPARROW is essential.

Table 3.18. *Comparison of communication methods by Authors*

Criteria	Wi-Fi	Bluetooth	Radio
Range	Low	Low	High
Data Rate	Fast	Slow	Slow
Power	High	Medium	Low

Communication Method Selection

Given the need to prioritize both rapid video transmission and extensive range, radio communication is the most suitable option. While radio typically offers slower data transfer rates compared to Wi-Fi, Wi-Fi's range is insufficient for practical use in this context. One effective strategy we could use is to use high frequencies to transmit data. Higher frequencies support much faster data rates, which is crucial for transmitting video feeds efficiently. However, it's important to consider that higher frequencies also demand more power. To address this, we could use different frequencies for different types of data. For the video feed, which requires higher data rates, we could use higher frequencies, accepting the increased power consumption to ensure minimal data loss. For less bandwidth-intensive data, we can transmit at lower frequencies to save power.

Antennas

To achieve optimal communication with the SOAR drones, several antenna factors must be carefully considered, including directivity, gain, beamwidth, and polarization.

The antenna's directivity is crucial. Some antennas have high directivity, which means that the signal is focused in a specific direction which isn't ideal for a drone that moves freely in all directions. Instead, an omnidirectional antenna radiates signals in all directions, providing continuous connectivity as the drone maneuvers around SPARROW.

Antenna gain also plays a pivotal role. Higher gain antennas concentrate their signal over a narrower area, almost like zooming in on a camera. This narrow area may not pair well with a drone's dynamic movements. Alternatively, antennas with lower gain offer a wider coverage area ensuring stable communication despite the drone's varying positions.

Beamwidth, the angular spread of the antenna's radiation pattern, is also critical. The beamwidth of the antenna determines the width of its signal coverage. A wider beamwidth ensures the antenna maintains a connection across a broader area. This feature is critical for accommodating the drone's movement and ensuring consistent signal strength throughout its operation.

Lastly, polarization impacts how well the antenna can receive signals based on their orientation. If an antenna is linearly polarized, the antenna's electrical field oscillates vertically or horizontally from the transmitter. Linearly polarized antennas could face alignment issues as the drone changes orientation since a vertically polarized antenna cannot receive an electromagnetic signal with horizontal polarization. To combat this, an antenna with circular polarization would be necessary. Circular polarization allows the antenna to receive signals regardless of its orientation relative to the receiving drone, ensuring consistent reception throughout the operation.

In summary, for effective communication with the drone, SPARROW should ideally employ an omnidirectional antenna with low gain, wide beamwidth, and circular polarization to accommodate the dynamic movement and orientation changes of the drone, optimizing connectivity and reliability.

Dipole

Dipole antennas are characterized by their straightforward design of two identical conductive elements connected to a central feed line. These antennas are versatile, coming in various configurations tailored for specific applications, with the half-wave dipole being the most common due to its high efficiency and its operability across a wide range of frequencies.

The half-wave dipole antenna has an omnidirectional radiation pattern, making it suitable for scenarios requiring coverage in multiple directions without the need for constant antenna adjustment. It typically achieves a maximum gain of around 2.15 dBi and offers a relatively wide beamwidth of 78°, providing effective coverage for a variety of communication scenarios, making the half-wave dipole antenna suitable for radio broadcasting and communication systems.

However, a limitation of the half-wave dipole antenna lies in its linear polarization. Linearly polarized antennas emit and receive electromagnetic waves oscillating in a single plane, either vertically or horizontally. This polarization characteristic requires precise alignment between the antenna and the transmitted signal for optimal reception. Variations in antenna orientation or signal polarization can lead to mismatch, potentially resulting in reduced signal strength and reliability, especially in dynamic environments like drone operations.

Additionally, the performance of dipole antennas varies with their length relative to the wavelength of the operating frequency. Generally, directivity increases as the antenna length approaches approximately 125% of the wavelength. At that point, there’s a sharp drop in directivity, but beyond that point, while there’s still an upward trend in directivity as the length increases, it does so in a non-monotonic manner.

Due to their versatility, dipole antennas are highly effective across a wide range of frequencies. While not widely used in every band, dipole antennas are theoretically capable of operating as low as the very low frequency (VLF) band and as high as the extremely high frequency (EHF) band, which is why they’re so commonly used in radio and television broadcasting and other wireless communication systems.

Given these considerations, while dipole antennas offer advantages such as simplicity, low gain, and omnidirectional coverage, their linear polarization may make them less suitable for drone operations. In scenarios where maintaining consistent and reliable communication with a moving drone is essential, an antenna with circular polarization is typically preferred. Circular polarization allows the antenna to receive signals effectively regardless of the drone's orientation, ensuring stable connection in dynamic environments. Therefore, for drone applications requiring stable communication, antennas with circular polarization remain the optimal choice despite the advantages of dipole antennas.

Patch

Patch antennas are known for their compact design, typically consisting of a flat conductive patch mounted over a ground plane, often integrated directly onto a printed circuit board

(PCB). This integration makes them compact, lightweight, cost-effective, and suitable for applications where space and weight are critical factors to consider.

In terms of performance, patch antennas achieve higher gains compared to dipoles, typically around 8 - 9 dBi for a simple patch design. This higher gain is advantageous for applications requiring focused coverage in a specific direction. However, this higher gain also results in a narrower beamwidth, with the typical patch having a beamwidth around 65°, which could pose a challenge in any scenario that may require broader coverage.

Additionally, unlike dipole antennas, patch antennas offer flexibility in polarization, supporting both linear and circular configurations to meet diverse communication needs while ensuring high efficiency and directional accuracy. This versatility provides a significant advantage over dipole antennas,

However, patch antennas are primarily suitable only for microwave frequencies due to their compact size, which limits their use in lower-frequency bands. For this reason, these types of antennas are widely used in applications such as WiFi, cellular networks, and satellite communications.

Overall, patch antennas offer advantages such as compactness and the ability to choose between linear and circular polarization. For drone applications where stable and uninterrupted communication is crucial, having an antenna with circular polarization is preferred due to its ability to maintain reliable signal reception regardless of the drone's orientation. Despite these advantages, the directional gain and the narrower beamwidth of a patch antenna may present challenges in achieving broader coverage in dynamic environments.

Yagi-Uda

Yagi-Uda antennas offer directional radiation patterns with higher gains and narrower beamwidths, compared to dipole antennas. They are characterized by their design consisting of multiple elements: a driven element (which is connected to the feed line), a reflector element placed behind it, and one or more director elements positioned in front. This allows Yagi-Uda antennas to achieve greater directivity compared to omnidirectional antennas like dipoles, making them ideal for applications requiring concentrated communication in specific directions, such as point-to-point communication.

The gain of a Yagi-Uda antenna typically ranges from a few decibels (dBi) to over 20 dBi, depending on the number and lengths of its elements. Additional elements generally result in higher gains, but narrower beamwidths. For example, a three-element Yagi-Uda antenna has a HPBW of around 50°, while a six-element antenna has a HPBW of around 30°. These narrower beamwidths and high gains make Yagi-Uda antennas more suitable for applications requiring long-distance communication and improved signal strength.

However, Yagi-Uda antennas are versatile and can be designed to be operated across a wide range of frequencies, typically between 3 MHz and 3 GHz, but their bandwidths are relatively narrow, usually around only 10% of their operating frequency. This characteristic of the Yagi-Uda antenna requires careful design and tuning to achieve optimal performance for specific frequencies.

Similar to dipole antennas, Yagi-Uda antennas typically operate with linear polarization. In dynamic environments like drone operations, where the orientation of the drone and its antenna can change rapidly, maintaining this alignment can prove to be challenging and may lead to reduced signal strength or reliability.

In summary, while Yagi-Uda antennas are versatile across many frequencies; their high gain and narrow beamwidths, as well as their linear polarization can limit their effectiveness in dynamic environments such as drone operations.

Parabolic

Parabolic antennas, also known as dish antennas, are highly valued for their highly directional radiation patterns and high gains, which makes this antenna ideal for applications requiring long-distance communication in very precise directions. The main components of a parabolic antenna include the reflector (often made of metal or mesh), a feed antenna (such as a dipole or a horn antenna) located at the focal point, and supporting structures like a mount and a feed mechanism. The curved shape of the antenna's reflector is crucial as it allows incoming radio waves to be reflected and concentrated onto the feed antenna.

The gain of a parabolic antenna is determined by its size. Larger diameter dishes result in higher gains, but the gain of most parabolic antennas falls between 30 and 40 dBi. These very high gains also supply very narrow beamwidths, often only a few degrees wide, which enhances the antenna's ability to transmit or receive signals over long distances with minimal interference.

Parabolic antennas also operate within specific frequency ranges depending on their size. Smaller dishes generally operate at higher microwave frequencies, between 2 and 28 GHz, while larger dishes can operate at lower frequencies in the VHF band (30 MHz - 300 MHz). Regardless of size, however, parabolic antennas typically have very narrow bandwidths, requiring precise tuning to achieve optimal performance within their operating frequency range.

Similar to patch antennas, parabolic antennas can operate with both linear and circular polarization. While the antenna itself isn't necessarily polarized, the feed antenna located at the focal point of the reflector determines the polarity of the antenna. While capable of both types of polarity, since these antennas are mainly used to communicate with stationary targets, these antennas tend to be linearly polarized since the orientation of either antenna will not change throughout the operation.

While parabolic antennas are highly effective for specific applications requiring strong directionality and high gain, parabolic antennas may be less suitable for mobile or dynamic environments like drone communication due to their fixed orientation and the need for precise alignment with the target.

Helical

Helical antennas are generally valued for their directional radiation patterns and gains, making them suitable for many applications requiring long-distance communication. These antennas consist of a wire wound in a spiral shape around a central axis. The helical shape of the antenna is critical as it allows radio waves to be efficiently radiated and focused in a specific direction.

The gain of helical antennas is determined by their physical dimensions and the number of turns. Antennas with larger circumferences or more turns generally exhibit lower gains. Typically, helical antennas have gains ranging from 5 dBi to 12 dBi. These moderate gains provide decent coverage and wider beamwidths compared to parabolic or Yagi-Uda antennas. Depending on the design of the antenna, the beamwidth can vary, but it typically ranges between 40° and 95°.

Helical antennas can operate across a wide range of frequencies, spanning from the VHF band (30 MHz - 300 MHz) to the UHF band (300 MHz - 3 GHz). Larger antennas are capable of operating at lower frequencies and smaller antennas at higher frequencies. Helical antennas also operate at wider bandwidths compared to other antennas, reducing the need for very precise tuning.

One major advantage of helical antennas is their ability to operate with circular polarization. Unlike linearly polarized antennas that are sensitive to alignment issues, circular polarization allows helical antennas to receive signals regardless of their orientation relative to the transmitter. This characteristic of helical antennas enhances the reliability of communication systems, especially in dynamic drone operations.

Overall, helical antennas are versatile and efficient solutions for various communication needs, offering moderate gains and beamwidths, a wide frequency selection and bandwidth, and the advantage of having circular polarization.

Table 3.19. *Comparison of antenna types*
By Authors

Criteria	Dipole	Patch	Yagi	Parabolic	Helical
Frequency Range	VLF - EHF	UHF - SHF	HF - UHF	UHF - EHF	VHF - UHF
Gain (dBi)	2.15	8 - 9	5 - 20	30 - 40	5 - 12
Directivity	Omni-directional	Directional or Omni-directional	Directional	Highly directional	Directional or Omni-directional
Polarization	Linear	Circular or Linear	Linear	Circular or Linear	Circular

Beamwidth	78°	40° - 65°	30° - 50°	1° - 5°	40° - 95°
Efficiency	High	High	High	High	High

Antenna Technology Selection

After researching some of the most common antenna types, we initially identified patch and helical antennas as potentially suitable for our project's requirements, due to their circular polarization. These antennas offer moderate gain, directional capabilities, and they can also be configured to achieve omnidirectional radiation patterns. However, we ultimately decided against using circularly polarized antennas due to their larger physical size, which is a critical component for our design, since the drones will have very limited space.

While circular polarization naturally minimizes signal loss by maintaining consistent alignment with the target antenna, we opted for a practical alternative to achieve similar benefits. By using two linearly polarized antennas positioned 90 degrees apart, we can reduce signal loss and ensure consistent alignment with the target antenna, without severely compromising on space. The best choice for our purposes would be to use dipole antennas since they offer low gains, wide beamwidths, and omni-directionality.

Radio Communication Protocol

In addition to antenna selection, choosing the right radio communication protocol is essential for ensuring reliable, efficient wireless communication between the base station and the drones. Each protocol is optimized for specific needs, such as range, power consumption, and data rate. However, some protocols may be more susceptible to interference, especially in crowded frequency bands. Given these factors, it's important to compare different protocols to determine which best aligns with the needs of our project.

LoRaWAN

LoRaWAN is a wireless communication protocol ideal for applications requiring long-range connectivity with minimal power consumption. LoRaWAN uses unlicensed sub-gigahertz radio frequencies like the 915 MHz band in North America. This lower frequency allows for a much greater range, typically covering up to five kilometers in urban areas and up to 15 kilometers in rural areas.

One of LoRaWAN's key advantages is its ability to support long-range communication with minimal power usage, prolonging the battery life significantly when compared to Wi-Fi. Moreover, LoRaWAN supports bi-directional communication, enabling SPARROW to both receive video footage and transmit commands or data to the drones seamlessly.

While Wi-Fi excels in high-speed data transfer, LoRaWAN is designed for applications that don't require real-time data transmission. It operates at lower data rates, typically from a few hundred bits per second to a few kilobits per second. This makes it ideal for applications that prioritize extended range and power efficiency over data speed.

Additionally, while LoRaWAN excels in providing long-range connectivity, its performance can be impacted by environmental factors such as terrain and interference from other devices, potentially impacting its reliability.

For applications requiring long-range connectivity with minimal power consumption, LoRaWAN presents itself as a viable option. However, for scenarios demanding higher data rates or real-time communication, such as SPARROW, alternative technologies may be more appropriate, despite their higher power demands.

Zigbee

Zigbee is a wireless communication protocol designed for applications requiring low-power, short-range connectivity. It primarily operates on the 2.4 GHz frequency band, although some devices in North America can use the 915 MHz band. This frequency band allows Zigbee signals to penetrate obstacles effectively, making them less susceptible to attenuation.

One of Zigbee's key advantages is low power consumption compared to Wi-Fi, making it suitable for battery-powered devices that need to operate for extended periods without frequent battery changes. This becomes very helpful for us because the drone will be in locations where providing a continuous supply of power isn't possible.

However, while Zigbee excels in low-power, short-range communication, its effectiveness can be influenced by the physical environment. To extend coverage beyond typical limits, Zigbee can be deployed in a mesh network configuration. This setup would enable the drones to relay data among themselves, effectively expanding coverage without requiring constant communication with SPARROW. This capability enhances the reliability of our system and extends the effective range of our network by allowing data to hop between connected devices. Additionally, Zigbee supports bi-directional communication, which would allow the drones to both transmit video footage and receive commands or data from SPARROW.

In terms of data transfer rates though, Zigbee typically operates at lower speeds compared to Wi-Fi or Bluetooth with data rates ranging from 20 kbps to 250 kbps. This factor makes Zigbee more suitable for applications that prioritize low power consumption and reliability over high-speed data transmission.

Additionally, despite the benefits of mesh networking, Zigbee's transmission range remains very small. The transmission range of Zigbee only ranges from 10 to 100 meters, which means that achieving a range of 1 mile, would require us to deploy more than 16 drones, which is impractical given project constraints such as time and budget.

Given our project's requirements for higher data rates and longer-range communication, Zigbee may not be the most practical choice. Exploring alternative technologies could better suit our needs, balancing data speed, range, and power efficiency.

APRS

APRS, or Automatic Packet Reporting System, is a digital communication protocol used primarily by amateur radio operators to transmit real-time data over radio frequencies. It allows for the transmission of various types of information, including GPS location data, weather reports, and messages. APRS operates on designated frequencies within the amateur radio spectrum and is widely utilized for tracking vehicles as well as for providing situational awareness during emergencies and events.

APRS utilizes packet radio technology within the amateur radio bands, with most APRS activity on the 144.29 MHz frequency. Users equip their stations with APRS-capable radios, GPS receivers, and sometimes weather sensors. Data is transmitted in short bursts or packets, containing information such as callsigns, GPS coordinates, and timestamps. APRS packets can be received by other stations or digipeaters, which retransmit the packets to extend the network's coverage.

Unlike Wi-Fi, which relies on traditional internet infrastructure and is limited by its range and susceptibility to interference, APRS operates independently over radio waves. This autonomy makes APRS particularly valuable in situations where internet access is unavailable or unreliable, such as in remote areas or during emergencies.

APRS facilitates the exchange of data packets between stations, utilizing a decentralized network of amateur radio operators to relay information globally. Its integration with GPS technology enables precise location reporting, making it ideal for tracking moving assets like vehicles or drones. This capability ensures that controllers can receive crucial data in real-time, regardless of the location of the transmitting station.

Due to the high support for APRS, the range can be considered almost unlimited as long as a repeater is in range. In contrast to Wi-Fi's high-speed data transfer within limited ranges, APRS excels in extending coverage over vast distances using existing amateur radio infrastructure. Its robustness in adverse conditions and ability to operate independently from internet-based networks make APRS a preferred choice for applications requiring reliable, long-distance communication and data transmission.

For scenarios involving drones where quick responses and reliable data transmission are critical, APRS offers distinct advantages over Wi-Fi, particularly in remote or challenging environments where maintaining connectivity is essential for operational success.

MAVLink

MavLink is a messaging protocol used to facilitate data exchange between drones and ground control stations. MAVLink supports a variety of tasks necessary for the successful operation of the drone, including the transmission of GPS coordinates, flight status, sensor readings, and commands.

A notable advantage of MAVLink is its compatibility with Ardupilot, the autopilot system SOAR will operate on. Ardupilot utilizes MAVLink to manage communication between the ground station and the drones’ on-board computers. These messages are sent in a way that helps us differentiate between the drones and the different sensors. Additionally, the drones' computers receive all the MAVLink data produced by the autopilot and can use it to make decisions during operation.

Additionally, these messages can also be sent over almost any serial connection, making the protocol highly adaptable and independent of specific technologies. This flexibility is particularly advantageous in scenarios where reliable data transmission is critical, such as in remote or challenging environments where maintaining connectivity is essential for successful operation.

Table 3.20. *Comparison of communication protocols*
by Authors

Criteria	LoRaWAN	Zigbee	APRS	MavLink
Range	15km	100m	10km - 30km	<10km
Data Rate	22 kbps	250 kbps	1.2 kbps	9.6 kbps - 57.6 kbps
Power	Low	Low	Low	Low
Operating Frequency	902.3 – 914.9 MHz	915 MHz/2.4 GHz	144.39 MHz	915 MHz

Radio Communication Protocol Selection

Given our project's goals and responsibilities, particularly the need for reliable communication between SOAR and SPARROW, MAVLink is the most suitable choice. Its compatibility with Ardupilot ensures seamless integration and its open-source nature offers significant flexibility, allowing us to adapt the protocol to fit our specific needs. Additionally, the extensive community support available for MAVLink will be invaluable in ensuring a smoother implementation process and resolving any issues that may arise.

Radio Modem Selection

A radio modem is essential on the base station to ensure reliable, bidirectional communication between SPARROW and SOAR. This communication link allows SPARROW to transmit commands to SOAR while also receiving data from the SOAR drones. Without a radio modem, our system would lack the capability to send commands remotely or receive any data, severely limiting the effectiveness of our search and rescue operations. A properly selected radio modem should ensure stable, long-range communication and supports the required frequencies and data rates necessary for mission success.

RFD900x-US Modem Bundle

The RFD 900x-US Modem is a powerful, long range wireless communication module designed specifically for remote control and telemetry applications. This modem boasts a range of up to 40 km and a high data transfer rate of 250 kbps, making it well-suited for projects requiring reliable long-distance communication.

A key feature of the RFD900x is its adjustable transmission power, which can reach up to 1 watt, providing flexibility for both short and long-range communication. Additionally, the modem also offers superior sensitivity, allowing it to maintain a strong link even at lower signal strengths, which is crucial for maintaining communication over long distances. In terms of integration, the RFD900x is compatible with the MAVLink protocol and Ardupilot, much like the 3DR SiK radios, making the setup process straightforward.

Another key advantage is the modem's relatively low power consumption with a nominal supply of 5 volts and a peak current around 800 mA, when at maximum power. While the modem itself is quite expensive, the RFD900x-US Modem Bundle includes two of these modems with 900MHz antennas for all antenna ports, making it a cost-effective solution for long-range, reliable communications.

Microhard P900

The Microhard P900 is a communication solution designed specifically for telemetry for remote control applications. Operating in the 900 MHZ band, it provides reliable data transmission over great distances, making it an excellent choice for SPARROW's needs since both range and maintaining data integrity are essential.

One of the standout features of the P900 is its adjustable transmit power, which can be adjusted up to 1 W. It also supports data rates up to 276 kbps, making it well-suited for SPARROW since we require real-time feedback and reliable connection over long distances.

However, the integration process for the P900 is more complex than some alternatives. Unlike a plug-and-play module, it is offered as just a chip, which requires more configuration. Despite this, the P900 does offer both serial and Ethernet interfaces, allowing it to be easily adapted to different communication needs. Like the RFD900x, it supports MAVLink, making it compatible with SPARROW and other drone applications.

While the P900 is a low-cost option with efficient power consumption on top of great reliability and range, its implementation process may be too complicated for SPARROW's immediate needs, making it a less practical option despite its impressive capabilities.

Microhard P900-ENC

The Microhard P900-ENC is an advanced version of the P900 modem, designed to simplify integration by providing an enclosed, ready-to-use solution for telemetry. Unlike the P900 chip, which requires a more complex setup, the P900-ENC comes with all the necessary components in a durable, compact enclosure, making it much easier to implement for projects like SPARROW.

Operating in the 900 MHz band, the P900-ENC offers reliable communication with adjustable transmit power up to 1 watt, providing excellent range and flexibility depending on the environment. It maintains the same data rate as the P900, ensuring it is still well-suited for applications that require real-time data transmission.

A major advantage of the P900-ENC is its plug-and-play design, which significantly reduces the complexity of integration into a system. It supports both serial and Ethernet interfaces, providing multiple options for connectivity to fit various needs.

Like the P900, the P900-ENC supports the MAVLink protocol and is compatible with Ardupilot, making it a strong candidate for SPARROW. Its low power consumption combined with the convenience of a pre-enclosed unit makes the P900-ENC a practical choice for SPARROW.

Overall, the Microhard P900-ENC offers the same strong performance as the P900 but in a more accessible form. This makes it an excellent alternative for SPARROW where simplicity and reliability are important factors to consider.

Table 3.22. *Comparison of radio modem products by Authors*

	RFD900X-US	**P900**	**P900-ENC**
Frequency Band	900 MHz	900 MHz	900 MHz
Range	<40 km	<65 km	<65 km
Data Rate	<250 kbps	<276 kbps	<276 kbps
Transmit Power	1 W	100 mW - 1 W	100 mW - 1 W
Sensitivity	-121 dBm	-115 dBm	-115 dBm
Power Consumption	<4.4 W	9.8 W - 49 W	9.8 W - 49 W
Interface Options	Serial, USB	Serial, Ethernet	Serial, Ethernet
Cost	$226	$199	$215

Radio Modem Selection

The RFD900x-US Modem Bundle is the best option for SPARROW's needs due to its superior range, flexibility, and ease of use. With an impressive range up to 40 km, it ensures reliable communication over long distances, a key requirement for SPARROW's search and rescue operations.

The RFD900x's adjustable transmit power, which can be set up to 1 watt, provides flexibility to conserve power during shorter operations while maintaining strong signal integrity for longer distances. While the Microhard P900 and P900-ENC also offer adjustable power, the RFD300x has superior sensitivity for maintaining signal strength in challenging environments, which gives it an edge in maintaining reliable communication links.

Much like the Microhard alternatives, the RFD900x supports MAVLink and is compatible with Ardupilot, which simplifies the setup process for SPARROW. Another benefit is the much lower power consumption of the RFD900x compared to the Microhard options. Its ability to operate efficiently with 5 volts and draws no more than 800 mA ensures that it won't overburden SPARROW's power systems. This is particularly beneficial when compared to the Microhard P900, which not only uses more power, but requires additional components for integration.

Although the RFD900x-US Modem Bundle is more expensive than the Microhard P900 and P900-ENC, the value it offers in range, reliability, and ease of integration justifies the investment. The bundle includes all necessary components, including the 900 MHz antennas, eliminating the need for any additional purchases. This cost-effective solution combined with its high performance makes the RFD900x the best option for SPARROW.

3.11 Drone Automation Software

A crucial role in the autonomous operation of drones is what drone automation software to use to perform complex tasks with minimal human intervention. These software systems, such as ArduPilot or PX4, provide the framework for drones to navigate, manage sensors, and communicate with other drones or a base station controller. By automating tasks like flight path planning, obstacle avoidance and data collection, these platforms empower drones to efficiently execute missions like search and rescue, environmental monitoring, and ensuring reliability in various applications. While our project does not involve a GPS for letting the be set out, our package of sensors is included for this software as it interacts with the various sensors for setting up the connection and autonomous flight. While SPARROW is not in control for the autonomous flight of the drones, our sensor package does have to integrate with the ground base station, hence we still require the software to connect the ground station to the sensor package in order to execute the task of detecting humans throughout the expedition.

ArduPilot

ArduPilot is an option for the drone automation software implementation of the SPARROW as it provides powerful capabilities for controlling and navigating the drone autonomously. On top of the ability to provide autonomous navigation to our drone, ArduPilot includes the ability to automate takeoff and landings, mission planning, and real-time telemetry. ArduPilot supports a wide range of hardware platforms and sensors, making it versatile for our project as depending on our choice of sensors and hardware selections, ArduPilot's wide support allows us to test various hardware technologies to ensure that the drone will be able to achieve the autonomous flight goal. ArduPilot also provides integration ability with ground control stations such as Mission Planner and QGroundControl which makes it easier for our project's integration as with such ability, ArduPilot allows the scripting of missions and simulations of the missions. The ability to live-stream telemetry data and video feeds from the drone to the ground control station enhances situational awareness and operational effectiveness. Additionally, these ground control tools offer advanced diagnostics, calibration utilities, and user-friendly interfaces that simplify the setup and maintenance of the SPARROW system.

Another benefit of ArduPilot comes with the development of MAVProxy which is a ground control station protocol that runs on the command line and has the ability to forward MAVLink data between endpoints of the system, for instance, forwarding data packets from a radio modem serial port over to a host listening, such as Mission Planner. MAVProxy simplifies data transmission within the device through the use of entering and running a single command line to ensure the data are being sent through correctly.

ArduPilot also provides an open-source framework, which grants SPARROW the ability to customize and extend functionalities to meet specific project requirements. For instance, it allows the development of unique scripts and plugins to tailor mission execution, sensor data processing, and communication protocols. This adaptability aligns perfectly with SPARROW's mission to serve as a versatile and efficient drone-based sensor platform for diverse use cases. Overall, ArduPilot's comprehensive feature set, wide hardware compatibility, and integration capabilities make it a cornerstone of the SPARROW project, ensuring robust communication and operational synergy between the drone and its ground base station.

PX4

Moving onto the next option of autonomous software for our drone, the PX4 offers another wide variety of traits that can be implemented to help our drone achieve the goal of autonomous flight. PX4 is a sophisticated open-source autopilot software designed for a wide range of unmanned vehicles, specializing in drones and aerial systems. Developed under the Dronecode Project, PX4 offers advanced capabilities in autonomous navigation, obstacle avoidance, and sensor integration. The PX4 supports various flight modes and configurations, thus allowing it to make our drone adaptable to various requirements. On top of all of this, the PX4 integrates with ground control stations like QGroundControl, offering intuitive tools for mission planning, real-time monitoring, and system customization.

In addition to its core features, PX4 stands out for its scalability and modularity, which allow it to accommodate a wide range of hardware components and sensors. This adaptability is particularly beneficial for SPARROW, as it enables integration with thermal imaging cameras, high-resolution video systems, or other payloads necessary for detecting humans in search and rescue operations. PX4’s advanced support for obstacle avoidance algorithms and precision landing capabilities ensures safe and reliable operation in challenging environments, which is critical for locating and assisting individuals in need during rescue missions. Furthermore, PX4’s compatibility with MAVLink communication protocols enhances its ability to transmit telemetry and video data efficiently to the ground base station. The platform's extensive documentation and active developer community make it easier for the SPARROW team to customize the software for specific project needs while ensuring reliable performance. Additionally, PX4 includes a Hardware-in-the-Loop (HIL) simulation feature, enabling comprehensive pre-flight testing and mission validation. This allows the team to optimize mission parameters and troubleshoot potential issues in a controlled environment, ultimately enhancing the reliability and effectiveness of the SPARROW drone system. Overall, similar to ArduPilot, the PX4 offers a wide variety of features such as autonomous navigation and sensor integration while also being able to connect with ground stations and mission planners to allow simulations of the mission and thus, allow us to integrate it easily into our project to go alongside the ground base station and transmitting video data over.

DroneKit

Another solid option for autonomous drone software implementation for our project is DroneKit. DroneKit is a powerful open-source software development kit designed to facilitate the creation of custom applications for drones. Developed by 3DR, DroneKit simplifies drone programming by providing APIs for Python and Android, enabling developers to interact with drones, plan missions, and process real-time data. Alongside such aspects, DroneKit supports integration with some popular autopilot systems such as ArduPilot, to enable better communication between the application and drone flight controller. Through these features, DroneKit provides a versatile software for a vast range of applications where precision and automation are essential for the application. Through the use of Python or Android languages, DroneKit is able to provide APIs to allow users to write complex behaviors and missions for the drones.

Additionally, DroneKit’s ability to process real-time telemetry and sensor data enables the development of intelligent drone applications that can adapt dynamically to changing conditions or mission requirements. For example, developers can program the drone to make in-flight decisions, such as rerouting based on obstacle detection or adjusting sensor parameters for optimal data capture. DroneKit also supports functionality for geofencing, payload management, and custom event handling, making it highly suitable for applications requiring precision and automation, such as SPARROW's sensor-based data collection missions. DroneKit allows for remote monitoring and control, data storage, and analysis, which aligns with SPARROW’s goal of creating a solid and efficient sensor platform. With its open-source nature, DroneKit also provides opportunities for extensive customization, enabling the team to tailor the software to the unique requirements of SPARROW while ensuring scalability for future enhancements.

Paparazzi UAV

Jumping into another option for autonomous software technologies for our drone, Paparazzi UAV is an open-source autopilot system tailored for drone projects, supporting both fixed-wing and multirotor aircraft. Its modular design allows for versatile customization to meet specific drone mission requirements. The platform excels in autonomous flight control, precise mission planning, and real-time telemetry, making it ideal for a variety of drone applications. Through its strong emphasis on user-friendly operations and comprehensive documentation, Paparazzi UAV supports drones in developing and deploying reliable autonomous drone systems for tasks such as aerial mapping, surveillance, and scientific research. In our case, the desirable aspect of Paparazzi UAV would be the surveillance as we are aiming to have to drone take the video feedback of the surrounding and sending the video feed back to a controller station so that the imaging can be used to detect if there are any power line faults or transformer heating in the scanned area. Through all of these properties of Paparazzi UAV, it enables the ease to create very complex fully automated missions without the operator's intervention.

Paparazzi UAV's solid architecture also supports integration with various sensors and payloads, allowing SPARROW to leverage thermal cameras, LiDAR, or other specialized imaging systems for detecting power line faults or transformer heating. Its real-time telemetry capabilities ensure that critical data is transmitted reliably to the ground base station, providing operators with actionable insights during flight. Additionally, Paparazzi UAV includes advanced features such as geofencing, fail-safe protocols, and multi-aircraft coordination, which enhance the safety, scalability, and versatility of drone operations. Similar to DroneKit and ArduPilot, Paparazzi UAV is also open source, giving SPARROW the flexibility to adapt and extend the software to meet certain project requirements.

Cleanflight

One of the many other options for autonomous drone software technologies is Cleanflight. Cleanflight is a specialized open-source flight control firmware tailored for racing drones and high-performance aerial applications. Derived from the Baseflight project, Cleanflight emphasizes agility, responsiveness, and low-latency control to meet the rigorous demands of competitive drone racing. It boasts compatibility with a wide array of flight controllers and sensors, offering extensive customization options for fine-tuning flight modes and PID settings. Cleanflight's intuitive interface and active community support empower pilots to optimize flight characteristics such as speed, maneuverability, and stability, crucial for success in FPV racing environments. While our drone project is not meant to be for drone racing, Cleanflight still has properties that make up for being an option for our autonomous software as its intuitive interface and extensive community support simplify the process of configuring and fine-tuning flight parameters, crucial for autonomous operations. Overall, with all of these traits in mind, Cleanflight is a solid choice for developers seeking reliable and adaptable software for autonomous drone applications.

Although Cleanflight is primarily designed for racing drones, its emphasis on agility and responsiveness can be beneficial for SPARROW’s search and rescue operations, where precise maneuvering and rapid adjustments may be necessary in complex or confined environments. Cleanflight's compatibility with various flight controllers and sensors allows the SPARROW team to integrate the necessary payloads, such as thermal cameras or high-resolution imaging systems, to effectively detect and locate humans in need. Additionally, its ability to fine-tune PID settings ensures stable and efficient flight performance, even in challenging conditions like wind or uneven terrain. Cleanflight's active community and extensive documentation also provide valuable resources for troubleshooting and customizing the firmware to suit SPARROW's unique mission requirements. While it may lack some of the advanced mission planning and simulation features found in other software, Cleanflight's simplicity and adaptability make it a viable option for projects that prioritize real-time control and responsive flight behavior.

Table 3.23. *Comparison of autonomous software by Authors*

Criteria	ArduPilot	PX4	DroneKit	Paparazzi UAV	CleanFlight
Development Language	C/C++	C/C++	Python, Android	C	C
Mission Planning	Good	Good	Moderate	Good	Bad
Real-time Telemetry	Yes	Yes	Yes	Yes	Yes
Ease of Use	Moderate	Moderate	High	Moderate	High
Sensor Integration	Good	Good	Moderate	Good	Moderate
Autonomous Navigation	Advanced	Advanced	Moderate	Advanced	Basic
Modularity and Customization	High	High	High	High	Moderate

Automation Software Selection

ArduPilot is the best option for this project due to its proven stability, extensive community support, and versatility across various unmanned vehicles. Its wide range of features, including waypoint navigation, real-time processing, and sensor integration, makes it ideal for complex missions like detecting humans. Additionally, ArduPilot's open-source nature allows for custom configurations, such as mesh networking for drone communication, enabling efficient and safe operation in challenging environments. The strong documentation and community resources further ensure that any technical challenges can be effectively addressed, making ArduPilot the most reliable and adaptable choice. On top of this, ArduPilot contains the MissionPlanner software which is important for establishing a connection between the drone and the base station so that both sides can communicate with each other. Through the use of MissionPlanner, our display can show the footage via the communication from the drone to control, hence making ArduPilot the superior choice for the autonomous software portion of SPARROW.

3.12 Computer Vision Library

Human detection from a drone using computer vision is a vital application in areas such as search-and-rescue operations, crowd management, and security surveillance. Drones provide a unique vantage point, allowing for large-scale monitoring of environments that may be difficult to access or view from the ground. However, detecting humans in real-time from aerial footage presents significant challenges due to factors like varying altitudes, motion, lighting conditions, and the presence of occlusions or cluttered backgrounds. Computer vision techniques, powered by deep learning, are crucial for overcoming these obstacles. Algorithms trained to recognize humans can help identify and track individuals even in complex scenes. Using libraries like OpenCV, PyTorch, or TensorFlow allows for the development of highly efficient models that can be trained or fine-tuned on drone-specific datasets. These models can accurately detect humans in various contexts and scales, whether in wide-open fields or dense urban environments. Leveraging deep learning techniques enables drones to perform tasks autonomously, detecting and tracking humans across multiple frames while handling challenges like motion blur or low resolution. Moreover, with the help of optimization tools within these libraries, models can be made lightweight enough to run in real-time on embedded devices, allowing drones to operate without relying heavily on external processing power. This combination of real-time detection, accuracy, and the ability to adapt models using powerful computer vision libraries opens up a broad range of applications, making human detection from drones a highly effective and versatile tool for modern aerial monitoring.

OpenCV

OpenCV is a computer vision library designed for fast and efficient image processing, making it well-suited for real-time object detection tasks. One of the key advantages of OpenCV is its simplicity and speed, especially when using pre-trained models through its DNN module. OpenCV is lightweight and runs efficiently on a wide range of platforms, from desktop systems to mobile and embedded devices like Raspberry Pi, making it ideal for applications that require fast performance and low computational overhead. Additionally, OpenCV can handle not only object detection but also image editing tasks such as resizing, cropping, filtering, and feature extraction, providing a versatile solution for both detection and post-processing of images. However, OpenCV has limitations when it comes to training custom deep learning models—it's more of a deployment framework than a training framework. You would need to train your object detection models using other frameworks (e.g., PyTorch, TensorFlow) and then load them into OpenCV for inference, which may add complexity for users who wish to train their own models from scratch.

PyTorch

PyTorch is a powerful deep learning framework known for its flexibility and ease of use in research and custom model development. One of the key advantages of PyTorch is its support for cutting-edge deep learning techniques, making it ideal for training custom object detection models like YOLO, Faster R-CNN, and RetinaNet. PyTorch excels at transfer learning, allowing developers to fine-tune pre-trained models with minimal computational resources. It also has a strong community and rich ecosystem with libraries like Torchvision and Detectron2 for object detection tasks. However, the downside of PyTorch is that it can be more resource-intensive, often requiring a GPU to achieve real-time performance. Additionally, setting up a full pipeline for object detection (especially for beginners) might require a steeper learning curve compared to OpenCV, as it demands a good understanding of deep learning fundamentals, such as backpropagation and optimization techniques.

TensorFlow

TensorFlow is a powerful deep learning framework widely used for object detection due to its scalability and robust ecosystem. One of its key strengths is its versatility, allowing developers to build, train, and deploy sophisticated object detection models across a wide range of devices, from powerful GPUs to edge devices using TensorFlow Lite. TensorFlow offers pre-trained models like Faster R-CNN, SSD, and EfficientDet through its TensorFlow Object Detection API, making it easy to implement high-performing object detection systems without needing to train models from scratch. For custom use cases, TensorFlow provides extensive support for training models with custom datasets, allowing developers to fine-tune or fully train models to detect specific objects in unique environments. TensorFlow's distributed training capabilities make it highly suitable for large-scale projects, and its integration with cloud platforms like Google Cloud enables seamless deployment and scaling. However, TensorFlow models can be resource-intensive, especially during training, and might require careful optimization for real-time inference. TensorFlow's ecosystem also includes tools for model optimization and deployment, such as TensorFlow Lite for mobile and embedded devices and TensorFlow.js for running models in web browsers. This makes TensorFlow a comprehensive solution for end-to-end object detection tasks, from model development to deployment on a wide range of platforms.

Table 3.24. *Comparison of computer vision libraries by Authors*

Feature/Aspect	OpenCV	PyTorch	TensorFlow

Primary Focus	Computer vision tasks	Deep learning and neural networks	Deep learning and neural networks
Development Language	Python/C++	Python/C++	Python/C++/Java
Ease of Use	Moderate complexity	Easy-to-use	Steeper learning curve
Primary Applications	Image processing, real-time vision tasks	Deep learning	ML/DL and deployment
Pre-Trained Models	Limited	Lots of Variety	Lots of Variety
Performance Speed	Fast	Moderate	Moderate
Integration	Works with other vision libraries	Integrates with Python ML/DL ecosystem	Integrates with TensorFlow ecosystem
Ideal Use Case	Image processing, feature extraction	Rapid prototyping of neural networks	Machine learning

Computer Vision Library Selection

OpenCV stands out as the best choice for object detection when prioritizing efficiency, speed, and low resource consumption. Designed with performance in mind, OpenCV is optimized to run on both CPU and GPU, which makes it highly suitable for applications requiring real-time processing with minimal hardware resources. For tasks like human detection on drones, where power and computational capacity are limited, OpenCV's lightweight design ensures fast and accurate object detection without overloading the system. Its `DNN` module allows easy deployment of pre-trained models, such as YOLO and MobileNet SSD, which are highly effective for detecting humans and can achieve real-time performance even on embedded devices. Additionally, OpenCV's rich suite of image processing tools allows seamless integration of detection and post-processing, such as tracking or enhancing the quality of captured frames, without relying on heavy external libraries. This balance between speed, efficiency, and functionality makes OpenCV an ideal choice for resource-constrained environments, where every millisecond and watt of power saved is essential.

3.13 Object Detection Algorithm

Object detection algorithms are a crucial component of modern computer vision, enabling machines to not only classify objects within an image but also locate them by drawing bounding boxes around each detected item. These algorithms work by dividing an image into regions and analyzing each region to determine the presence of objects, predicting their class and location simultaneously. Popular object detection models, such as YOLO (You Only Look Once), Faster R-CNN (Region-based Convolutional Neural Networks), and SSD (Single Shot MultiBox Detector), use convolutional neural networks (CNNs) to detect objects efficiently by learning hierarchical features from images. These models are often trained on large datasets like COCO or PASCAL VOC, which contain a wide variety of objects in different contexts, allowing them to generalize well to many use cases. For practical applications, pre-trained models are commonly used, which significantly reduce the training time and computational cost. These models are trained on massive datasets and can be fine-tuned on smaller, specific datasets to adapt them for particular tasks, such as detecting objects in specific environments or under certain conditions. Fine-tuning pre-trained models, a technique called **transfer learning**, allows developers to use these models as a base and re-train them with their custom datasets, achieving accurate results with less data and computation. On the other hand, training models from scratch requires larger datasets and considerable computational resources but offers complete control over the model architecture and its training process. Custom training can be advantageous when working with unique datasets that significantly differ from the common data used in pre-trained models. During training, the model learns to identify features that define the objects and adjusts its weights through backpropagation and optimization until it can reliably predict the location and class of objects in new images. Whether using pre-trained models or training a model from scratch, object detection algorithms are highly effective for applications such as autonomous vehicles, surveillance, and industrial automation, where identifying and tracking objects in real-time is critical.

YOLO

YOLO is a very popular and widely used object detection algorithm due to its impressive speed and accuracy. It treats object detection as a single regression problem, which means it predicts both the bounding boxes and class probabilities directly from full images in one evaluation. This end-to-end approach makes YOLO extremely efficient, allowing it to process images in real-time. It is especially effective in scenarios where quick decisions making is crucial, such as autonomous driving or surveillance systems. Its latest versions have improved accuracy while maintaining speed, making it highly versatile.

Faster R-CNN (Region-based Convolutional Neural Networks)

Faster R-CNN builds upon the foundations of the R-CNN and Fast R-CNN algorithms, introducing a Region Proposal Network (RPN) that significantly speeds up the detection process by sharing computation with the network. This model offers high accuracy making it suitable for tasks that require precise object detection, such as medical imaging or detailed analysis in industrial applications. Although it isn't as fast as YOLO, it remains one of the most reliable choices when detection accuracy is the priority.

Mask R-CNN

An extension of Faster R-CNN, Mask R-CNN not only detects objects but also performs instance segmentation, which involves identifying the exact pixel boundaries of objects. This makes it highly valuable in applications like autonomous driving, where distinguishing between overlapping objects is essential, or in medical imaging, where precise segmentation of regions is required. It builds on Faster R-CNN by adding a parallel branch for predicting segmentation masks, allowing the network to generate more detailed outputs. This additional branch operates simultaneously with the bounding box regression and classification tasks, which makes it highly efficient for applications requiring both detection and segmentation.Overall, Mask R-CNN is a versatile and powerful algorithm that has become one of the leading methods for tasks requiring both object detection and instance segmentation.

SSD (Single Shot MultiBox Detector)

SSD is known for being faster than Faster R-CNN and can perform real-time object detection while maintaining a good level of accuracy. It achieves this by predicting bounding boxes and class probabilities directly in one pass through the network. SSD is particularly effective in detecting bounding boxes and class probabilities directly on pass through the network. SD is particularly effective in detecting objects of various sizes and performs well in tasks such as video analysis and image annotation. Its ability to handle objects at different scales makes it suitable for real-world applications where object size may vary significantly.

RetinaNet

RetinaNet introduced the concept of the "Focal Loss" to address the issue of class imbalance, which often affects object detection tasks where some classes are more prevalent than others. This model is effective in identifying objects that may be smaller or appear less frequently in the dataset. RetinaNet strikes a balance between speed and accuracy, making it a solid choice for applications where detecting small or infrequent objects is critical.

EfficientDet

EfficientDet is based on the EfficientNet backbone and is one of the most advanced object detection models available. It combines high accuracy with computational efficiency, making it suitable for applications where resources are limited, such as edge computing or mobile devices. The algorithm employs a scalable architecture that allows you to choose different levels of accuracy and speed, depending on your requirements. The EfficientDet model represents a significant advancement in the field of object detection by introducing a framework that is both highly efficient and scalable. One of its most notable features is the use of the EfficientNet backbone, which serves as the foundation for feature extraction. EfficientNet is known for its ability to scale neural networks efficiently by adjusting their depth, width, and resolution, which results in superior performance with fewer parameters compared to traditional backbones.

CenterNet

CenterNet detects objects as center points and regresses their size and shape from there. This innovative approach allows it to achieve high accuracy with a relatively simple architecture, resulting in faster detection times. It performs well in scenarios requiring real-time detection, such as sports analytics or drone-based object tracking.

This streamlined design is particularly beneficial in real-time detection scenarios. In applications like sports analytics, CenterNet can rapidly detect players, balls, or other relevant objects and track their movements in fast-paced environments. Similarly, in drone-based object tracking, speed is essential to avoid obstacles and navigate through dynamic environments. CenterNet's ability to process information quickly without sacrificing accuracy makes it well-suited for these high-demand, time-sensitive tasks. Furthermore, its efficient architecture is advantageous for deployment on hardware with limited computational power, such as embedded systems or mobile devices, making it a versatile choice for a wide range of use cases.

Table 3.25. *Comparison of object detection algorithms - Part 1*
by Authors

Attribute	YOLO	Faster R-CNN	Mask R-CNN	SSD
Architecture	Single-stage	Two-stage	Two-stage	Single-stage
Speed	Very fast	Moderate	Moderate	Moderate to fast
Accuracy	Moderate	High	High	Moderate to high
Strengths	Fast inference, real-time applications	Excellent accuracy	Can perform both object detection and segmentation	Good balance of speed and accuracy
Weaknesses	Lower accuracy on small objects	Slower inference	More computationally expensive	Struggles with small object detection

Table 3.26. *Comparison of object detection algorithms - Part 2*
by Authors

Attribute	RetinaNet	EfficientDet	CenterNet

Architecture	Single-stage	Single-stage CNN	Single-stage
Speed	Moderate	Very fast	Fast
Accuracy	High	High	High
Strengths	Good for imbalanced data, handles small objects well	Lightweight, efficient model with high accuracy	Good for detecting keypoints, more accurate in crowded scenes
Weaknesses	Slower than YOLO, more computationally expensive than SSD	Can struggle with very complex scenes	May be slower for simple scenes

Object Detection Algorithm Selection

YOLO is an outstanding choice for object detection, especially in scenarios that require real-time processing with limited resources. Unlike other models that may require multiple stages or complex region proposals, YOLO treats object detection as a single regression problem, predicting both bounding boxes and class probabilities in one swift evaluation. This end-to-end approach makes YOLO highly efficient, enabling it to process images at an impressive speed while maintaining a high level of accuracy. For applications like human detection from a drone, where the system needs to make fast decisions to track or avoid obstacles, YOLO's rapid detection capabilities make it ideal. Additionally, YOLO's newer versions, like YOLOv4 and YOLOv5, offer even greater accuracy while retaining the algorithm's signature speed, making it versatile enough to handle complex scenes or dynamic environments with minimal computational power. In situations where power and resource efficiency are crucial, YOLO shines as the preferred model, balancing speed, accuracy, and lightweight deployment in ways that are highly advantageous for mobile or embedded systems. This blend of real-time speed, efficient architecture, and accuracy makes YOLO a top choice for resource-constrained, time-sensitive tasks.

Chapter 4 - Standards and Design Constraints

4.1 Industrial Standards

PCB Design Standards

PCB design standards outline what is required for a PCB to meet industry specifications. These standards ensure that PCBs are reliable, manufacturable, and perform according to the intended design. Some of the key standards include PCB thickness, clearances, tolerances, material selection, and mounting. These standards include:

IPC-2221

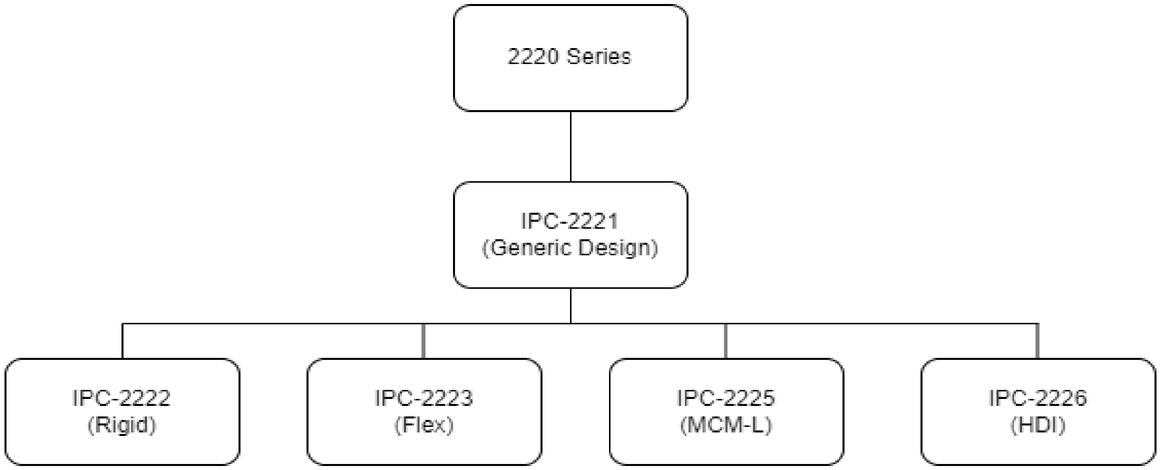


Figure 4.1. *2220 Series Hierarchy*
by Authors

IPC-2221 is a generic standard, meaning it provides broad guidelines that apply to various PCB types, including rigid, flexible, and rigid-flex boards. The purpose of this standard is to establish a framework that ensures that PCBs are manufacturable and meet the necessary performance requirements. It covers all aspects of PCB design, including materials, mechanical layout, electrical properties, thermal management, and manufacturability considerations.

1. **Material Selection**: IPC-2221 is a generic standard, meaning it provides broad guidelines that apply to various PCB types, including rigid, flexible, and rigid-flex boards. The purpose of this standard is to establish a framework that designers can follow to ensure that their PCBs are manufacturable and meet the necessary performance requirements. It covers all aspects of PCB design, including materials, mechanical layout, electrical properties, thermal management, and manufacturability considerations.

2. **Mechanical Design**: This standard outlines the requirements for mechanical layout, including board dimensions, thickness, hole sizes, and tolerances. These guidelines help prevent mechanical failures such as warping or cracking and ensure that the PCB can withstand physical stresses during assembly and operation.

3. **Electrical Considerations**: IPC-2221 details the electrical design requirements, including trace widths, spacing, and impedance control. It ensures that the PCB will perform reliably in its intended application by minimizing issues like signal loss, crosstalk, and electromagnetic interference (EMI).

4. **Thermal Management**: Effective thermal management is crucial for PCB reliability, especially in high-power applications. IPC-2221 provides guidelines on managing heat within the PCB, including the use of thermal vias, heat sinks, and appropriate materials to dissipate heat effectively.

5. **Manufacturability**: The standard emphasizes design for manufacturability (DFM), which ensures that the PCB can be produced efficiently and cost-effectively. This includes guidelines for layer stack-up, drill sizes, and via types, helping designers avoid common manufacturing issues that could lead to increased costs or delays.

IPC-2221 serves as a general guideline for PCB design, providing a comprehensive set of standards that cover all aspects of the design process. By adhering to this standard, we can ensure that our PCBs are reliable, manufacturable, and capable of meeting the rigorous demands of modern electronics while maintaining low costs.

IPC-7351

IPC-7351 aims to standardize land pattern designs to increase the manufacturability, reliability, and performance of PCBs. The standard addresses the challenges created by the diversity of surface mount components, each requiring specific land patterns for optimal performance. By adhering to IPC-7351, we can create footprints that ensure consistent results across different manufacturing processes, reducing the risk of errors and defects. The scope of IPC-7351 includes:

1. **Land Pattern Creation**: IPC-7351 outlines the guidelines for designing the physical dimensions and geometry of land patterns for a wide range of surface mount components, including resistors, capacitors, ICs, and connectors.

2. **Pad Design**: IPC-7351 provides detailed guidelines on the design of pads, which are the conductive areas on the PCB where components are soldered. The standard specifies the optimal pad sizes and spacing for different component types, ensuring that the solder joints are strong and reliable. Proper pad design also facilitates automated optical inspection (AOI) and testing processes.

3. **Solder Mask and Plate Stencils**: The standard makes recommendations for solder mask clearance and stencil aperture design to optimize solder paste deposition and prevent defects like bridging or insufficient solder.

4. **Environmental and Thermal Factors**: IPC-7351 ensures considerations for designing land patterns that can withstand environmental stresses such as thermal cycling and mechanical vibration are made.

PC-7351 is an essential standard for PCB designers, providing a robust framework for creating reliable and manufacturable land patterns for surface mount components. By following the guidelines outlined in this standard, we can ensure that their PCBs meet the necessary quality and performance requirements, leading to more cost-effective electronics manufacturing.

IPC-2615

The primary purpose of IPC-2615 is to standardize the dimensional and tolerance requirements for PCBs to ensure consistency and reliability across different manufacturing processes and suppliers. By adhering to this standard, we can avoid common issues related to misalignment, fit, and function, which are crucial for the long-term reliability of electronic assemblies. The main standards of IPC-2615 are:

1. **Dimensional Specifications**: IPC-2615 outlines specific requirements for various PCB dimensions, including the overall board size, thickness, hole sizes, and the placement of features such as pads, traces, and vias. The standard also provides guidance on how these dimensions should be measured and documented to ensure accuracy.

2. **Tolerance Guidelines**: The standard sets forth acceptable tolerance ranges for critical PCB dimensions. These tolerances account for variations in manufacturing processes and materials, ensuring that PCBs remain within functional limits even when minor deviations occur. The tolerances cover aspects such as hole diameters, trace widths, spacing, and board thickness.

3. **Layer Registration and Alignment**: Proper alignment of layers in a multi-layer PCB is essential for maintaining electrical connectivity and preventing shorts or openings. IPC-2615 includes guidelines for layer registration, specifying acceptable misalignment limits to ensure that all layers are correctly aligned during the manufacturing process.

4. **Surface Finish Considerations**: The standard also addresses the impact of surface finishes on PCB dimensions and tolerances. Different surface finishes, such as HASL (Hot Air Solder Leveling), ENIG (Electroless Nickel Immersion Gold), and OSP (Organic Solderability Preservative), can affect the overall thickness and flatness of a PCB. IPC-2615 provides guidance on how to account for these variations during the design phase.

5. **Documentation Requirements**: IPC-2615 emphasizes the importance of clear and accurate documentation. It specifies the type of information that should be included in design files, such as detailed drawings, tolerance notes, and material specifications. This ensures that manufacturers have all the necessary information to produce PCBs that meet the required standards.

IPC-2615 plays a critical role in the PCB design and manufacturing process by providing clear guidelines for dimensions, tolerances, and documentation. By following this standard, we can ensure that our PCBs meet the highest quality and reliability standards, ultimately leading to better-performing and more durable electronic products.

Battery Standards

Battery standards must be in place to ensure the safety, reliability, and performance of lithium-ion cells. These standards are essential because lithium-ion batteries, while highly efficient, pose significant risks if not properly designed, manufactured, and handled. The standards provide rigorous testing protocols and guidelines to mitigate hazards such as thermal runaway, short circuits, overcharging, and mechanical damage, which could lead to fires or explosions. Moreover, they ensure that batteries perform consistently under different conditions and have a reliable lifespan, which is crucial for both manufacturers and end-users. By adhering to these standards, we can minimize the risk of product recalls, liability issues, and ensure compliance with regulatory requirements across different markets.

IEC 62133

IEC 62133 is an internationally recognized safety standard for rechargeable batteries, particularly those using lithium-ion and nickel systems. Established by the International Electrotechnical Commission (IEC), this standard outlines the essential safety requirements and testing protocols to ensure the safe operation of batteries used in portable devices. These standards include:

1. **Electrical Tests**: The batteries must undergo tests to evaluate their performance under normal and abnormal conditions. This includes overcharge, over-discharge, short circuit, and forced discharge tests. These tests simulate conditions that could occur during the battery's life cycle, ensuring it can withstand such scenarios without causing harm.

2. **Mechanical Tests**: Batteries are subjected to tests that assess their durability against mechanical abuse. This includes vibration, shock, and drop tests, which mimic the physical impacts that batteries might encounter during transport or everyday use.

3. **Environmental Tests**: The standard mandates tests for evaluating battery performance under various environmental conditions, such as extreme temperatures, humidity, and pressure. These tests ensure that batteries remain safe and operational in a wide range of environments.

4. **Battery Assembly**: The design and construction of battery packs, including protective circuitry, are also addressed. The standard emphasizes the importance of proper assembly to prevent electrical hazards, such as short circuits, and to ensure reliable performance.

5. **Battery Management Systems (BMS)**: For lithium-ion batteries, the integration of a Battery Management System is crucial. The BMS is responsible for monitoring and controlling battery parameters, such as voltage, current, and temperature, to prevent unsafe conditions. IEC 62133 outlines the requirements for BMS functionality and testing to ensure the safe operation of the battery.

The implementation of IEC 62133 is crucial for the safety and efficacy of lithium-ion cells. This standard is designed to address the unique risks associated with lithium-ion technology by enforcing rigorous testing and quality controls. IEC 62133 provides a comprehensive framework that ensures batteries are safe, reliable, and perform consistently across various conditions. Adherence to this standard not only mitigates potential hazards but also helps us avoid costly recalls and legal issues, ultimately protecting consumers and maintaining trust.

UL 1642

UL 1642 is a design standard developed by Underwriters Laboratories (UL) that specifies safety requirements for lithium batteries. It is primarily used to ensure the safe performance and reliability of lithium batteries used in various applications. The standard outlines tests and requirements that battery manufacturers must meet to mitigate risks associated with lithium batteries, such as overheating, fires, and explosions. The main standards outlined by UL 1642 are:

1. **Battery Construction and Design**: UL 1642 focuses on the design and construction of lithium batteries to ensure they meet safety criteria. This includes requirements for battery cells and packs, emphasizing the need for robust mechanical and electrical designs that minimize the risk of failure. The standard specifies that batteries must be constructed with protective features to handle overcharge, over-discharge, and short-circuit conditions.

2. **Testing and Evaluation**: The standard prescribes a series of rigorous tests to evaluate battery safety. These tests include:

    - **Overcharge Test**: Batteries are subjected to overcharging conditions to assess their response and ensure they do not pose a hazard.

    - **Short-Circuit Test**: The battery is short-circuited to evaluate its reaction and ensure it does not result in dangerous thermal events.

    - **Thermal Abuse Test**: Batteries are exposed to high temperatures to check their stability and safety under thermal stress.

    - **Mechanical Abuse Test**: This test involves subjecting the battery to mechanical stress, such as crushing or puncturing, to evaluate its safety under physical impact.

3. **Performance Requirements**: UL 1642 sets performance benchmarks that lithium batteries must meet. These include capacity and discharge rate requirements to ensure that batteries operate reliably within specified limits. The standard also mandates that batteries should maintain safety and performance over their expected lifespan.

4. **Marking and Documentation**: To comply with UL 1642, manufacturers must provide adequate marking and documentation for their batteries. This includes labeling that provides information about the battery's specifications, safety warnings, and handling instructions. Documentation should also detail the battery’s compliance with UL 1642 and other relevant standards.

UL 1642 is a critical standard for the safety of lithium batteries, ensuring that they are designed, tested, and manufactured to minimize risks. By ensuring our batteries adhere to this standard, we can be confident that we produce a reliable and safe product, while the user can be confident in the safety and performance of the product they use.

ANSI C18

ANSI C18 is designed to standardize the construction, performance, and labeling of portable batteries, including those used in consumer electronics and other applications. The standard aims to provide a uniform basis for comparing battery performance and safety across different manufacturers and battery types. These standards include:

1. **Battery Classification and Terminology**: The standard provides clear definitions and classifications for different types of batteries, including alkaline, nickel-cadmium (NiCd), nickel-metal hydride (NiMH), and lithium-based batteries. It establishes standardized terminology to avoid confusion and ensure consistent communication about battery specifications.

2. **Performance Specifications**: ANSI C18 outlines performance requirements for batteries, including capacity, voltage, and discharge rates. These specifications ensure that batteries provide adequate power and operate reliably under specified conditions. Performance testing methods are detailed to assess how batteries perform in real-world scenarios.

3. **Safety Requirements**: Safety is a critical aspect of ANSI C18. The standard includes guidelines for battery design to prevent hazards such as leaks, explosions, and overheating. It covers aspects such as venting mechanisms, insulation, and containment to protect users and devices.

4. **Labeling and Marking**: ANSI C18 mandates clear labeling of battery products to provide users with essential information, including battery type, voltage, capacity, and disposal instructions. Proper labeling helps consumers make informed choices and ensures safe handling and disposal of batteries.

5. **Environmental Considerations**: The standard addresses environmental concerns by setting guidelines for battery recycling and disposal. It encourages manufacturers to design batteries with minimal environmental impact and to provide information on how to dispose of batteries responsibly.

6. **Testing and Compliance**: ANSI C18 specifies testing procedures to verify that batteries meet the required standards. Compliance with these procedures is necessary for battery manufacturers to demonstrate adherence to the standard and ensure product quality.

Selecting batteries that adhere to the ANSI C18 standard is crucial for ensuring consistency, safety, and environmental responsibility. By providing clear definitions, performance specifications, and safety guidelines, ANSI C18 enables us to reliably compare battery products and make informed decisions. The standard's focus on uniform labeling and rigorous testing ensures that batteries meet high-quality benchmarks, thus minimizing risks and enhancing user trust. Additionally, ANSI C18's emphasis on environmental considerations supports sustainable practices, making it essential for responsible battery usage and disposal.

IEEE 1625

The IEEE 1625 design standard, officially titled "IEEE Standard for Rechargeable Batteries for Portable Computing Devices," provides a comprehensive framework for designing and manufacturing rechargeable batteries used in portable electronic devices. Published by the Institute of Electrical and Electronics Engineers (IEEE), this standard aims to ensure the safety, reliability, and performance of batteries in a wide range of portable computing devices, such as laptops, tablets, and smartphones. These standards include:

1. **Safety and Reliability**: One of the primary goals of the IEEE 1625 standard is to enhance the safety and reliability of rechargeable batteries. It sets guidelines to prevent common issues such as thermal runaway, leakage, and electrical failure, which can pose serious hazards to users and devices. The standard provides specifications for battery design, including the selection of materials, cell construction, and protection mechanisms to mitigate risks.

2. **Performance Metrics**: IEEE 1625 defines performance criteria for batteries, including capacity, charge/discharge cycles, and energy density. It outlines testing procedures to ensure that batteries meet these performance metrics consistently. This helps manufacturers deliver products that provide reliable power supply and meet user expectations for battery life and efficiency.

3. **Environmental Considerations**: The standard addresses environmental concerns by promoting the use of environmentally friendly materials and practices in battery design and disposal. It encourages the reduction of hazardous substances and emphasizes recycling and proper disposal to minimize the environmental impact of used batteries.

4. **Testing and Quality Assurance**: IEEE 1625 outlines rigorous testing protocols for battery manufacturers to follow. These tests assess various aspects of battery performance, including thermal management, mechanical integrity, and electrical safety. By adhering to these testing procedures, manufacturers can ensure that their batteries meet the required standards and perform reliably in real-world conditions.

5. **Documentation and Compliance**: The standard emphasizes the importance of comprehensive documentation and compliance with its guidelines. Manufacturers are required to maintain detailed records of battery design, testing, and quality assurance processes. This documentation helps in verifying compliance with the standard and provides valuable information for troubleshooting and quality control.

The IEEE 1625 standard has had a significant impact on the portable electronics industry by setting a high benchmark for battery design and manufacturing. Its adoption has led to improvements in battery safety, performance, and environmental responsibility. If we comply with IEEE 1625 can assure consumers of the quality and reliability of the batteries in our product.

Thermal Camera Standards

Thermal cameras require strict standards to ensure reliable performance, and accuracy. These standards provide guidelines for testing thermal cameras under various conditions, ensuring they meet the necessary safety and performance criteria, while also addressing the environmental and mechanical stresses these devices might encounter in real-world applications. By adhering to these standards, we can ensure consistent performance, minimize the risk of malfunction, and protect users from potential hazards.

ISO 12233

ISO 12233 is an international standard that outlines methods for measuring the resolution of electro-optical devices, including thermal cameras. This standard ensures that thermal cameras are able to capture accurate, high-resolution images, which is critical in applications such as medical diagnostics, industrial inspections, and military operations.

1. **Resolution Testing**: Establishes methods to measure and quantify the resolution of thermal cameras under different settings. This ensures cameras can detect fine details and temperature gradients accurately.

2. **Image Quality**: Defines parameters for evaluating image sharpness, noise levels, and distortion, helping to ensure thermal cameras produce clear and reliable images for end users.

3. **Performance Consistency**: Ensures that cameras perform consistently across various lighting conditions and temperatures, which is essential for their reliability in critical applications.

IEC 60068-2-1

IEC 60068-2-1 is a standard for environmental testing that applies to thermal cameras to ensure they function reliably under cold conditions. Thermal cameras, often exposed to extreme environmental conditions, must be able to operate consistently without degradation. This standard includes:

1. **Cold Test**: Simulates extreme cold environments to assess the camera's ability to maintain performance without failure.

2. **Material Durability**: Tests the resilience of the camera's materials and components, ensuring that they do not become brittle or malfunction in low temperatures.

IEC 60068-2-2

IEC 60068-2-2 is a companion standard that focuses on testing thermal cameras under high-temperature conditions. Since thermal cameras are used in industrial and outdoor environments where heat is a concern, it is crucial that they can function effectively in such conditions.

1. **Heat Stress Testing**: Exposes the camera to elevated temperatures to ensure that it continues to perform without issues like overheating or image distortion.

2. **Thermal Stability**: Verifies the camera's ability to capture accurate thermal images even under high-temperature stress, ensuring reliable operation across different applications.

IEC 80601-2-59

IEC 80601-2-59 is a standard specific to medical electrical equipment, including medical-grade thermal cameras. This standard addresses the performance and safety requirements for thermal imaging devices used for screening purposes, particularly in healthcare settings. Key elements include:

1. **Accuracy of Measurement**: Ensures that the thermal camera can detect subtle temperature differences, which is crucial for applications like fever detection or monitoring medical conditions.

2. **Patient Safety**: Focuses on safety protocols to protect both patients and healthcare professionals, ensuring that the camera does not emit harmful radiation or electrical hazards.

3. **Hygienic Design**: Outlines requirements for the device to be easily sanitized and maintained in medical environments, reducing the risk of cross-contamination.

By adhering to these thermal camera standards, we can ensure the safety, accuracy, and durability of our project. This results in higher reliability, improving the efficiency of out product. Compliance also helps prevent costly product recalls, enhances user satisfaction, and ensures global regulatory compliance.

MAVLink Standards

MAVLink (Micro Air Vehicle Link) is a lightweight communication protocol designed for unmanned vehicles, primarily drones, and is used to exchange data between drones, ground control stations, and onboard systems. It operates in low-bandwidth, high-latency environments, making it ideal for drone operations where efficient and reliable communication is essential. MAVLink messages are structured into small packets containing a header, payload, and checksum, allowing the transmission of telemetry data, such as GPS and Altitude, and control commands such as flight modes and waypoints, across various communication media like radios, Wi-Fi, or satellite links.

Each MAVLink message follows a standardized structure that includes fields such as a system ID, component ID, message ID, and a payload with relevant data. This format ensures consistency in communication between systems, supporting both telemetry messages and command messages that can control vehicle operations. The protocol is widely used for autonomous drones and supports various applications, from navigation and flight control to mission planning and vehicle health monitoring.

MAVLink has evolved into two main versions: MAVLink 1.0 and MAVLink 2.0. While MAVLink 1.0 remains in use for legacy systems, MAVLink 2.0 introduces significant improvements, including extensibility, message signing, and larger payload support, making it more secure and adaptable. Despite these advancements, MAVLink 2.0 maintains backward compatibility with MAVLink 1.0, ensuring continued support across older systems while encouraging adoption of newer features.

Key features of MAVLink include the heartbeat mechanism, which continuously sends vehicle status updates to ensure synchronization and allow ground stations to monitor drone health. MAVLink also enables mission and parameter management, allowing users to upload waypoints, manage flight paths, and adjust onboard settings remotely. These capabilities make the protocol versatile for both manual and fully autonomous drone operations.

In addition to its communication reliability, MAVLink is compatible with popular ground control software like QGroundControl and Mission Planner, which support real-time drone monitoring and mission execution. The protocol's solid design, security features, and wide adoption in UAV operations make it essential for drones used in fields ranging from mapping and surveying to search and rescue missions.

GPS Standards

The Global Positioning System (GPS) is a satellite-based navigation network that offers precise location and time data worldwide. Developed by the U.S. Department of Defense and operational since the 1990s, GPS functions by triangulating signals from a minimum of four satellites. These signals provide details on each satellite’s position and transmission time, allowing receivers to determine their exact location (latitude, longitude, and altitude) and synchronize their clocks with satellite time. The system comprises at least 24 satellites orbiting Earth, ground control stations, and user receivers, all working in concert to ensure accurate positioning.

To enhance accuracy, GPS utilizes Differential GPS (DGPS), which employs ground-based reference stations to broadcast corrections for errors caused by signal degradation and atmospheric interference. This system refines positioning accuracy to within a few meters by correcting GPS data received. For even greater precision, Real-Time Kinematic (RTK) positioning technology is used, delivering centimeter-level accuracy through real-time corrections from a base station. This technology is essential for high-precision applications, such as construction and surveying.

Furthermore, the Wide Area Augmentation System (WAAS) in the U.S. enhances GPS signals with corrections from geostationary satellites, boosting accuracy to within three meters for aviation and critical applications. The European Union’s Galileo system, fully operational from 2020, complements GPS by providing its satellite network and infrastructure, enhancing global positioning services with high precision and reliability. Galileo aims to offer superior performance in challenging urban areas where GPS signals are often obstructed or reflected.

GPS standards also include various signal formats and communication protocols, ensuring compatibility and interoperability across devices globally. GPS signals are transmitted on L1, L2, and L5 frequency bands, with L1 used for civilian navigation and L2 and L5 providing additional signals for military and high-precision use. International organizations like the International Committee on Global Navigation Satellite Systems (ICG) work to standardize GPS globally, promoting interoperability and enhancing GPS's effectiveness across different regions and applications. This standardization is crucial for the extensive use of GPS in fields such as transportation, agriculture, and disaster response, significantly improving its reliability and global applicability.

In addition to the technologies and systems mentioned, GPS standards also encompass various international regulations and certifications to ensure safety and interoperability. The International Organization for Standardization (ISO) and the International Telecommunication Union (ITU) play pivotal roles in defining global standards for GPS technology, promoting uniformity in signal formats, frequency usage, and system performance. These standards facilitate seamless integration of GPS with other global navigation satellite systems (GNSS), such as Russia's GLONASS, China's BeiDou, and India's NavIC, enhancing global positioning accuracy and reliability. The development of new signals and technologies, such as the Galileo High Accuracy Service (HAS) and GPS Modernization, continues to advance the capabilities of GPS, ensuring its relevance and precision in an increasingly interconnected world.

Overall, since the GPS standards are intact, we must abide by these regulations when using GPS for our project. Our project involves the drone sending its GPS coordinates to the base station to pinpoint the locations of any people in need. Adhering to these standards ensures that our project can deliver precise and reliable location data, enhancing the accuracy of our detection system. By following established GPS guidelines, we ensure interoperability, safety, and performance, making our drone capable of effectively navigating and performing its tasks in a real-world environment. This adherence not only aligns with industry best practices but also guarantees that our project meets the necessary compliance and safety standards, ultimately contributing to the success and credibility of our initiative.

4.2 Practical Constraints

Time

Senior design projects are strictly limited to one academic year, imposing a significant time constraint on our group. This time limitation requires us to meticulously plan, develop, fabricate, and go through multiple project iterations within a very narrow window. The design process alone, which includes everything from initial brainstorming to extensive research, consumes a large portion of our schedule even before any physical construction can begin.

Before we can begin building, we must allocate time to procure necessary components, which is a critical and often unpredictable part of the project. For instance, ordering a custom-designed PCB might take several days to weeks, and we must account for potential delays or shortages in parts. Such delays could compress our already tight schedule, leaving us with less time to complete the project and increasing the risk of not meeting our deadlines.

Once we have received all the necessary components, we move into the assembly and testing phase, which will likely be challenging. This stage is almost guaranteed to encounter setbacks, as it is unlikely that everything will work perfectly on the first attempt. These setbacks could significantly reduce the time available for finalizing the project, forcing us to make rapid adjustments despite having little margin for error. Additionally, the project requires us to learn and implement various complex processes, such as detection algorithms and flight path automation, which further adds to the project's complexity and time demands.

Moreover, we face another significant time constraint in coordinating with a separate team responsible for the drone itself. Ensuring seamless communication between the drone and our base station will require extensive testing and integration efforts. This need for collaboration introduces an additional layer of complexity and time pressure, making effective coordination and communication between teams essential to our success.

Given these constraints, our group must maintain a clear focus on the end goal throughout the project. We need to anticipate potential errors and be prepared to implement solutions swiftly to ensure that all contingencies are addressed. Any lapse in time management could jeopardize our ability to meet the project objectives, which could ultimately result in failure in the Senior Design course.

To mitigate these risks, our group plans to begin work as early as possible, allowing us the necessary time to adjust and refine our project as needed. By starting early, we aim to build in the flexibility required to adapt to unforeseen challenges and ensure that we meet all deadlines with a completed and functional project.

Economic

A major design constraint for our project were economic constraints. Through our list of goals and objectives for our drone project, it is no surprise that such a project with all the components would be very costly for college students. To begin, we must obtain a drone which can cost from hundreds to thousands of dollars just to invest in one drone for our project where our ideal plan is to have a drone and a base station covered. Following such, we also have other components from all the sensors to the cameras that are attached to the drones, the budget for our project would be incredibly high even if we want to stick to cheaper components. Luckily, our sponsor from Lockheed Martin is providing us a budget of $2000 to spend for this project, hence allowing us to choose the better components for assigned tasks.

Starting from our components list, our sensors that are being used for proximity detection are already costing around hundreds of dollars. One constant issue within our economic constraint for our project is that choosing the cheaper option would massively hinder our project’s performance since it would be downgrading its potential with cheaper components, thus we choose the best ones for our project, which leads to an increase in the price for the components that we choose for our drone. Following the proximity sensor comes the thermal cameras which is a big factor in terms of economic constraint. Thermal cameras are very costly and on average, they take over hundreds of dollars to buy and some more advanced ones come into the thousands range of price. While we did list multispectral imaging as an option for our project, those cameras are all over thousands of dollars whereas some thermal cameras are cheaper with lower specifications as they still are able to fulfill the duties of the thermal detection while being cheap enough to not harm our overall cost significantly.

Moving forward, the parts that we would choose next that impacts economic constraints were the regular cameras and communication. Regular cameras, depending on the type and specifications, can be extremely costly like thermal cameras. Ranging up to hundreds of dollars, the cameras can vary in their abilities and cheaper ones tend to be lacking in certain specifications, such as resolution, and thus lead to us choosing the more expensive and better cameras overall for our project. Another thing that is costly is the antenna that we would use for communication within the drones and the base station. Those can range up to hundreds of dollars as well, leading to another significant increase in the cost of our project.

Lastly, our project involves the microcontroller and batteries to support our various other components throughout the design. While microcontrollers are not that costly, depending on the specs of the device, it may cost a lot which affects our economic constraint. The batteries, while not so expensive, could lead to economic constraints due to the drone requiring lots of batteries as we would like the drones to maintain flight for a solid period of time before requiring recharge.

Overall, the economic constraints contribute to a good portion for our project as within the various components and parts of our drone and base station, the budget is already sitting in the hundreds range. The add up of all these devices and parts can easily sum our total cost to the thousands, especially since we are sticking to good components rather than cheaper ones that may lack the specifications to fulfill our goals and objectives with the project. If it were out of pocket money, we would be broke and could not afford such powerful components for this project, but luckily, our sponsor is providing us with a budget of $2000 and some components from their end, leading to our economic expenditures being a small amount.

Environmental

Environmental constraints play a significant role in our project, as we cannot ensure the real-world conditions for demonstrating the drone’s capabilities in search and rescue operations. Since it’s impractical to simulate an actual search and rescue mission with missing persons or hazardous situations during the demo, our project will serve as a proof of concept. We will be flying the drone within a controlled campus environment, and to demonstrate its ability, we must simulate realistic scenarios, such as detecting heat signatures or locating targets, without endangering people or property.

For example, instead of sending the drone into areas where search and rescue might take place, such as dense forests, collapsed buildings, or flooded areas, we will simulate these scenarios through artificial means. For thermal detection, we are not allowed to generate high-temperature sources or hazardous conditions. Therefore, we may use printed images or safe heat sources, such as heating elements, to simulate people or objects in need of rescue. Regardless of how we approach this situation, we are limited as we cannot replicate many of the said environments within our limited resources.

Another environmental constraint is that our demonstration will be performed in an academic setting, which differs from actual search and rescue environments. Our goal is to develop technology that could operate in challenging environments, such as disaster zones, dense forests, or mountainous terrain. While we are limited in replicating these conditions for the demo, our drone will need to demonstrate adaptability to complex environments, such as flight path adjustments, obstacle avoidance, and target detection, even within the limitations of a campus environment.

Additionally, our drone to base station communication systems might face interference from other electronic devices, research equipment, or Wi-Fi networks present on campus. In the intended application, the drone might face less interference in open or remote areas, but during the demonstration, we must account for these electromagnetic constraints. Therefore, our drone will require careful planning and possibly enhanced shielding or interference mitigation techniques.

Overall, environmental constraints shape our project significantly, as we cannot fully replicate the search and rescue conditions during the demonstration. However, by adapting to the controlled environment and simulating rescue scenarios, we aim to showcase the potential of our drone system while working within these limitations. Our project will be a proof of concept, demonstrating the drone’s capability to perform search and rescue operations using the resources available.

Remaining Constraints

Sustainability

Sustainability is a key constraint for this project, especially given the varying environmental conditions such as temperature, air quality, and electromagnetic interference. These factors affect the drone's durability and operational capability in search and rescue missions. In harsher conditions, such as extreme heat or cold, the drone will need enhanced protective measures to ensure it can operate effectively without interference or damage. This requires careful selection of parts that can withstand a wide temperature range and environmental stresses, ensuring the drone remains functional in intense scenarios typical of rescue operations.

Beyond environmental factors, sustainability also involves the components and materials chosen for the drone. This includes selecting efficient batteries and durable components that can handle the demands of an autonomous drone flying in search and rescue missions. Although the demonstration will occur in a controlled environment with less harsh conditions, the goal is to design the drone and controller for real-world applications. Therefore, ensuring the sustainability of the system for more challenging rescue operations is crucial.

While the controlled environment for demonstration is less demanding, sustainability will be more rigorously tested when the drone is deployed for its practical objective of rescuing individuals in difficult and unpredictable terrains. By optimizing the drone and base station controller designs and components selection, we aim to enhance the sustainability and longevity of the system for its intended purpose.

Ethics

Ethical constraints serve as a factor of where we source our parts from for our project as we do not want to obtain from companies or supplies that engage in unethical practices such as child labor or slavery. It is essential for us to avoid supporting companies that exploit these forms of labor in developing countries, especially balancing cost efficiency with ethical responsibility which our group wants to be aware of.

To address this, we have chosen to source parts from reputable suppliers with a strong commitment to ethical practices. Our project specifically relies on components from companies known for their fair labor standards, ensuring that we do not support exploitative labor conditions. This approach involved thorough research to confirm that all components meet our ethical standards, aligning our project with our values and ensuring we avoid any involvement in unfair labor practices to the best of our knowledge.

Health and Safety

Another important constraint regarding this project is health and safety. Since we are flying a drone for our project, we must ensure that our drone is safe and stable to test and fly around others, especially watching out for drone malfunctions during its autonomous flight scenarios. On the off chance that our drone may malfunction while flying around, if the drone crashes and damages other humans or property, we are liable for such damage and must account for such situations. We can mitigate this constraint by checking for surroundings and making sure it is safe before testing our drone flying around the area for testing or demonstration purposes.

Another part of this constraint that needs to be considered is the safety of the parts on the project. This applies heavily to the battery in the system as it may cause problems through explosions if not tested under the correct environment. All the components alongside the drone and base station can be immensely dangerous, especially during the situation of when the drone malfunctions and crashes, which can lead to bigger explosions that would be hazardous to the health and safety of the surrounding bystanders at the crash sight.

Lastly, the possible constraint for our project is securing appropriate drone insurance. Given the nature of our project, which involves flying a drone on university grounds to demonstrate its capability in search and rescue operations, it is essential to have comprehensive insurance coverage. This ensures protection against potential damages, liabilities, and accidents that could occur during flight operations. The University of Central Florida's guidelines mandate that we have insurance coverage to fly on campus, safeguarding against any unforeseen incidents. Additionally, our insurance policy must comply with FAA regulations and cover various scenarios, including equipment damage, third-party injuries, and property damage. By securing adequate insurance, we mitigate risks and ensure the project's continuity and safety, aligning with both university requirements and federal regulations.

Manufacturability

The final constraint that should be accounted for in our project is the manufacturability for such a complex project. For our group of undergraduate students, we are limited to the lab equipment that is offered by the University, which severely limits the productivity and manufacturing that we can put into this project. This constraint impacts our project as a whole since it keeps the overall design of our project simple to the point where it can be done and designed with the lab equipment.

One upside to this project is that our group does not have to be involved with the building and design of the drone and thus can purchase an already built drone for this project's purpose. On top of this, we can purchase all the other components and parts online and then piece them together to reduce the mechanical design aspects of this project and limit the amount of manufacturing involved within the mechanical parts of this project. On the other hand, the electrical components and parts of our project, such as the PCB, will require us to manufacture it with the lab equipment and ensure it is stable and desirable for our project, which is a factor in the manufacturability constraint. Due to our project not being manufactured in a factory setting, it is not intended for mass production and a prototype construction of our project will be made for proof of concept demonstration purposes and will be done so via whatever equipment is available in the lab offered by the University.

Chapter 5 - Comparison of ChatGPT with other Similar Platforms

AI is a powerful tool that's quickly transforming every industry, with ChatGPT emerging as the most popular AI engine. While ChatGPT, along with other platforms like Copilot and Gemini, can provide guidance for starting research on different topics, their answers can be misleading or inaccurate. Therefore, when using AI platforms as search engines, it is essential to remain cautious of the results produced and to verify them with more reliable resources. This chapter aims to compare the results of ChatGPT with the results of other platforms by asking them questions related to our project and evaluating how well their responses met our needs.

Case Study #1

Question: "What to consider when placing components onto a drone?"

In ChatGPT's case, it produced an output that signifies many important key aspects for our case study. ChatGPT responded with multiple factors for consideration when placing components on a drone. While ChatGPT may not cover every idealistic consideration, it has produced plenty of keypoints that we must take into consideration when designing our drone for this project. For the most part, ChatGPT produced the results that are not to waste as ChatGPT states the extremely important considerations for our project such as weight distribution and balance alongside the components placement on the drone. On the other hand, a similar platform in Copilot, when prompted with the same question, produced similar results as ChatGPT with small differences in the listing of traits to consider. Due to the nature of Copilot, it comes with three different options for how the user wants the response to be like. The setting options are creative, balanced, or precise when it comes to responses from Copilot. From our experience, the precise option from Copilot is the norm for when it comes to researching and looking up facts as it tends to generate well noted information. Copilot gave less options to consider when prompted with the same case question and most of Copilot's options were covered by ChatGPT's lists of traits to consider for this case study.

When it comes to other AI platforms that are similar to ChatGPT, Gemini is another choice that may provide research and useful data for the user. Gemini, in comparison to ChatGPT and Copilot for this case study question, provided a shorter list than both the platforms and appears to be a much weaker platform for researching purposes when compared to ChatGPT and Copilot. In terms of the AI platforms in comparison, Gemini is much newer than the other two, while still providing great materials when prompted with the right question. Overall, when it comes to this case study question, all the AI platforms provided similar responses with ChatGPT reining over the others as it provided more details and main points that should be accounted for.

Digging from our experiences when it comes to using such AI platforms for research with the case study, ChatGPT seems to be dominant as it has been around for longer than the other platforms used in comparison. It seems like ChatGPT is the superior option in this case since it is able to produce a bigger list for the user so that the user can be more informed from their prompt. On the other hand, Copilot may be optimal in cases where the user would like the source of the information as Copilot does browse the internet and links to the sources used in its response, which can be helpful in research scenarios. It is a struggle with Copilot as the free version has a prompt limit whereas ChatGPT does not concern itself with such issues in many cases. There are many upsides and downsides to these AI platforms and their abilities, as such, it is always advised to make sure the information provided is correct and not just straight up rely on the responses generated via these platforms. Generally, from an experience perspective, all these AI platforms have offered a great set of ideas and answers to various questions and concerns that have appeared throughout the journey of Senior Design.

Even when it comes to Senior Design assistance, the use of AI platforms has helped tremendously for research and learning how to do certain tasks and assembling the project. The use of AI platforms for Senior Design is almost treated like a google search in such a case as it will search through its database and find information to present back to the user.

When we are lost in any case, AI platforms are there to support and assist us with guidance, although not always reliable, it still is able to help us progress within our project.

Case Study #2

Question: "What safety considerations should I consider when selecting a battery for a drone controller?"

In exploring the selection of batteries for drone controllers, ensuring safety is paramount. ChatGPT, Copilot, and Gemini all provided responses that highlighted various safety considerations, although they differed in depth and structure. ChatGPT produced a comprehensive list of factors, while Copilot and Gemini offered shorter, more streamlined responses. Despite these differences, many of the key points were shared across the three platforms, reflecting the critical nature of specific battery safety measures when operating drones.

ChatGPT's response stood out due to its extensive coverage of the subject. The platform discussed ten key points, including: battery chemistry, the battery's capacity (mAh), discharge rate (C-rating), the inclusion of protection features such as short-circuit protection, battery quality/brand, charging considerations, cycle life, and storage.

Copilot's response, while shorter, touched on many of the same critical areas, particularly in terms of battery types and compatibility. The concise nature of Copilot's response may appeal to users looking for a quicker summary, but it did not provide as much technical depth as ChatGPT. Notably, Copilot's attention to discharge levels and short circuit prevention aligned with ChatGPT's recommendations, emphasizing the need for monitoring battery usage to avoid over-discharging and minimizing the risk of electrical hazards.

Gemini's response, the briefest of the three, repeated much of what ChatGPT and Copilot had covered, albeit in a more simplified format. It reiterated the significance of selecting the appropriate battery type, ensuring voltage and amperage compatibility, and following proper charging practices. Like the other platforms, Gemini stressed the importance of reputable brands and adherence to manufacturer recommendations. Despite the brevity, Gemini's response addressed the core concerns, such as battery protection features and safe storage practices, indicating a shared understanding of the risks involved in selecting a battery for drone controllers.

In comparing these three AI platforms, ChatGPT provided the most in-depth and technical guidance, making it an excellent resource for users seeking a comprehensive understanding of battery safety for drones. It explored the topic from various angles, offering insights into battery chemistry, performance considerations, and specific protection features that ensure safe operation. Copilot, on the other hand, was more succinct, focusing on high-level points without delving too deeply into technical specifics. This may be beneficial for users who prefer quick, actionable advice. Lastly, Gemini, while the most limited in scope, still captured the essential points and would suffice for users with more basic needs or familiarity with drone technology.

Ultimately, the safety considerations for selecting a battery for a drone controller are consistent across platforms, with key factors including battery type, voltage compatibility, discharge rates, charging practices, and proper storage. Each platform offers varying levels of detail, allowing users to choose the tool that best suits their needs. For more in-depth research and an exhaustive list of considerations, ChatGPT proves to be the strongest option, while Copilot and Gemini may serve well for users requiring a more straightforward, summarized approach. These AI platforms collectively provide a solid foundation for understanding the safety measures necessary when selecting batteries for drone controllers, which is critical for both performance and the prevention of accidents.

Case Study #3

Question: "What are some important parameters to consider when selecting sensors for a search and rescue drone?"

ChatGPT's response effectively addresses the critical parameters for selecting sensors for a search and rescue drone, balancing both technical and practical considerations. ChatGPT excelled in providing comprehensive coverage of the key parameters such as the environmental conditions, detection capabilities, and data processing. Each parameter was relevant to our project, and the inclusion of several sensor types helped clarify how different sensors could meet our needs. The mention of technical aspects like interfaces shows they are aware of potential integration challenges, and the section on cost also highlights the need to balance high-performance sensors with budget constraints.

However, while all the parameters it gave are relevant to our project, not all of them have the safe level of importance for our project. For example, the detection capabilities of the sensors and power consumption are arguably more crucial than latency or IP ratings. Their response could better prioritize the parameters based on applications. Additionally, their response could have been enriched by providing more detailed examples on how the sensors would be used in practical scenarios. Specific recommendations for acceptable thresholds for latency and field of view would also make their advice more commendable.

Overall, ChatGPT's response is well-structured and informative, particularly in providing actionable insights for sensor selection. With minor adjustment in prioritization and the inclusion of more practical examples, it would become an even more valuable and insightful tool.

Similarly, both Copilot and Gemini provided comprehensive and clear responses tailored to our specific needs. However, they too could have included more specific scenarios where particular sensors could be used as well as how they could integrate with other systems on the drone. This would make the guidance even more practical and applicable to real-world scenarios.

Using tools like ChatGPT, Copilot, and Gemini has proven to be highly beneficial for our project. Each provided detailed and tailored responses that help us reduce uncertainty and guide us through complex decisions. While all three excelled in offering comprehensive guidance, they could all improve by providing more specific, practical examples and deeper insights into how these components could be integrated into our final product. Still, these tools offer valuable advice that helped us shape our decision-making process, and with continued use, we could further refine our approach to selecting and integrating the best sensors for SPARROW's needs. Overall, they serve as excellent resources for technical consultation, but they should be used more as a starting point and not as the only source of information.

Case Study #4

Question: "What are some important things to consider when wanting to select wireless communication hardware and protocols?"

When it comes to selecting wireless communication hardware and protocols, various essential factors must be evaluated to ensure optimal system performance. ChatGPT offered a well-rounded bullet-point format that highlighted a range of considerations, including signal range, power efficiency, data transmission rates, and interference management. It emphasized not only the current capabilities of the chosen protocols but also their adaptability to future technological advancements, making scalability a key theme in its response. Furthermore, ChatGPT addressed potential hardware limitations and security protocols, providing practical advice for ensuring a robust communication system.

In comparing the responses from ChatGPT, Copilot, and Gemini, similarities emerge in their focus on core topics, although the presentation styles differ significantly. Copilot and Gemini share a more concise format, emphasizing key considerations such as range and energy consumption. However, Copilot stands out with its structured approach, using bold headers to highlight critical elements like data rates and compatibility with existing systems. This design helps users quickly identify essential areas of focus, though it tends to gloss over more nuanced aspects, such as security and the long-term implications of protocol selection.

Gemini's response, being the briefest of the three, touches on fundamental concepts such as choosing protocols based on environmental factors and basic interference resistance. While it provides a solid introduction to the topic, it lacks the depth and technical specifics found in ChatGPT and Copilot. Gemini's focus is more on providing a high-level understanding, making it suitable for users who require straightforward insights without extensive technical jargon.

ChatGPT's detailed perspective stands out as it encompasses a wide range of technical considerations, from frequency band options to interference management and security measures. What makes its response particularly valuable is the emphasis on the importance of long-term adaptability and the capacity for growth in communication protocols. ChatGPT discusses scalability in depth, ensuring that the chosen technology can evolve to meet future demands, and it raises awareness of legal and ethical implications—topics that are not prioritized as highly by the other AI models.

Copilot, while technical, organizes its information to emphasize actionable steps for implementation. Its focus on data quality and real-time processing efficiency is essential for users aiming to develop a reliable communication system. However, Copilot may overlook aspects like energy consumption or hardware limitations, which are critical for ensuring that the technology remains effective over time.

Gemini's straightforward approach simplifies the complexities of protocol selection, addressing core factors but not delving deeply into technical specifics. It serves as a good starting point for users needing basic guidance on wireless communication hardware, though it lacks the comprehensive analysis provided by ChatGPT.

Overall, when assessing the responses from all three AI models, ChatGPT emerges as the most comprehensive, addressing not only technical specifications but also practical concerns such as hardware constraints and adaptability to future challenges. Copilot provides a structured and practical overview, ideal for users looking for quick and actionable insights. Meanwhile, Gemini offers a basic introduction suitable for those with less technical knowledge or who seek a simplified understanding of the subject.

Each AI model contributes uniquely to the conversation. ChatGPT excels in providing a holistic view that considers both the software and hardware aspects of wireless communication. Copilot is particularly strong in delivering technical guidance that helps users navigate specific implementation steps. Gemini, with its simplified approach, is useful for those needing a quick reference. Depending on the user's needs and the stage of their project, these AI platforms offer varying degrees of insight and practicality, with ChatGPT standing out for its comprehensive coverage of both immediate and long-term considerations.

Case Study #5

Question: "What should the team consider when developing a detection algorithm?"

ChatGPT responded with a well rounded bullet point style that brought in a bunch of consideration when trying to build a detection model. ChatGPT responded with a list of factors that should be considered in how the detection algorithm will work and introduced concepts on how the algorithm should be able to grow and develop with time being most of its main points on this list. ChatGPT also considers the limitations of the battery and hardware constraints by giving advice on what should be done to have a well rounded algorithm. Furthermore, when comparing the AI responses from Copilot, Claude and ChatGPT there are similarities in the style of the output but the topics on each list from Copilot and Claude resemble each other more than ChatGPT's response. Copilot and Claude mentioned the importance of having a large dataset for the algorithm to be trustworthy and credible.

Continuing with the similarities in the Copilot and Claude the lists target the concept of training with appropriate datasets to allow for a capable detection model. The lists continue with a lot of similar concepts relating to performance metrics and features to possibly implement into the system. When looking into the different AI models like Copilot and Claude, you can see the differences in the style of writing with Claude and Copilot having similar list styles but Copilot bolds the concept of each bullet point to focus more on giving advice no matter how brief the idea was that was given to us by the AI.

ChatGPT approaches the task with a broad perspective, covering everything from accuracy and precision to hardware constraints and battery life. What stands out the most in ChatGPT's response is the focus on ensuring the algorithm is not only functional in the present but also adaptable for future challenges. ChatGPT brings up points like scalability, which ensures the algorithm can handle different environments and conditions over time, and adaptability, which introduces the idea of continuous learning from new data to improve performance. There's also a heavy emphasis on being aware of legal and ethical considerations, something the other AI models don't prioritize as much. The holistic nature of this response makes it ideal for a project that needs to take a lot of different factors into account.

On the other hand, Copilot provides a more structured and technical list, with a lot of focus on data quality, feature engineering, and evaluation metrics. It organizes the information in a way that emphasizes specific technical steps, with bold headers for each section that make it easy to see where attention should be directed. The focus here is on using high-quality and diverse data to ensure accuracy and on scalability and real-time processing, which are essential for handling large datasets efficiently. However, Copilot's list doesn't touch on hardware limitations or energy consumption as much as ChatGPT does, instead zeroing in on the core algorithm performance and user trust.

Claude seems to follow a similar technical route to Copilot, also emphasizing data quality, algorithm selection, and performance metrics. However, Claude takes things a step further by discussing class imbalance, adversarial attacks, and long-term maintenance like model versioning and updates, which shows that it's thinking about how the algorithm will function over the long haul. Claude also mentions the importance of domain expertise and incorporating expert knowledge into the algorithm's design, adding another layer of practical relevance. It seems to be focused on making sure the algorithm is robust and able to adapt to different types of threats or challenges that might arise in the future.

Overall, when comparing all three models, ChatGPT stands out by giving a more comprehensive view that includes real-world limitations like battery life and hardware constraints, making it suitable for a project where adaptability and scalability are key. Meanwhile, Copilot and Claude have more overlap in terms of focusing on data quality and technical precision, but Claude goes a bit deeper into the long-term deployment strategy and resilience to adversarial conditions.

Each AI model brings something different to the table. ChatGPT shines when it comes to giving a full picture, factoring in not only the algorithm itself but also the external factors that could impact its performance in the long run. Copilot is highly technical and focuses more on giving step-by-step guidance that's practical for building a solid detection algorithm from the ground up. Claude offers a mix of technical expertise with a forward-looking approach, preparing the algorithm for challenges it may face after deployment. Depending on what stage of the project you're in and what you need, each of these AI models offers unique insights that can guide the development process. But for a project that's focused on longevity and real-world application, ChatGPT's response seems to cover the most ground by considering both software and hardware elements, as well as adaptability over time.

Case Study #6

Question: "How should we live demonstrate human detection via both camera and thermal camera from a drone?"

When prompted with such a question, ChatGPT responded with a guide to setting up the situation alongside the demonstration process throughout the live demo and gave us examples on how to execute the AI detection. From what it seems, ChatGPT provides solid guidance on how we can demonstrate the human detection algorithm and software during the live demo of the project. While ChatGPT made some assumptions in our project, for the most part, it provided solid guidance and steps for our purpose.

On the other hand, Copilot's approach was somewhat different from ChatGPT as rather than making certain assumptions of the products and technologies that we were going to be using for our project, Copilot made some suggestions of products and technologies that we could use for this situation alongside providing similar guidance towards ChatGPT. Similar to other experiences, Copilot instantly provides where it obtains the information that it is providing for the prompt. However, the significant improvement of Copilot comes from the suggestion of ThermalYOLO which we learned that we can use to help our project train for thermal camera robot vision. While this is very similar to YOLO for training the regular camera, it is still something that ChatGPT did not suggest which shows that Copilot has an advantage for this case as Copilot gave a better guide towards the right direction for our project.

Moving onto the next AI platform, Gemini gave a similar response to ChatGPT where the guidance has the core ideas from equipment setup to flight planning to the demonstration stage. When compared to the other two AI platforms, Gemini gave a whole step on camera calibration which indicates that this platform watches out for specific equipment preparation. Where Gemini differs from ChatGPT and Copilot comes from the part where Gemini did not provide any example products or technologies that we can use when prompted this question. Gemini only gave the generic steps and assumed that we have the products and technologies chosen and selected, hence only continued forward with telling us to continue with whatever those were rather than giving any suggestions towards products and technologies for the project. The other difference coming from Gemini is that Gemini provided some factors and considerations that we should take into account for the project demonstration such as environmental, ethical, lighting conditions and real-world scenarios. While ChatGPT and Copilot did not provide as many factors and considerations that we should factor in, all three AI platforms provided the general steps outlined for guidance towards our project demonstration.

Overall, all three AI platforms were able to provide significant guidance towards the steps for us to live-demonstrate our project's functionality. Each of the AI platforms has its own positives and downs. From our experience, the AI platforms provide significant advice for Senior Design as with the prompts and questions provided for the AI platforms, they are able to provide guidance that would significantly help the progress of Senior Design and our learning throughout doing this project. For this case solely, the use of AI platforms were able to give us direction and guidance towards significant preparation for our final demo of our project as it provided various guidelines and examples towards making a successful demonstration of our project. At the end of the day, the AI platforms are not always 100% accurate as they can provide responses with mistakes within them, hence we always have to be careful with the AI responses and verify them to make sure that the responses are trustworthy and reliable for our project.

Chapter 6 - Hardware Design

As we approach SPARROW's hardware design, it's important to review how each component is going to be connected to ensure seamless integration and functionality. Each component in SPARROW's base station has requirements that need to be met. The main concerns for our project include power requirements and signal compatibility. Ensuring proper connections between these components is essential to maintaining an efficient, well-functioning system that supports the overall goals and objectives of the project.

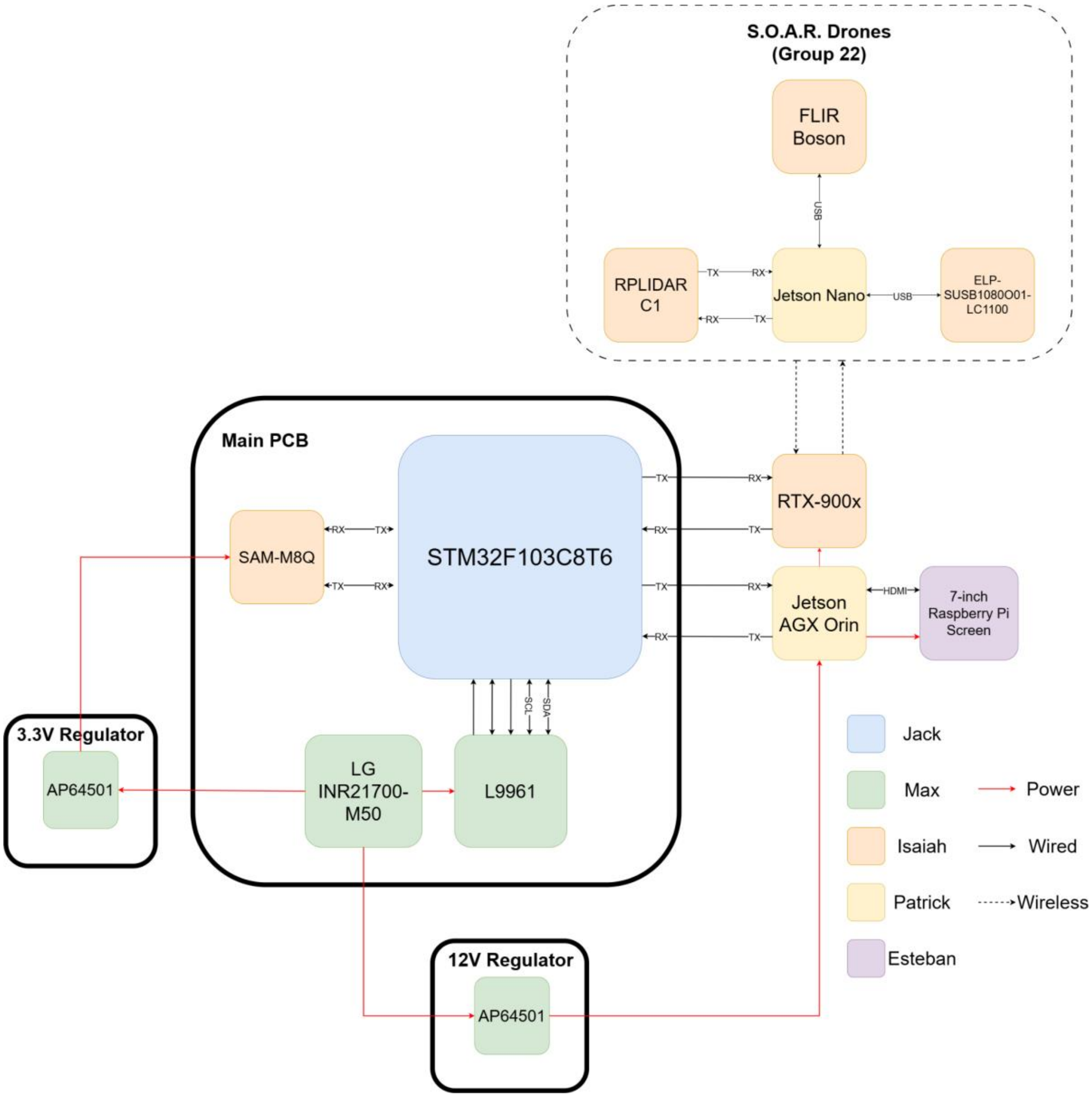


Figure 6.1. *Hardware Diagram*
By Authors

GPS

The SAM-M8Q GPS module is integrated onto the main board, which simplifies its connection to the PCB by requiring minimal external circuitry. The module is powered through VCC, VCCIO, and V_BCKP, with V_BCKP tied to the battery, ensuring continuous power.

For communication, the GPS module will interface with the STM32 using the UART interface. Since these UART lines are cross-coupled, the RX pin on the GPS connects to the TX pin on the STM32 and the TX pin on the GPS connects to the RX pin on the STM32.

Since I2C communication is not used, the SDA and SCL pins are left unconnected. Similarly, The TIMEPULSE pin is unused as an external timing reference isn't necessary, and the SAFEBOOT and EXTINT pins are not connected due to their lack of relevance.

A reset is not needed, as the GPS will be used since power up, so the reset pin is configured with a pull-up resistor to 3.3V since it is active low. Additionally, an LED is connected to the 3.3V power supply rail as a clear visual indication that the GPS is powered on and should be functioning correctly.

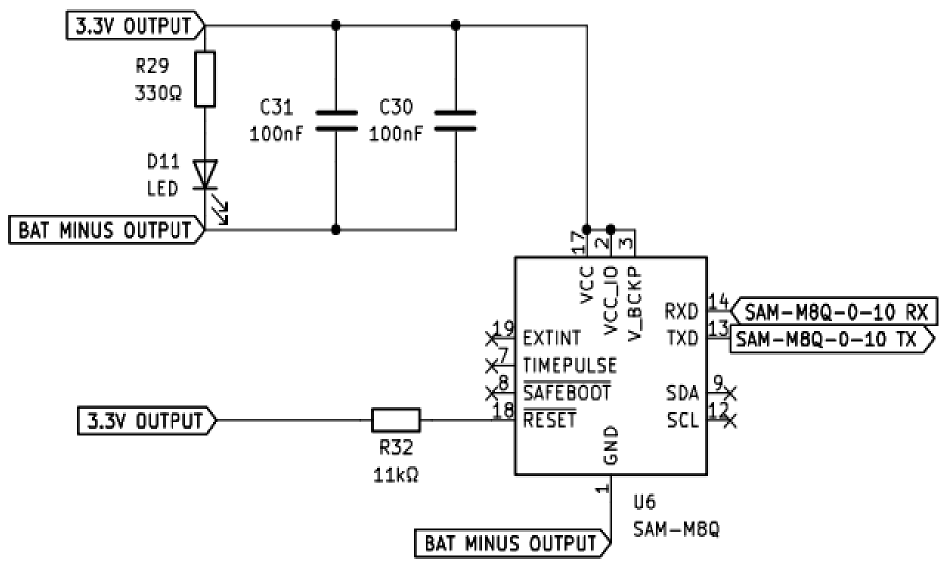


Figure 6.2. *GPS Pinout*
By Authors

Modem

To interface with the Jetson AGX Orin Developer Kit, the RFD-900x modem utilizes UART communication, along with the RTS and CTS lines to indicate when it is requesting data to send (RTS) or clearing data to send (CTS). The RTS line on the modem indicates when it is ready to send data, while the CTS line signals when it is clear to receive data. These lines are cross-coupled, so pin 11 (CTS) of the modem connects to pin 11 (RTS) on the Orin, and pin 3 (RTS) of the modem connects to pin 36 (CTS) on the Orin.

Similarly, the Tx (Transmit) and Rx (Receive) lines follow this same cross-coupling principle. Pin 9 (TX) on the modem is connected to pin 10 (RX) on the Orin, and pin 7 (RX) on the modem is connected to pin 8 (TX) on the Orin. This arrangement ensures seamless data transfer between the modem and the Orin.

To power the RFD-900x modem, a stable 5 V DC supply is required. To monitor the power status, an LED is connected to the 5 V supply rail to provide a visual indication as to whether or not the modem is receiving any power. This setup helps ensure straightforward status monitoring during operation.

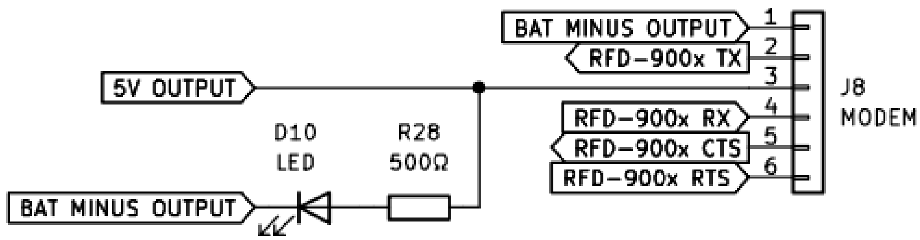


Figure 6.3. *Modem Connections*
By Authors

Processors

The STM32F103C8T6 microcontroller is used to drive the power supply unit in our system, managing its operation and communication with peripheral devices. To provide a clear visual indication that our MCU is powered on, an LED is connected to its 3.3 V power rail, which should illuminate when power is supplied. Additionally, a reset button is tied to the NRST pin.

To communicate with our Battery Management System, a L9961, we utilize I2C to exchange battery-related data to the MCU. In addition to I2C communication, the BMS uses three dedicated GPIO pins to relay critical battery status information, such as charge levels, temperature, and fault conditions, directly to the STM32. These connections provide direct monitoring, enhancing the safety and reliability of our system.

To program the STM32F103C8T6 microcontroller, an STLink programmer is used to establish a connection. The STlink dongle is plugged into a USB-A port on a computer, while its header pins are connected to the appropriate pins on the STM32F103C8T6.

This communication is set up by linking the communication lines between the two devices. SWDIO on the STLink is connected to pin 34 (SWDIO) on the STM32F103C8T6, and SWCLK on the STlink device is connected to pin 37 (SWCLK) on the microcontroller. These connections use the Serial Wire Debug (SWD) interface to facilitate programming and debugging.

We then supply power to the STM32F103C8T6 by connecting a 3.3 V DC supply to pin 8 on the STLink and grounding pin 4. This ensures that the microcontroller receives sufficient power during the programming process.

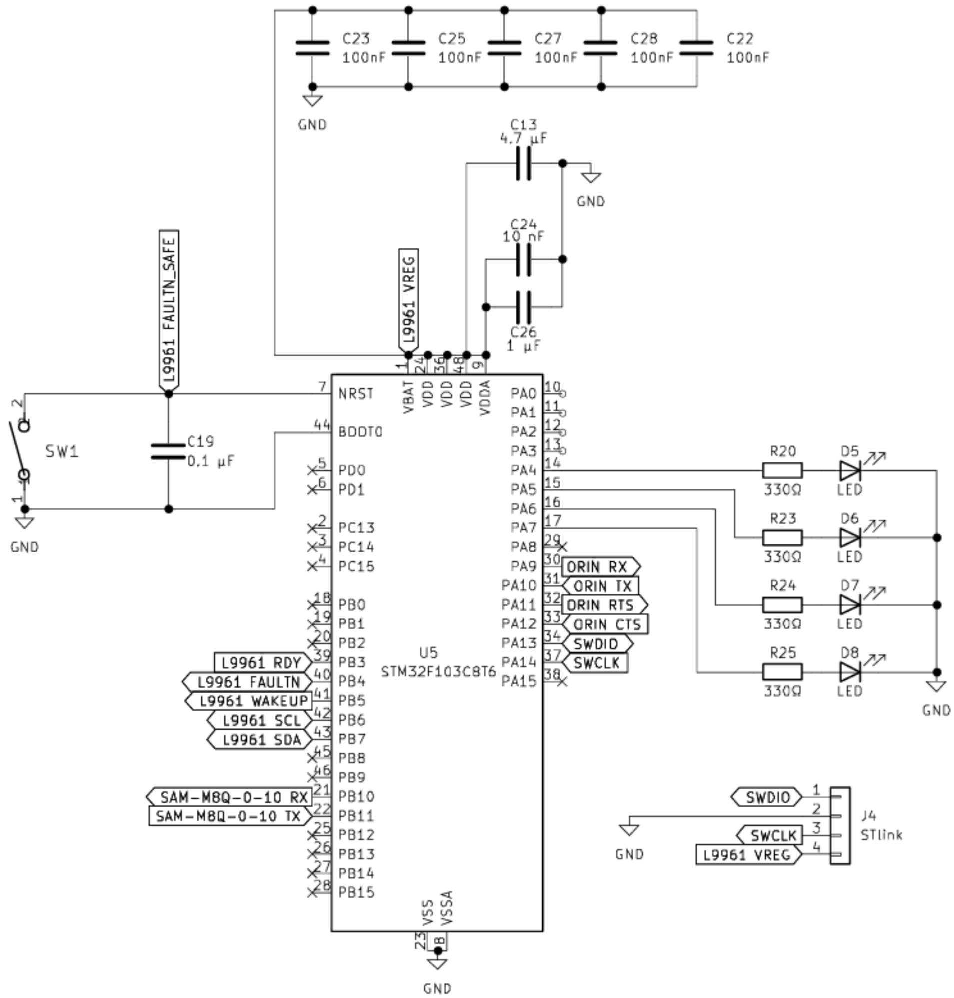


Figure 6.4. *STM32F103C8T6 Pinout*
By Authors

To relay information from our STM32 to the Jetson AGX Orin Developer Kit, we use the UART interface, which is accessed through the Orin's 40-pin expansion header.

To utilize the expansion header, a 5-pin header is used, providing the proper input to the appropriate pins, while leaving the pins we don't use unconnected.

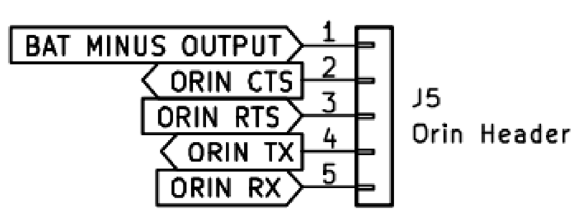


Figure 6.5. Jetson AGX Orin Developer Kit Header Connections
By Authors

Additionally, to power the Jetson AGX Orin Developer Kit we use a barrel jack, delivering a reliable 12 volt supply for efficient and stable operation.

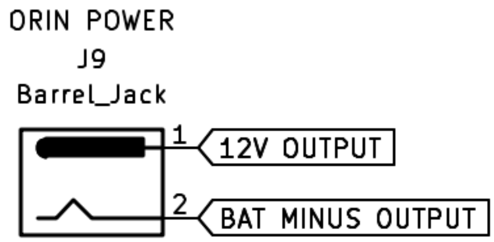


Figure 6.6. *Jetson AGX Orin Developer Kit Power Connections*
By Authors

Battery Management System

To ensure the system operates continuously for at least two hours under normal load conditions, including when the Jetson AGX Orin developer kit is running in its 30 W power mode, the battery array must provide approximately 82 W of power. This requirement is met using five lithium-ion batteries, each supplying 18.2 W, for a total combined output of 91 W, ensuring a sufficient power margin to support stable operation.

The L9961 is a Battery Management System (BMS) designed to regulate and protect the lithium-ion battery array. It offers critical functionalities such as overvoltage, undervoltage, overcurrent, and temperature protection, ensuring the safety and reliability of the power system. Additionally, the L9961 monitors these parameters and communicates them to the processor, specifically the STM32F103C8T6, to facilitate dynamic system control and diagnostics.

One of the L9961's notable features is its ability to perform passive cell balancing. It achieves this by discharging individual battery cells through its Cx pins, which helps maintain uniform voltage levels across the cells and extends the lifespan of the battery array. Furthermore, the VREG pin powers the processor and is connected to an LED indicator, providing a visual confirmation that the processor is receiving power.

Several key pins enable the integration of the L9961 within the system:

- **RDY Pin**: Signals the system's microcontroller unit (MCU) when new data is ready to be processed.
- **FAULTN_SAFE Pin**: Connects to the MCU's reset pin (active low) via an open-drain output, preventing overvoltage conditions and ensuring system safety.
- **SDA Pin**: Facilitates bidirectional data transfer as part of the I2C communication protocol, clocked by the master unit of the bus.

- **SCL Pin**: Receives clock signals from the I2C master unit, ensuring synchronized communication.
- **WAKEUP Pin**: Attached to a push button, allowing the L9961 to transition from standby mode to active operation as needed.

These integrated functions and connections enable the L9961 to efficiently manage the power output of the five cell lithium-ion battery array, maintaining system reliability and safety.

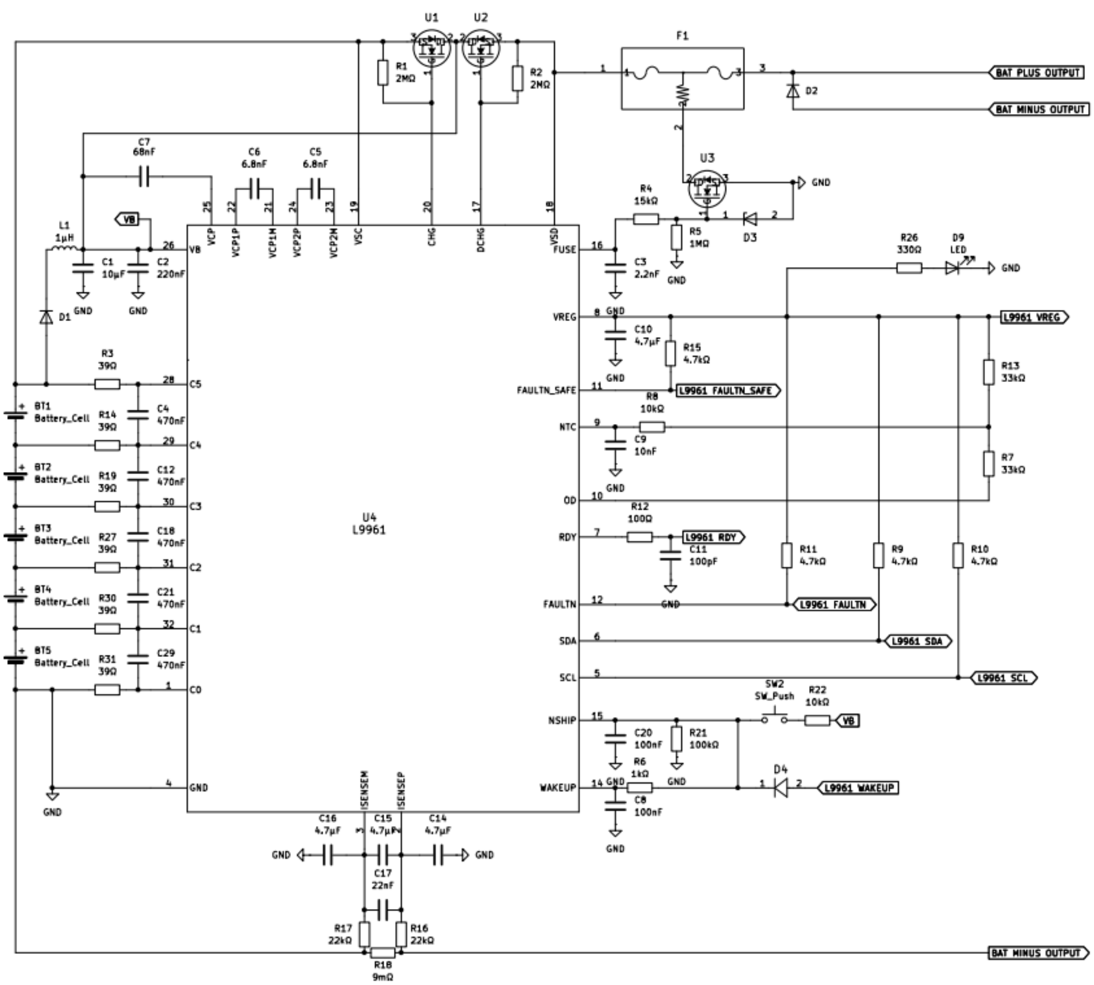


Figure 6.7. *Battery Management System Pinout*
By Authors

3.3 V Buck Voltage Regulator

The AP64501 is a high-efficiency, synchronous step-down DC-DC switching voltage regulator designed to convert the voltage from the lithium-ion battery array on the controller, which can range from 12.5 - 21 V, to a stable 3.3 V output. The circuit schematic for this design follows the typical application circuit provided in the AP64501 datasheet.

To monitor the board's status, an LED is connected to the 3.3 V output, serving as a visual indicator that the board is actively powered and the power inductor set to the appropriate value (3.3 μH).

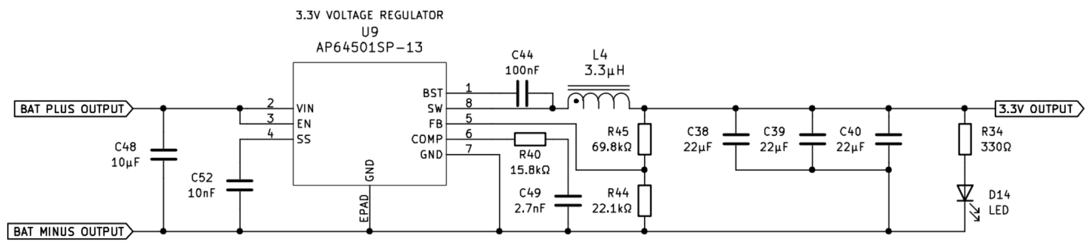


Figure 6.8. *3.3 V Buck Voltage Regulator Schematic*
By Authors

12 V Buck Voltage Regulator

Similarly to the 3.3 V buck voltage regulator, the 12 V buck voltage regulator utilizes the AP64501, converting the voltage from the lithium-ion battery array to a stable 12 V output for the Jetson AGX Orin. It has the same design considerations as the 3.3 V Buck voltage regulator, including an LED to indicate if the regulator is providing power and the power inductor set to the appropriate value (6.8 μH).

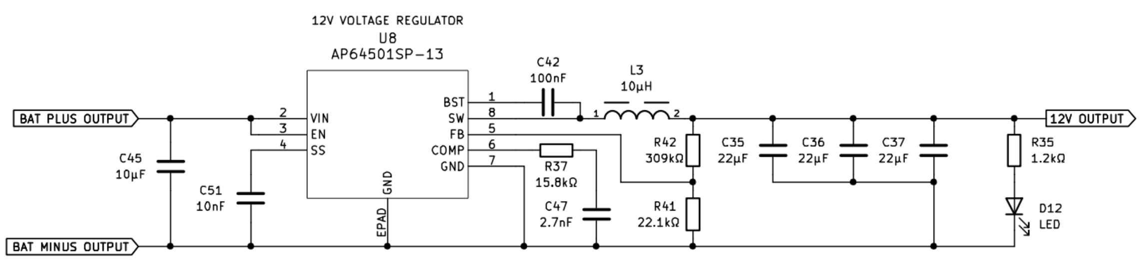


Figure 6.9. *12 V Buck Voltage Regulator Schematic*
By Authors

Chapter 7 - Software Design

The software architecture for our drone communication employs a decentralized approach where the drone operates as an independent node, capable of communicating with the base station controller. The command center acts as a monitoring hub, processing incoming data and dispatching additional instructions when necessary.

This decentralized approach is essential to ensure robustness and scalability. By allowing each drone to function independently, the swarm can continue operating even if individual drones encounter issues such as communication failures or mechanical breakdowns. The mesh network enhances this resilience by enabling drones to dynamically adjust their routes, share information in real-time, and distribute tasks efficiently across the entire swarm. This prevents the system from relying on a single point of failure and ensures continued operation in challenging environments such as remote areas or disaster zones where traditional communication infrastructure might be unavailable or damaged.

The software design is focused on maximizing the flexibility of the drone swarm. Each drone is capable of local decision-making, allowing it to respond to immediate environmental changes—such as obstacles, weather conditions, or new areas of interest—without waiting for direct instructions from the command center. This autonomy not only reduces latency in the search and rescue process but also optimizes resource allocation, as drones can collaborate and adjust their roles based on their current status, such as battery life or sensor performance. To further support operational effectiveness, the command center plays a critical role in monitoring overall swarm behavior, analyzing collected data, and providing strategic guidance as needed. While the drones autonomously handle local coordination and task execution, the command center can intervene with high-level commands, such as adjusting search patterns based on updated survivor reports or reassigning drones to high-priority areas. This balance between drone autonomy and centralized oversight provides a highly adaptable system that can respond quickly to both real-time events and broader mission objectives.

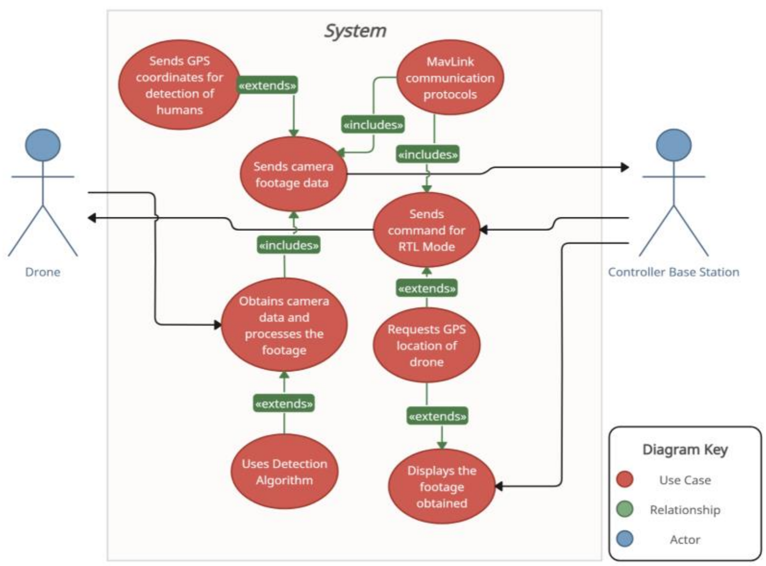


Figure 7.1. *Software Use Case Diagram by Authors*

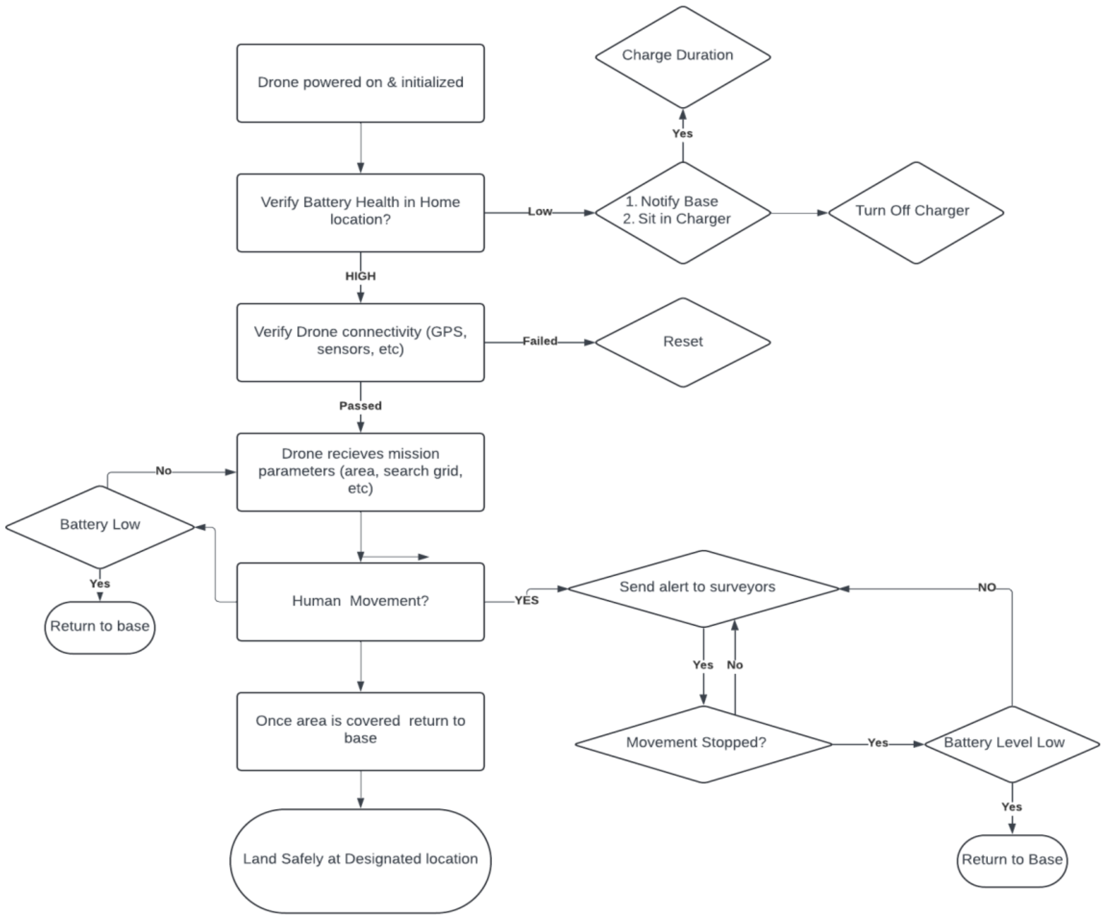


Figure 7.2. *Software Activity Diagram by Authors*

Failsafe Features

The software includes built-in failsafe mechanics to handle potential errors in the field. For instance, if a drone detects low battery, it will autonomously return to a designated location which will most likely always be the control station. While detecting low battery and migrating back to the designated location the tasks will be transferring its assigned tasks to nearby drones. In the event of a communication failure, the drone will enter failsafe mode and try to land at its place before enabling another action to be done. It would usually require a reboot to the drone system in the event of a failsafe activation.

The software includes built-in failsafe mechanics to handle potential errors from the base station. For example, when a drone's battery level reaches a critical threshold, the base station sends a return-to-base command. This command is only triggered if the remaining battery life is sufficient to ensure a safe return. If battery levels fall below this safety margin, the base station sends a low-power hover command, guiding the drone to a nearby safe landing site until assistance arrives. Another failsafe aspect of the software is that

ArduPilot comes with built in failsafe during flight mode where if the signal is bad or detected to be detrimental, the drone would go into failsafe mode where it would try to land itself down wherever it is and be stopped from flying while Mission Planner would display the error or cause of the failsafe to be enacted, such as bad GPS signal or bad compass signals, which are important data required for the flight of the drone as without them, the drone would not be able to function as intended for its purpose.

Additionally, if a drone crashes or becomes immobile, the base station immediately sends a pin-location command, marking the drone's last known GPS coordinates for retrieval. To maintain effective communication, the base station sends periodic heartbeat signals to check drone connectivity and status. It can also issue an altitude adjustment command in response to sudden terrain changes, ensuring the drone adapts to environmental conditions. While most of the drone commands can be issued by the user, the drones are intended to be flying autonomously and the waypoints and destinations are to be set by the user onto the flight controller before the drone would take off and execute the mission. By centralizing these controls, the base station enhances both operational safety and the reliability of search missions.

ArduPilot Mission Planner

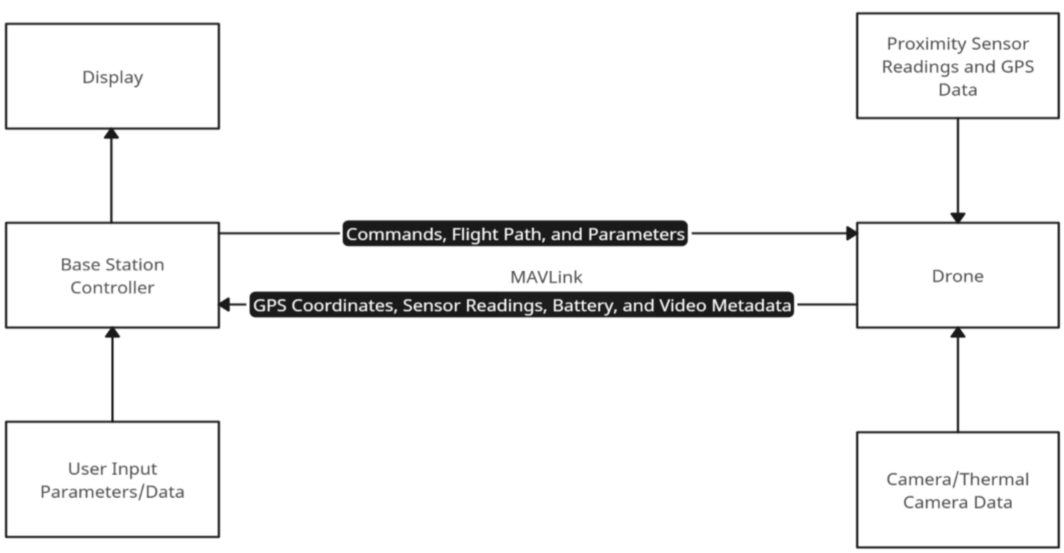


Figure 7.3. *ArduPilot Mission Planner Flowchart by Authors*

This ArduPilot Mission Planner depicts the interactions between the base station controller, drone, and various data input/output elements during a typical mission. At the core of the system, the base station controller processes user inputs such as flight path commands and parameters, transmitting them to the drone via MAVLink. The base station also gathers crucial feedback from the drone, such as GPS coordinates, sensor readings, battery status, and video metadata. This data is displayed for the operator's monitoring and decision-making purposes.

On the drone side, key systems like proximity sensors, and cameras (including thermal cameras) feed real-time data into the control loop. The proximity sensors help with collision avoidance and path adjustments, while the camera provides critical visual or thermal feedback, especially important in search and rescue missions. The drone uses this data to make decisions on-the-fly, such as avoiding obstacles while following the mission parameters set by the base station. The feedback loop between the base station and the drone ensures that commands are executed correctly and that real-time information is continuously relayed back for human or AI-driven adjustments. In essence, the ArduPilot Mission Planner allows for a clean interface between the drone and the base station controller as it sets up the communication between the and engages with the planning of flight for autonomous flights if need be.

For both the drone and the base station connecting via MAVLink, rather than trying to set up the scripts to directly read and feed MAVLink data packets through the ports, the alternative was the use of MAVProxy which is a MAVLink routing protocol that comes with the usage of ArduPilot. MAVProxy allows the inputs of master and out devices to set which devices are the inputs and which are the outputs of the routing such that the drone data can be routed accordingly to the modem where the data is sent over to the base station before having MAVProxy route the data to Mission Planner and another port listening for image transmission data.

Computer Vision

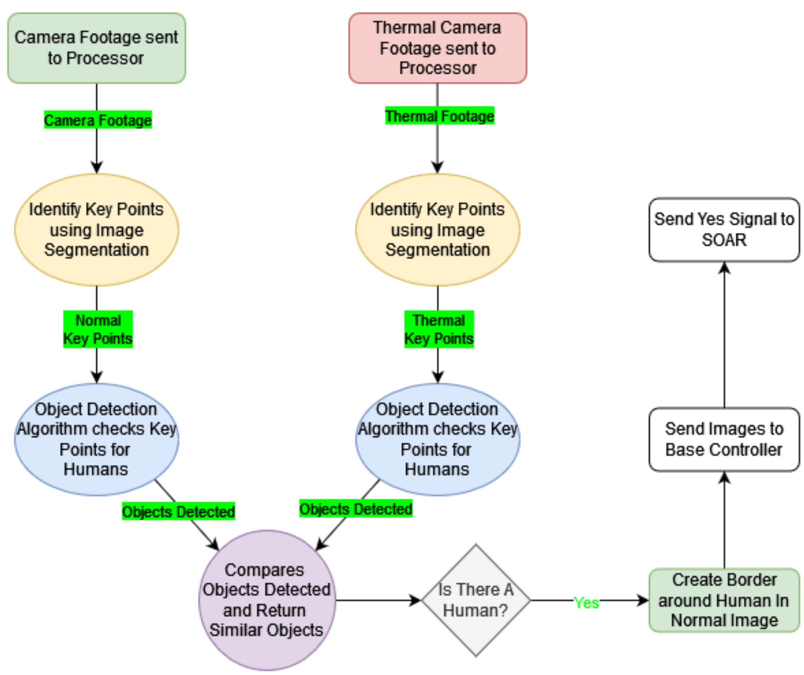


Figure 7.4. *Computer Vision Human Detection Flowchart*
By Authors

Each drone is equipped with multiple sensors, including infrared and visual cameras, which feed data into onboard processing units. A custom algorithm processes this stat in real-time, scanning for heat signatures or movement that could indicate the presence of somebody. Once someone is detected, the drone captures the GPS coordinates and relays this information to nearby drones and command center for verification.

In designing software for computer vision-based human detection for drones using OpenCV, the process can be broken down into a series of image processing and object detection tasks that work in tandem to identify humans in both normal and thermal footage. First, the drone's onboard camera and thermal camera capture footage and send it to a processor, where OpenCV image segmentation techniques identify key points, distinguishing relevant features in each frame. This segmented data aids in distinguishing potential human shapes based on unique patterns in the thermal and normal footage. Using a YOLO (You Only Look Once) model, which is efficient for real-time object detection, the software examines these key points to detect objects resembling human forms. The model’s architecture allows the software to classify these shapes quickly, aiding in the identification of possible human entities in both normal and thermal images.

Once objects are detected in both types of footage, the software proceeds to compare the identified objects to confirm the presence of humans. By comparing corresponding objects in the thermal and normal images, the system enhances the detection accuracy, reducing false positives. If the software identifies an object as a human, it draws a border around the detected human in the normal footage for visual confirmation and sends this information to the base controller. This detection also triggers a "Yes" signal to the SOAR system, enabling the drone to respond appropriately. This multi-step process ensures that the human detection algorithm remains accurate and responsive, making it a reliable solution for search-and-rescue operations.

Model Training

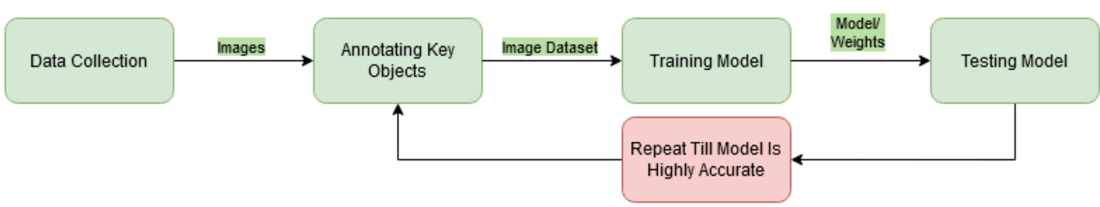


Figure 7.5. *Model Training Process Diagram*
By Authors

Training a YOLO model using PyTorch is pivotal for creating an AI system that caters to the niche requirement of human detection from a bird's-eye perspective, as pre-existing models may not adequately address such specific use cases. PyTorch offers a comprehensive framework for constructing and fine-tuning neural networks, enabling the customization of model architectures to meet unique project demands. This framework is instrumental for defining neural network layers, optimizing the model using hyperparameters such as learning rates, batch sizes, and weight decay, and ensuring smooth model training, validation, and exportation for deployment.

The process begins with data collection, gathering a diverse set of bird's-eye-view images containing humans. These images serve as the foundation for building a robust AI system. Next, the dataset undergoes annotation, where key objects such as humans are labeled. Annotation tools are employed to create bounding boxes around people, producing an image dataset that can be utilized for training.

Once annotated, the dataset is fed into PyTorch for training the YOLO model. Data augmentation plays a critical role in this step, transforming the images through operations such as scaling, rotation, flipping, and color adjustments. These augmentations simulate real-world variations, enhancing the model's ability to generalize across diverse scenarios and lighting conditions. Hyperparameter tuning is then employed to optimize the model’s performance. Parameters like learning rate determine the step size in updating model weights, while batch size impacts memory utilization and training speed. The training loop involves iterative backpropagation and optimization, guided by loss functions such as Mean Squared Error for localization and Cross-Entropy Loss for classification.

Validation is a critical intermediate step that ensures the model is performing effectively on unseen data. Metrics such as precision which is how accurate the detected humans are, recall which is how many humans are detected compared to the total present, and mean Average Precision are used to evaluate the model’s accuracy and identify areas requiring improvement. Based on these insights, iterative refinement of the model is conducted, as indicated in the diagram's feedback loop.

Once the YOLO model achieves a satisfactory level of accuracy, its weights are exported for deployment. OpenCV, which specializes in real-time computer vision tasks, plays a crucial role in this phase. The trained model is integrated into an OpenCV pipeline, enabling the detection of humans in live video feeds or new image data. Unlike PyTorch, which is used for model training, OpenCV facilitates inference by leveraging the pre-trained YOLO weights to perform tasks like object detection and bounding box overlay in real-time.

The final step involves rigorous testing of the integrated system in various real-world scenarios, including crowded areas, low-light environments, or occlusions. Insights from this field testing may prompt further refinement of the dataset, model architecture, or augmentation techniques, completing the cycle illustrated in the diagram. Through this iterative process, the AI system becomes highly accurate and adaptable to its intended application.

Since creating a fully annotated, real-world dataset from scratch was both time-consuming and resource-intensive, we opted to use three publicly available, high-quality datasets: RGBTDronePerson, AU-AIR, and FLIR ADAS. Each dataset brought unique strengths to our training pipeline, contributing to the performance improvements seen in our final models.

The RGBTDronePerson dataset was particularly valuable due to its dual-spectrum approach. It features both RGB and thermal images captured from drones in aerial perspectives. This matched the intended application of our model and allowed us to train on the specific angles and environments we expected during deployment. Its single-class annotation for humans simplified the task and helped improve precision in thermal detection.

The AU-AIR dataset was chosen for RGB model training. It provides a diverse set of RGB images from drone footage with annotated pedestrians and vehicles across varying altitudes, backgrounds, and lighting conditions. This dataset was critical in teaching the model to generalize, especially since our own test environment had different terrain and elevation compared to the training footage. It also allowed us to benchmark early progress with a more standardized dataset.

Finally, we used the FLIR ADAS dataset to train and validate our thermal model further. Collected from a vehicle-mounted camera system, FLIR provided thousands of annotated thermal images with real-world lighting scenarios and occlusions. This dataset was instrumental in achieving high mAP scores during validation — reaching up to 99.5% in some cases — and served as an excellent source of variation in thermal pedestrian detection. Although it was not captured from drones, the realism and variety of the dataset helped improve the robustness of the thermal detection system when tested on actual campus drone footage.

By combining these datasets, we were able to create a model that was not only trained on drone perspectives but also exposed to a broad spectrum of environments, lighting, and human behaviors. This fusion of datasets significantly improved generalization and was a key factor in raising our test mAP from just 7% to 60%.

Chapter 8 - System Fabrication/Prototype Construction

8.1 PCB

The controller PCB was designed in KiCAD 9.0, a versatile open-source software suite that allows for detailed schematic capture and PCB layout. The design prioritized both reliability and simplicity, opting for a 2-layer stackup that met the project's requirements without unnecessary complexity. The top layer was dedicated to signal routing, ensuring clear and efficient pathways for communication, while the bottom layer served as a continuous ground plane to improve signal integrity and minimize electrical noise. Careful consideration was given to trace widths and via sizes to accommodate expected current loads, particularly for the high-power input and connections to voltage regulators, ensuring stable power delivery throughout the board.

Special attention was paid to the placement of sensitive components, such as analog sensors, which were positioned away from high-frequency switching elements like inductors to prevent interference. To further reduce the impact of noise, ground vias were strategically placed around switching components to create an effective shield against crosstalk. Additionally, test points were incorporated into key signal lines, such as I2C, to facilitate debugging and testing.

Four holes were added for mounting the PCB to the housing enclosure and all of the connectors for the components powered by the PCB are put on the edge of the board so that they may easily be connected. The controller PCB is populated manually. This process involved applying solder paste using a stencil, placing the components, and then reflowing them in an oven or using a heat gun. To prevent moisture or electrostatic discharge from affecting the components, all parts were stored in electrostatic bags prior to assembly.

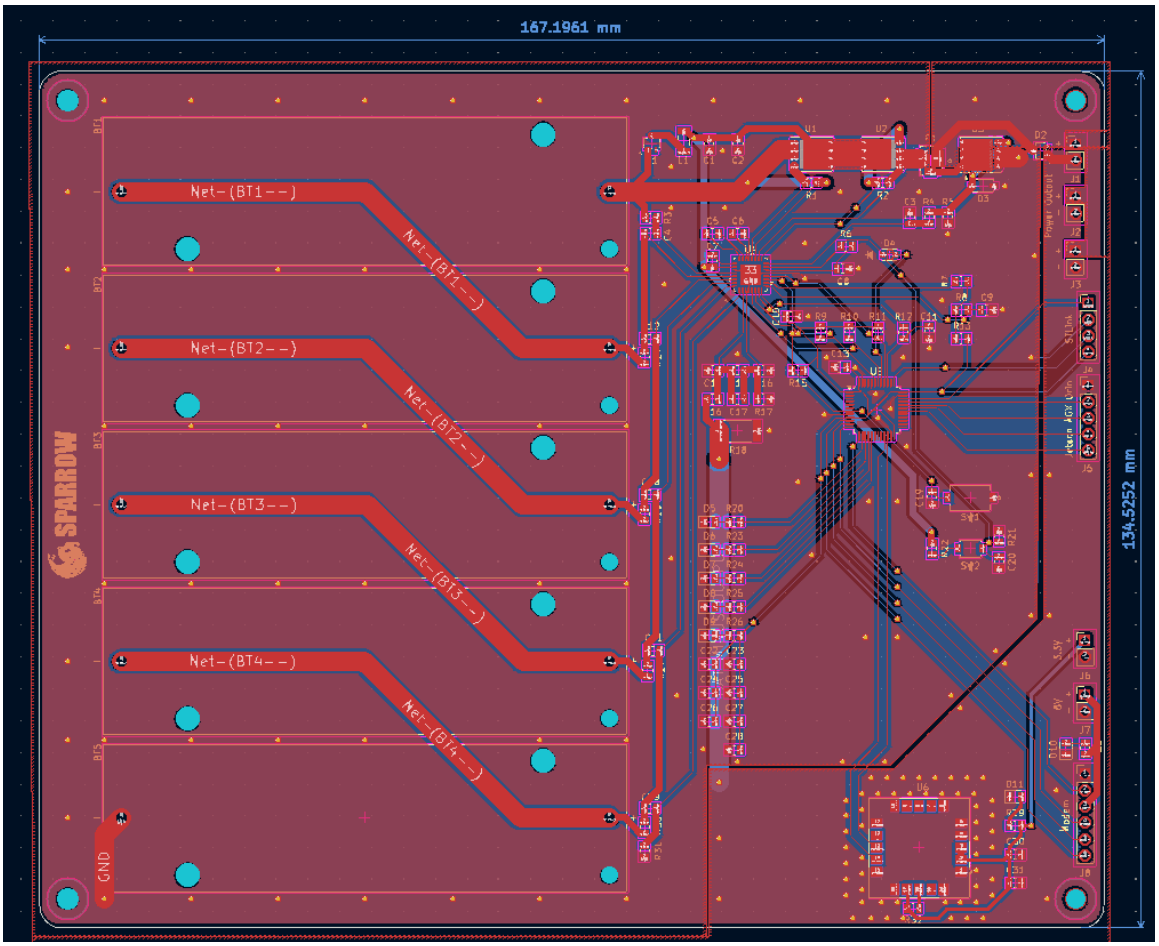


Figure 8.1. *BMS Rev.2 Board Diagram*
by Authors

For each voltage regulator, the recommended board layout provided by the datasheet was used. This was to ensure optimal thermal performance, electrical stability, and minimal output ripple. By closely following the manufacturer’s layout guidelines—especially for critical components like inductors, input/output capacitors, and feedback resistors—we were able to achieve consistent voltage regulation and efficient power conversion.

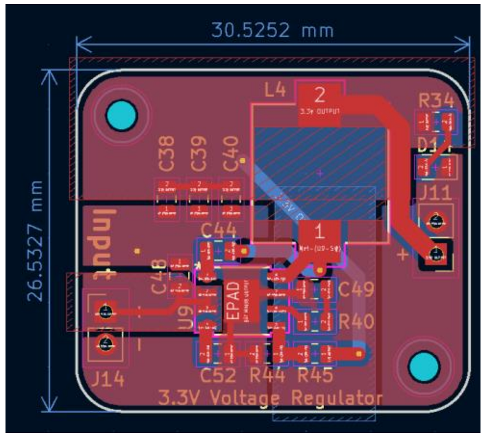


Figure 8.2. *3.3 V Voltage Regulator Rev.2 Board Diagram by Authors*

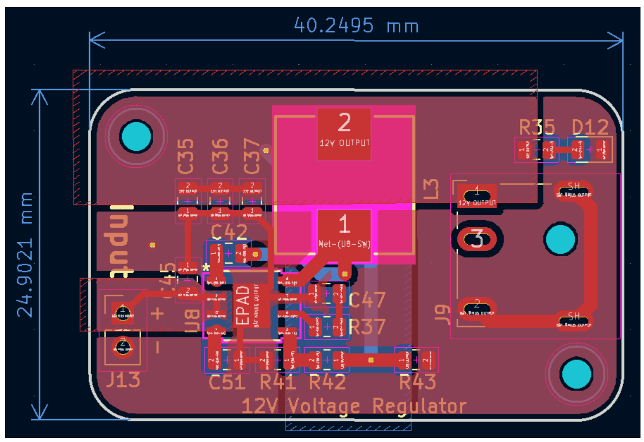


Figure 8.3. *12 V Voltage Regulator Rev.2 Board Diagram by Authors*

8.2 Enclosure

To securely house and transport all the key components of the system—including the PCB, Jetson AGX Orin developer kit, modem, and display—we designed a briefcase-style enclosure. This choice was made with portability and ease of deployment in mind, allowing users to move the entire station conveniently from one location to another. The enclosure consists of two halves, each lined with one inch of foam padding to protect the internal components from shocks and vibrations during transit. Additionally, a ¼-inch thick wooden panel will be mounted inside each half of the case, serving as a rigid base to which the PCB and display can be securely fastened. This layered design ensures both protection and organization of the components, making the system robust and ready for field use.

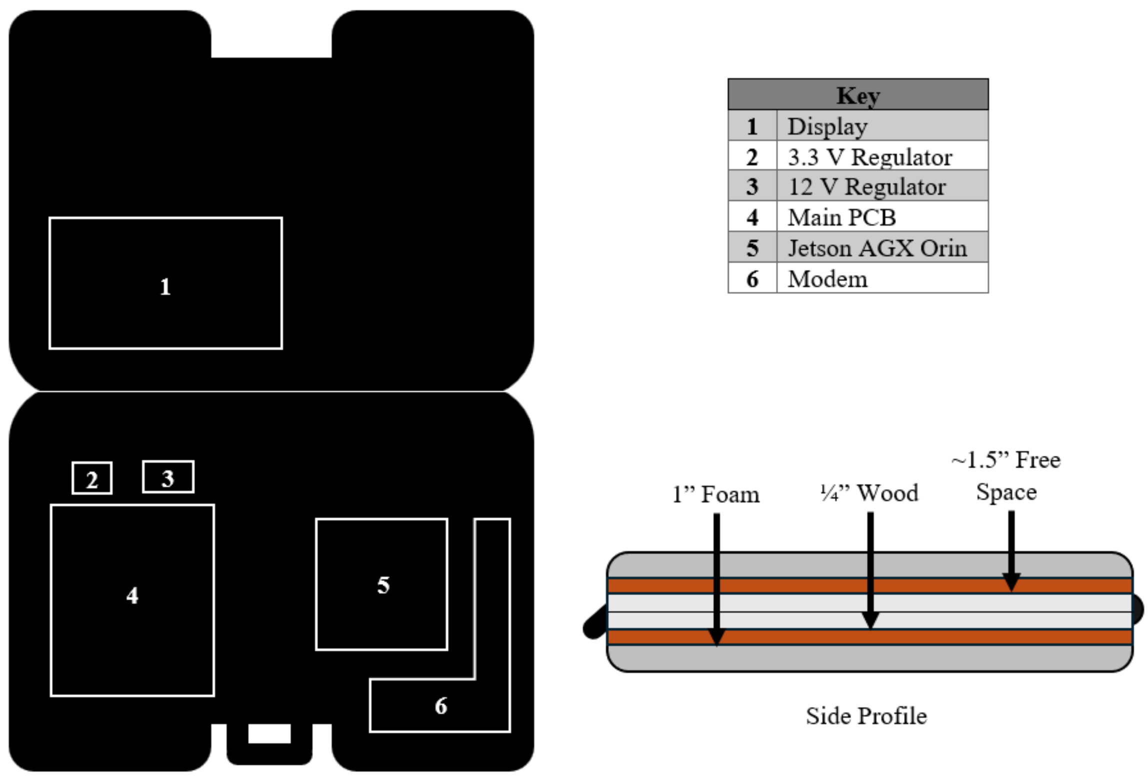


Figure 8.4. *Enclosure layout diagram by Authors*

Chapter 9 - System Testing and Evaluation

9.1 HMTECH 7-inch Raspberry Pi Screen

To test the HMTECH 7-inch Raspberry Pi Screen, the display will be connected to the Jetson AGX Orin using the appropriate interface cables. After powering on the Jetson Orin, we must ensure that the screen correctly received the video signal and displayed the Orin’s operating system interface. We must also verify the resolution, brightness, and color reproduction met the expected standards, and test the screen under various lighting conditions to ensure readability. The display will also be tested for stability during extended use to ensure it did not experience any flickering or other issues. The main aspect of this display for the ground station is to be running Mission Planner so that users can load parameters in and connect to the drones so that they can fly autonomously following the plan loaded.

9.2 STM32F103C8T6

For testing the functionality of the STM32F103C8T6 in driving the power supply unit, the process involved verifying both hardware and software operations. Hardware testing included ensuring the stability of the 3.3 V power rail supplied by the L9961 and checking that the connected LED illuminates correctly to confirm power is supplied. The reset button tied to the NRST pin should reset the MCU, which was validated by observing system initialization behavior. For communication with the L9961 Battery Management System (BMS), the I2C interface is tested using a logic analyzer or oscilloscope to confirm signal integrity and proper data exchange. Additionally, the GPIO pins used for battery status monitoring were tested by simulating fault and charge conditions to verify the MCU's response. On the software side, a Power-On Self-Test (POST) routine initializes the system by verifying LED status, I2C communication, and GPIO inputs. Firmware testing ensures accurate data handling from the BMS and proper error detection in cases like communication failure. The reset button's functionality is further validated by logging system uptime and checking for correct reinitialization upon activation. Tools such as ST-LINK for debugging and development environments like STM32CubeIDE and ArduinoIDE aided in unit and integration testing, while hardware tools like multimeters and oscilloscopes ensured reliability in real-world conditions.

9.3 L9961

The L9961, a power management IC, was tested by providing the necessary input voltage and connecting it to a load circuit. The L9961 chip was not easy to work or test with as initially, the values of this register chip would all read zero at the beginning due to the fact that it needed to be configured before it was able to properly monitor the system. It started off with an I2C communication and before it was able to read voltage levels of all the input batteries, there needed to be configurations such as overvoltage or overcurrent thresholds alongside their respective parts of the undervoltage or undercurrent aspects. After setting the thresholds with I2C write values, the L9961 had to be reconfigured such that no fault flags are on and made sure no over discharge occurs. In the event that any undesirable situation occurs, the L9961 chip would instantly turn on the MOSFETs that it is connected to and cut off the power from reaching the voltage regulators, hence shutting down the whole system to ensure no further damage is done to the system. The functionality of the L9961 was verified by observing its output voltages under normal load conditions, ensuring it correctly regulates the power distribution to various components of the system. We also monitored the IC's thermal performance to ensure that it remains within safe operating temperatures. In the end, the L9961 IC functioned as it was intended after many long periods of looking at its register mapping and the datasheet to ensure correct values were configured for it so it would know when the danger level of voltage or current is reached before it would shut down the entire PCB system to prevent the batteries from fully depleting.

9.4 Voltage Regulators

To test each voltage regulator, two LEDs are incorporated onto the board at each voltage output (3.3 V and 12 V). The typical use case conditions were applied by powering the board under normal operating loads for each output voltage. This allowed us to verify that the regulators are providing stable and accurate voltage levels at their respective outputs. The LEDs served as indicators to show when each voltage was being properly supplied.

Upon the successful configuration of the L9961 BMS chip, the voltage regulators were able to be powered correctly and the whole system was able to be powered through these regulators. Additionally, measurements were taken at each output to ensure that the voltage remains within tolerance and that the regulators maintain consistent performance under varying load conditions.

9.5 Jetson Orin AGX

To evaluate the functionality of the Jetson Orin AGX development board, designated for use within the ground base station, we commenced by setting up its power supply. This involved utilizing the AC power adapter included with the developer kit, which was securely connected to an electrical outlet. Once powered, the Jetson Orin AGX indicated a successful connection through its onboard status LED, confirming the hardware was receiving sufficient power and was operational.

Following the power setup, the development board was connected to a monitor, where it was confirmed that a Linux-based operating system had already been pre-installed. This discovery expedited our setup process, as it provided a ready environment for further software installation and configuration. Additionally, the board was found to have Secure Shell (SSH) capabilities pre-enabled, allowing for remote access and streamlined command-line interactions, further enhancing its versatility during testing. The SSH capabilities allows for other devices to access the Orin files through the command and modify or change files inside the Orin, hence making importing the required files for our project much easier on the Orin.

To interact with the system directly, an external keyboard and mouse were connected, providing intuitive control over the interface. This setup enabled the installation of critical software packages and tools necessary for our project, including those required for testing wireless communication protocols and implementing computer vision algorithms. These components are integral to SPARROW's objectives, particularly for the detection and identification of humans during search and rescue operations.

This initial testing phase was pivotal in verifying the hardware’s capabilities and compatibility with the project’s technical requirements. By successfully installing and configuring the foundational tools and verifying connectivity, we established a solid groundwork for subsequent development, including integrating computer vision models and establishing communication between the ground station and drone platform. Below here is a screenshot of the home screen upon turning on the Jetson Orin AGX which just shows the NVIDIA background alongside some default app configurations and a few codes that were imported to be used for the testing of SPARROW:

Figure 9.1. Jetson Orin AGX Homescreen
by Authors

9.6 ArduPilot and Mission Planner

For the ArduPilot and Mission Planner components of the SPARROW project, it is important that SPARROW initially focuses on validating the software installation process on the Jetson Orin AGX platform. As the project involves a sensor package communicating with a drone package rather than an operational drone, prioritizing that ArduPilot, running through Mission Planner, is successfully installed and operable on the Jetson Orin AGX. This step is crucial as it establishes the ground base station's ability to support the software platform needed for future integration and testing.

Given that the Jetson Orin AGX runs a Linux-based operating system, most of the installation steps were carried out via the terminal. This included downloading dependencies, configuring the environment, and setting up the necessary libraries to support ArduPilot and Mission Planner. The successful launch of the application, as illustrated in the accompanying screenshot, demonstrates that the platform is capable of running these critical software components without issues.

Overtime, the testing of the system involved using the ArduPilot Mission Planner to connect to the flight controller before fully testing the flight system where a plan can be loaded onto the flight controller and then flying the drone autonomously as it would follow the mission loaded into its memory.

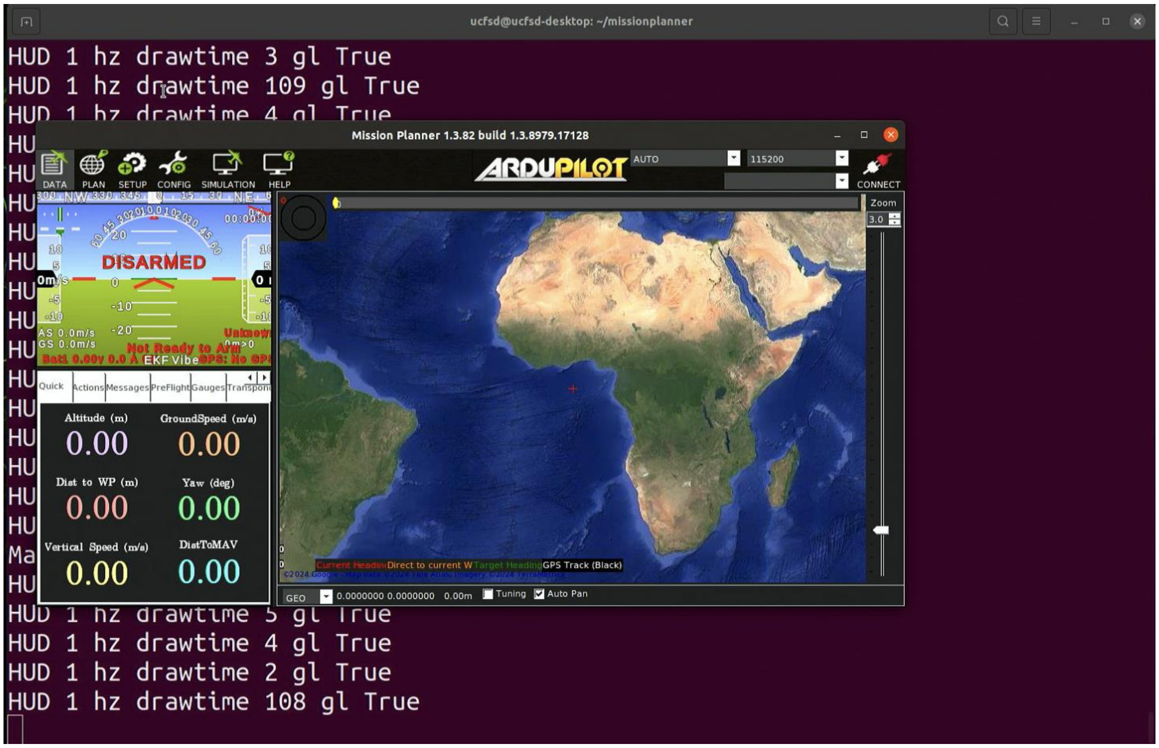


Figure 9.2. ArduPilot and Mission Planner Running on Jetson Orin AGX
by Authors

9.7 Wireless Communication

For the wireless communication testing of the system, the drone will connect to the RFD900x-us radio modems which will then connect with each other within the same network ID. The radio modems will communicate through sending each other MAVLink messages. Both the radio modems are connected via UART ports as the drone will have it connected to the Jetson Nano whereas the base station has the radio modem connected to the Jetson AGX Orin. The radio modems can be configured with different settings but some settings must be the exact same on both ends in order for the modems to communicate with each other. When two modems are successfully connected with each other, they have a red LED blinking on them to indicate that they have successfully established a connection with each other. Due to the flight controller on the drone constantly sending a ton of parameters and data over to the base station via the modem, the modems had the tendency to be overwhelmed when incorporating image transmission. To begin, the flight controller is not integrated with the cameras as the cameras will be connected to the Jetson Nano on board where the image will be taken before applying the human detection algorithm to locate the humans in the image. Following that the Jetson Nano will serve as a companion computer and will be transmitting flight controller data alongside image data to the radio modem, it will have to be able to route both input streams to the output modem in this case. Thankfully, to obtain this routing setup, MAVLink has a protocol known as MAVProxy which allows the user to run a terminal command where master and out devices are configured such that all the devices are able to communicate back and forth with each other.

To incorporate image transmission onto the communication stream, the Jetson Nano will have a UDP port input where image MAVLink data would come in from so that the MAVProxy would route image data and flight controller from the inputs to the modem output port. Following this setup, the Jetson AGX Orin at the base will have its own MAVProxy configuration such that the master input would be the radio modem and the out ports are being forwarded to Mission Planner via UDP and another script with UDP which will be running a GUI alongside listening for image data packers where it would reassemble the images once all the packets are obtained and show the detected humans on the image. The communication via the MAVLink packets were occasionally lost due to the massive flooding stream alongside RF design in general. To overcome this issue of losing image packets transmission over the network, multiple image packets were sent to ensure that the receiver had a good chance of obtaining all the image packets before reassembling everything. Upon successful MAVProxy initialization, the terminals for both the drone and the base would show that the connection is established alongside the data for the flight controller indicating its type and that messages are being sent to each other. After running the MAVProxy sessions, the MAVLink data packets are logged in a tlog file where another command line can be ran to decode the log file and examine all the MAVLink packets that went through the MAVProxy and see their source ID alongside whatever information that was encapsulated inside the packets.

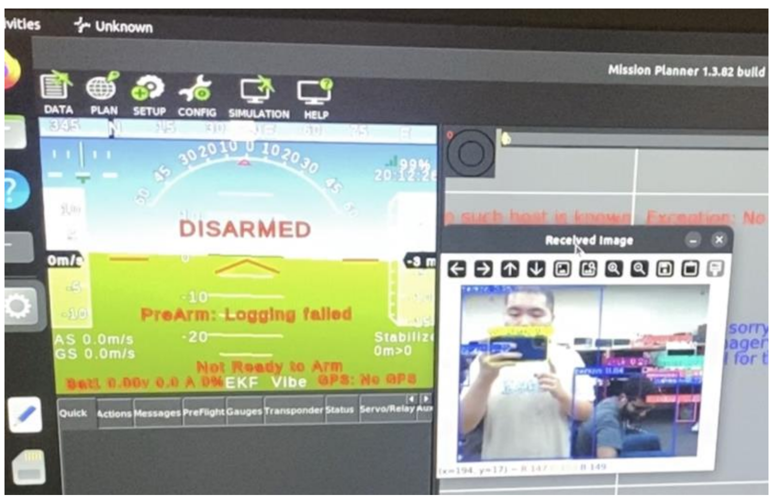


Figure 9.3. Image Transmission Communication Test
by Authors

9.8 Human Detection

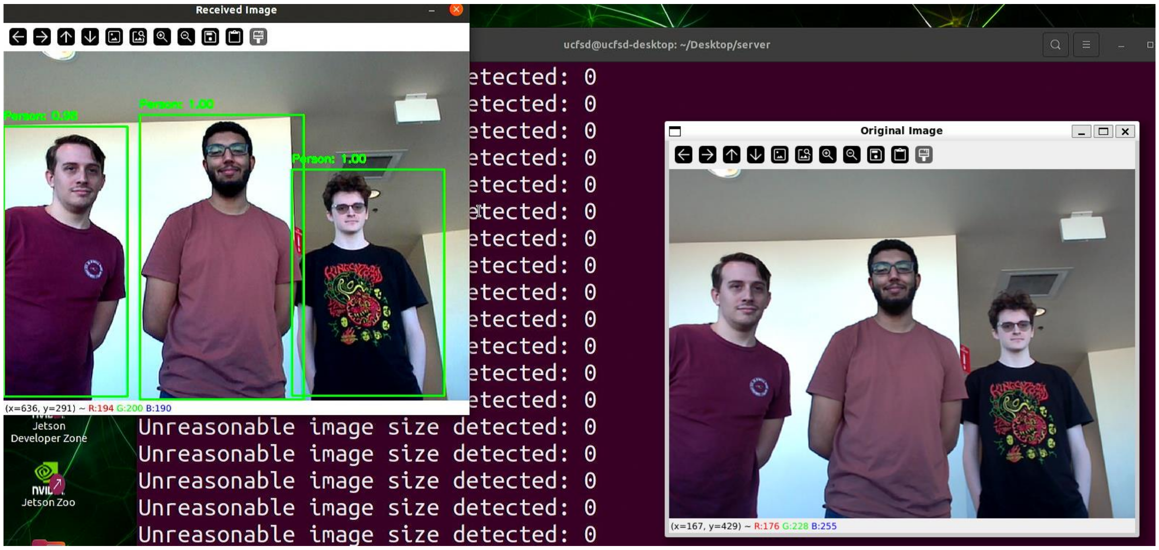


Figure 9.4. *Human Detection Code Test*
by Authors

To test the Human Detection Algorithm, we run the trained YOLO model through a simple Python script that uses OpenCV to input images and display them on the screen for review. Since we do not have the selected camera yet, this testing uses a basic USB webcam as the source. The script captures the current frame from the webcam using OpenCV and feeds it into the YOLO model for processing. After the model processes the frame and detects any people, OpenCV draws rectangles around the detected individuals on the output frame. This allows us to visually confirm the detections and check their accuracy. Additionally, we configured OpenCV to label each person with the confidence score provided by YOLO. This score helps us evaluate how confident the model is about each detection. By reviewing these confidence values, we can adjust the system to improve detection accuracy, raising the confidence on correct detections and lowering it on false ones.

For more advanced testing in the future, particularly when training the model on a new dataset, we will use a more detailed approach. The model will be tested with a dataset that includes a wide range of scenarios, environments, lighting conditions, and poses to ensure accurate detection. During this testing, the model will process each image in the dataset and output its predictions. These predictions will be compared to the expected results, which include the actual number of people and their locations in each image. If the prediction does not match the expected result, the difference will be used to adjust the model’s weights. This process will be repeated until the model can accurately detect all people in the dataset. By doing this, we aim to make the model robust enough to perform reliably in a variety of real-world conditions.

9.9 Overall Integration

For the overall integration of SPARROW to the SOAR drones, the Jetson Nano is set up as a companion computer to the flight controller on board so that the Jetson Nano can route flight controller data alongside image data to the base station. Following the setup of the Jetson Nano for routing flight controller data, it must also be configured to run the trained model to detect humans. To achieve the model running on the Jetson Nano, the scripts of the image transmission alongside the model processing were integrated together so that every image intake from the cameras would first be processed by the model for human detection before proceeding with the image transmission to the base station. Throughout the testing of the integration of the Jetson Nano as a companion computer, there were many issues that arose from the integration. A big one was trying to set up the Jetson Nano MAVProxy routing and image transmission script on bootup so that the drones would be able to connect as soon as they are booted up, but this approach resulted in an issue that was limitation of the Jetson Nano. Most of the time, upon initial first bootup, the Jetson Nano would load a little bit of data but then say that the device connection is dead for the radio modem UART port. This issue is detrimental as the port is required for the modem on the drone to communicate with the base station. To solve this issue was a simple yet annoying approach as all it took was a termination of the script and rerun it, hence the idea of scripts running upon bootup was scratched and the new way of starting the drone communication involved connecting to the Jetson Nano via SSH in order to activate the scripts multiple times due to the device dying on the first attempt.

Additionally, we encountered a critical issue during our final testing phase. Our original design included a 5V regulator, which we intended on using to power the modem. However, as we progressed through the final stages of integration between SPARROW and SOAR, we discovered that the regulator was unable to supply sufficient current to meet the modem's demands. This led to data loss and unreliable communication. After discovering this issue, we concluded that the best course of action would be to remove the 5V regulator from our design. Instead, we chose to utilize the 5V rail provided by the Jetson AGX Orin Developer Kit, which offered a more reliable power source for the modem. This change resolved our data integrity problems and ensured consistent modem operation.

In the end, the whole system was able to integrate as the drones along with the Jetson Nano as a companion computer was able to route all the data through the modems to the base station such that a connection on Mission Planner was able to be established and the GUI can show any image transmitted through the modem. The display monitor may be small but it is sufficient enough to allow users to load the mission parameters and run their autonomous flight on the selected drone alongside showing the GUI with the received images. While the components within the base station do power the whole system, the Jetson Orin draws a ton of power from the batteries and would drain it insanely quickly to the point where the operation time usually does not exceed over two hours. This was tested when the team was outside and running the drone flights integrated with the base station where batteries were used to power the Orin while trying to load flight parameters in. There were other issues in the integration as over time, the Jetson Orin started having trouble opening with Mission Planner and to fix such an issue, the cache was cleared on the Jetson

Orin for Mission Planner to try to fix the loading issue. While clearing the cache did work, the other approach was deleting and reinstalling Mission Planner so that it would be refreshed and brand new running on the device. These approaches did work out to solve the integration issue as there were still little minor bugs or inconsistencies but allowed the system to function as intended. Overall, throughout the integration process of SPARROW base station to SOAR drones, there were many challenges faced that had to be fixed with one way or another, but eventually, the system was able to connect to the drones and allow flight planning on top of human detection.

Chapter 10 - Administrative Content

10.1 Budget

The budget provided for this project by our sponsor Lockheed Martin was $2,000, and with this generous amount of budget, we aim to utilize the spending to the best potential in order to minimize personal costs from each of the group members while still being able to produce a solid result from this project.

Table 10.1. *Initial budget for project by Authors*

Sub-System	Cost
Display	$50
MCU	$15
Cameras	$3,000
Sensors	$250
Communication	$250
Battery	$50
Total	$5,700

While it may seem that we are over budget, it's important to note that Lockheed Martin will be lending us certain components at no additional cost. These generous contributions will not impact our $2,000 budget, but we should still document them for transparency. Doing so allows us to accurately represent the full scope of the project and showcases the value of our collaboration with Lockheed Martin. The table below shows estimated values of what we actually plan on spending for the project, using our allotment of $2,000.

Table 10.2. *Updated budget*
by Authors

Sub-System	Cost
Display	$150
MCU	$30
Sensors	$150
Communication	$300
Battery	$50
Total	$680

10.2 Bill of Materials

Below is our compiled bill of materials, which includes the component details, part name, the required quantity and the total price, which is composed of both the unit price and the quantity needed.

Table 10.3. *Itemized bill of materials*
by Authors

Component	Name	Price
Sensor Package		
LiDAR	RPLIDAR C1	$209.97
Thermal Camera **Provided by Lockheed Martin**	Boson Longwave Infrared (LWIR) OEM Module 320	$0.00
Camera	ELP-SUSB1080P01-LC1100	$68.99

Base Station		
PCB	First Revs	$122.54
	Second Rev	$129.03
Parts	Rev1 Parts	$145.74
	Rev2 Parts	129.03
Display	HMTECH 7-inch Raspberry Pi Screen	$38.33
Radio Modem	RFD900x-US Bundle	$226.00
STLink	ST-Link STM8/STM32 v2 Compatible Programmer & Emulator	$0.00
Processor **Provided by Lockheed Martin**	Jetson AGX Orin Developer Kit	$0.00
Batteries	LG INR21700-M50	$25.85
Subtotal		$1,095.48

10.3 Distribution of Work

The distribution of work among the team members is designed to ensure the project's success. Given the interdependency of each system, it's important for each team member to actively collaborate with each other. Each member's role is not isolated, but linked to the contributions of others. To achieve a functional product, collaboration is essential. This approach ensures that each member remains informed about the design process and understands how their individual contributions integrate with the contributions of others.

Table 10.4. *Distribution of work by Authors*

Name	Primary Responsibilities	Secondary Responsibilities

Jack Gao *Computer Engineering*	Embedded Software	Website Management
	Communication Setup	Administrative Documentation
Max Hoffner *Electrical Engineering*	PSU Design	Hardware Implementation
	PCB Design	Embedded Software
Isaiah McCarty *Electrical Engineering*	Sensor Selection	PCB Design
	Hardware Implementation	Embedded Software
Patrick Rizkalla *Computer Engineering*	Computer Vision	GUI
	Communication Setup	
Esteban Venegas *Computer Engineering*	Computer Vision	GUI
	Software Implementation	

10.4 Milestones

Multiple events and meetings are necessary throughout the project to create a successful project. Once finalizing an idea, we scheduled biweekly meetings to ensure we stayed on track with our deliverables.

Table 10.5. *Project initialization milestones by Authors*

Start Date	Planned End Date	Required End Date	Task	Description
08/20/2024	08/20/2024	08/22/2024	Recruiting	Members Recruited: Jack Gao (CpE), Max Hoffner (EE), Isaiah McCarty (EE), Patrick Rizkalla (CpE), Esteban Venegas (CpE)

08/22/2024	08/27/2024	08/27/2024	Brainstorming	Meeting in person to discuss potential ideas and pick one for the project.
08/27/2024	08/27/2024	09/06/2024	Initial Document	The first 10 pages of Divide and Conquer
08/27/2024	09/16/2024	10/29/2024	60-page Milestone	The first half of the document
08/27/2024	10/21/2024	11/26/2024	Final Document	The final document for SD1

Table 10.6. *Project fabrication milestones by Authors*

Start Date	Planned End Date	Required End Date	Task	Description
08/27/2024	09/09/2024	11/08/2024	Component Selection	Making a tentative budget and bill of materials for core components.
08/27/2024	09/09/2024	11/26/2024	System Design	Designing the overall schematic for the project.
09/09/2024	10/08/2024	11/26/2024	System Testing	Testing individual components and their compatibility within our project.

09/09/2024	10/29/2024	3/3/2025	PCB Design	Have specialized PCB designed and ready to be ordered.
3/10/2025	3/25/2025	4/13/2025	PCB Testing	Test PCB to make sure it works
3/17/2025	4/10/2025	4/13/2025	Prototype Completion	Complete project

Throughout the milestones and fabrication of the project, various tasks overlap with each other due to the requirements of this project. This milestone acts as a guideline for reference to a successful project done in a timely manner.

Chapter 11 - Conclusion

The SPARROW project has delivered a comprehensive, innovative solution to aid search and rescue operations through autonomous drone technology. The success of SPARROW lies in its dual focus on communication reliability and operational autonomy. By developing a centralized control hub with robust networking capabilities, SPARROW demonstrated a unique approach to coordinating a fleet of drones in real-time for efficient search and rescue coverage across hazardous areas. Throughout this project, SPARROW leveraged cutting-edge technologies such as LiDAR for obstacle detection, thermal imaging for human identification, and a mesh network to extend operational reach, ultimately addressing some of the most critical challenges in modern disaster response.

Project Outcomes and Technical Achievements

The development of SPARROW led to significant technical milestones that underscore the project's potential impact. The integration of LiDAR sensors enabled drones to navigate and detect obstacles autonomously, an essential feature for search and rescue missions in complex terrains. Additionally, the implementation of thermal imaging cameras allowed for efficient and accurate detection of human presence, an enhancement that could greatly accelerate rescue times and ensure precise identification in adverse conditions.

Another cornerstone of SPARROW's success is its mesh network capability, which significantly extended the effective range of drone operations without compromising data integrity. The mesh network facilitated continuous communication between drones and the base station, allowing for real-time video transmission and data exchange critical for on-the-ground situational awareness. These accomplishments collectively position

SPARROW as a versatile solution capable of adapting to various emergency scenarios, providing search and rescue teams with a reliable and responsive system.

Implications for Future Search and Rescue Applications

The potential applications of SPARROW extend beyond the traditional boundaries of search and rescue. SPARROW’s modular design, advanced sensor integration, and communication framework make it adaptable for a variety of fields where remote monitoring and autonomous operations are valuable. For instance, environmental monitoring and wildlife tracking are areas where SPARROW’s capabilities could be instrumental. In these fields, autonomous drones can be utilized to survey vast areas, gather critical data, and relay findings back to base in real-time, all while reducing human risk and operational costs.

Furthermore, SPARROW’s architecture provides a foundation for future systems that require both autonomous navigation and human detection capabilities, opening pathways for applications in disaster response, agriculture, and even smart city infrastructure monitoring. As drone technology continues to evolve, SPARROW represents a blueprint for developing specialized systems that leverage autonomy and communication for impactful, large-scale applications.

Challenges and Solutions in SPARROW’s Development

The journey of developing SPARROW was marked by numerous technical and logistical challenges, each contributing to the learning and growth of the team. One of the primary challenges was achieving the balance between operational power and processing efficiency. The integration of high-performance sensors like LiDAR and thermal cameras required significant power, potentially impacting flight duration. To address this, SPARROW’s design incorporated efficient power management solutions, including lightweight components and optimized energy allocation, ensuring sustained performance without compromising essential functionalities.

Additionally, the challenge of integrating diverse sensor technologies required innovative software solutions. The team developed custom software that facilitated seamless communication between components and enabled data synchronization across the network. This ensured that video feeds, sensor data, and control commands were processed efficiently, reducing latency and improving response times. The combination of these solutions underscored the team’s commitment to designing a reliable and functional system, capable of operating under diverse conditions and fulfilling the intended mission requirements.

User Experience and Field Testing

An essential aspect of SPARROW’s development was ensuring the system’s usability and reliability under real-world conditions. To achieve this, the team designed an intuitive user interface on the base station that simplifies the control and monitoring of multiple drones simultaneously. The interface features a live video feed from each drone, real-time location tracking on a GPS-enabled map, and an accessible menu for setting flight paths, battery monitoring, and issuing commands like recall and return to base. These user-centric features help ensure that even operators with minimal technical training can effectively manage the drones, making SPARROW versatile for diverse users in the field, such as first responders, environmental monitors, and field researchers.

Field testing was a critical phase in the project, allowing the team to observe how SPARROW performs in various environments, including open fields, wooded areas, and low-visibility conditions. These tests helped validate the system's capabilities, particularly its obstacle detection and human recognition functionalities. Testing also highlighted areas for improvement, such as refining the mesh network for more robust connectivity in challenging terrains and adjusting the interface to enhance ease of use during high-stress situations.

Reliability and Safety Considerations

The project placed strong emphasis on ensuring SPARROW's reliability and safety. The team implemented fail-safe protocols that prioritize operator safety, such as an automatic return-to-base function if a drone loses connection or reaches critical battery levels. These safeguards were rigorously tested to ensure that SPARROW would remain reliable even in unforeseen circumstances, reinforcing the system's value as a dependable tool for emergency response.

Final Reflection

The hands-on experience gained during field testing and user experience design underscored the importance of practical testing in engineering projects. This phase provided invaluable insights that shaped SPARROW's final design and informed recommendations for future enhancements.

Recommendations and Pathways for Future Enhancements

While SPARROW has successfully demonstrated its core capabilities, there remains ample opportunity for further enhancement and refinement. Future versions of SPARROW could benefit from an increase in battery capacity to extend drone flight time, thereby expanding the range and duration of search and rescue missions. Additionally, the integration of machine learning algorithms for advanced image recognition could enhance the system's ability to identify potential targets autonomously, increasing the speed and accuracy of human detection.

Expanding SPARROW's autonomy by enabling drones to make independent navigation adjustments based on real-time sensor data could further enhance operational efficiency. This capability would allow the drones to adapt dynamically to new obstacles or high-priority areas, making SPARROW even more effective in complex and unpredictable environments. To support these improvements, SPARROW could explore potential collaborations with industry partners, emergency response organizations, and research institutions to drive further innovation and integration.

Conclusion and Vision for SPARROW

In conclusion, SPARROW represents a transformative advancement in search and rescue technology, successfully addressing the critical needs of real-time coordination, human detection, and autonomous navigation. This project has underscored the potential for autonomous systems to operate safely and effectively in disaster environments, paving the way for faster and more efficient rescue operations. By bridging the gap between technological innovation and practical application, SPARROW offers a vision for the future of disaster response, where autonomous systems play an integral role in safeguarding lives.

The SPARROW project stands as a testament to the potential of collaborative engineering and the dedication of its team to pushing the boundaries of what autonomous systems can achieve. Looking forward, SPARROW’s evolution could make a lasting impact in fields beyond search and rescue, serving as a model for the deployment of advanced drone technology in various high-stakes environments. This vision for SPARROW is one of ongoing innovations, where future iterations continue to build upon the solid foundation laid by this project, ultimately contributing to a safer and more responsive world.

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Appendix B - Code

Jetson Nano Send Detected Image Code:

```
import cv2

import numpy as np

import serial

import time

from pymavlink import mavutil

import threading

from ultralytics import YOLO


# 1 for RGB cam and 2 for FLIR

camera = 0

camera2 = 1


# Open UART connection to RFD900x (adjust as needed)

udp_port ='udpout:127.0.0.1:14550'


connection = mavutil.mavlink_connection(udp_port, source_system=1)



def send_handshake(img_size, img_width, img_height, cycle):

    """Send MAVLink handshake before transmitting the image."""

    try:

        connection.mav.data_transmission_handshake_send(
```

```
            mavutil.mavlink.MAVLINK_DATA_STREAM_IMG_JPEG,  # Image type
            img_size,  # Image size in bytes
            cycle,  # Image width
            cycle,  # Image height
            (img_size // 253) + 1,  # Number of packets
            253,  # Payload per packet
            60  # JPEG quality
        )
        print(img_size // 253 + 1)
        print("Sent a transmission handshake")
    except Exception as e:
        print("Error in sending handshake")


def send_image(image, cycle):
    """Breaks image into MAVLink packets and sends them."""
    ret, encoded_img = cv2.imencode(".jpg", image, [cv2.IMWRITE_JPEG_QUALITY, 75])
    img_bytes = encoded_img.tobytes()
    img_size = len(img_bytes)

    print(f"Total image size: {img_size} bytes")

    # Send handshake
    send_handshake(img_size, image.shape[1], image.shape[0], cycle)

    # Send image in chunks
```

```
    chunk_size = 253  # MAVLink encapsulated data chunk size
    for s in range(6):
        for seq in range(0, img_size, chunk_size):
            chunk = img_bytes[seq:seq + chunk_size]

            # Pad last chunk if necessary
            if len(chunk) < chunk_size:
                chunk += bytes(chunk_size - len(chunk))

            chunk = bytearray(chunk)
            num = int(seq // chunk_size)
            try:
                connection.mav.encapsulated_data_send(num, chunk)
            except Exception as e:
                print(f"Error sending chunk {seq // chunk_size}: {e}")

        time.sleep(0.15)  # Prevent buffer overflows
    time.sleep(0.6)



# Load the YOLOv8n model
model = YOLO('yolov8n.engine', task='detect')
print("Model Loaded")
cap = cv2.VideoCapture(camera)  # Open camera
#cap2 = cv2.VideoCapture(camera2) #Open the other camera
```

```
cycle = 0

if not cap.isOpened():
    print("Error: Could not open webcam.")
    exit()

while True:
    try:
        # Resize the frame to the desired dimensions (e.g., 640x480)
        resized_frame = cv2.resize(frame, (640, 480))

        # Perform inference on the resized frame
        results = model(resized_frame, device='cuda')[0]  # Ensure 'cuda' is used for GPU inference

        # Extract detections
        boxes = results.boxes
        if boxes is not None:
            for box in boxes:
                cls_id = int(box.cls)
                if cls_id == 0:  # Only humans
                    x1, y1, x2, y2 = map(int, box.xyxy[0])
                    # Draw rectangle with no label
                    cv2.rectangle(resized_frame, (x1, y1), (x2, y2), (255, 0, 0), 3)

        resized_frame = cv2.resize(resized_frame, (160, 128))
```

```
        send_image(resized_frame, cycle)

        time.sleep(5)  # Adjust based on transmission speed and to not overflow buffer


        # Press 'q' to exit the loop

        if cv2.waitKey(1) & 0xFF == ord('q'):

            break

    except KeyboardInterrupt:

        break

cap.release()
```

Jetson Nano MAVProxy Command Line:

```
mavproxy.py --master=/dev/ttyACM0,115200 --master=udpin:127.0.0.1:14550 --out=/dev/ttyTHS1,57600
```

Jetson AGX Orin Receiver Code:

```
import tkinter as tk

from tkinter import ttk

from PIL import Image, ImageTk

import threading

import tempfile

import os

import time

import cv2

import numpy as np

import serial

from pymavlink import mavutil
```

```
# --- Config ---
connection = mavutil.mavlink_connection('udpin:127.0.0.1:14552')
ser = serial.Serial('/dev/ttyUSB0' , 115200)
rgb_received_chunks = {}
thermal_received_chunks = {}
rgb_expected_packets = None
thermal_expected_packets = None
img_type = 0  # 0 = RGB, 1 = Thermal
drone_selected = 1 # 1 = A, 3 = B, 2 = C

# --- GUI Setup ---
print("[GUI] Starting GUI...")

THEME_BG = "#2d3e50"  # Or whatever color you're using



root = tk.Tk()
root.title("SPARROW - Drone Ground Station")
root.configure(bg=THEME_BG)  # Light bluish-gray



# --- Top Bar ---
top_frame = tk.Frame(root, bg=THEME_BG)
top_frame.grid(row=0, column=0, columnspan=2, sticky="ew", padx=10, pady=5)
default_font = ("Segoe UI", 10)
```

```
image_frame = tk.Frame(root, bg=THEME_BG)
image_frame.grid(row=1, column=0, columnspan=2, padx=10, pady=10)
root.grid_rowconfigure(1, weight=1)
root.grid_columnconfigure(0, weight=1)

image_frame.grid_columnconfigure(0, weight=1)
image_frame.grid_columnconfigure(1, weight=1)

rgb_label = tk.Label(image_frame, text="RGB Feed", bg="gray", fg="white")
thermal_label = tk.Label(image_frame, text="Thermal Feed", bg="gray", fg="white")

# Make sure they expand
rgb_label.grid(row=0, column=0, padx=20, pady=10, sticky="nsew")
thermal_label.grid(row=0, column=1, padx=20, pady=10, sticky="nsew")

rgb_label.config(anchor="center")
thermal_label.config(anchor="center")

#set them to temporary size
rgb_label.config(width=50, height=15)
thermal_label.config(width=50, height=15)

gps_label = tk.Label(root, text="Drone A GPS: --, --", font=default_font, bg=THEME_BG,
fg="white")
```

```
gps_label.grid(row=2, column=0, sticky="w", padx=10)


base_gps_label = tk.Label(top_frame, text="Base GPS: --, --", font=default_font, bg=THEME_BG, fg="white")

base_gps_label.pack(side="left")


log_text = tk.Text(root, height=8, width=100, bg="black", fg="green", wrap="word", font=default_font, insertbackground="white")

log_text.grid(row=3, column=0,columnspan=2, padx=10, pady=10, sticky="nsew")

log_text.config(state="disabled")



battery_canvas = tk.Canvas(top_frame, width=80, height=30, highlightthickness=0, bg=THEME_BG,)

battery_canvas.pack(side="right", padx=10)


battery_canvas.create_rectangle(5, 5, 65, 25, outline="black", width=2)  # main battery body

battery_canvas.create_rectangle(65, 10, 70, 20, fill="black")           # battery cap


# Draw initial tiers (example with 3 out of 5 filled)

battery_tiers = []

for i in range(5):

    x0 = 7 + i * 11

    x1 = x0 + 9

    tier = battery_canvas.create_rectangle(x0, 7, x1, 23, fill="gray", outline="")  # empty initially

    battery_tiers.append(tier)
```

```
def show_battery(level, color):
    for i in range(level):
        x0 = 7 + i * 11
        x1 = x0 + 9
        tier = battery_canvas.create_rectangle(x0, 7, x1, 23, fill=color, outline="")  # empty initially
        battery_tiers.append(tier)
        if level < 5:
            for j in range(5 - level):
                tier = battery_canvas.create_rectangle(x0, 7, x1, 23, fill="gray", outline="")
                battery_tiers.append(tier)


def update_battery(life):
    if life > 80:
        show_battery(5, "green")
    elif life > 60:
        show_battery(4, "green")
    elif life > 40:
        show_battery(3, "yellow")
    elif life > 20:
        show_battery(2, "yellow")
    else:
        show_battery(1, "red")
```

```
#Toggle Buttons
def show_rgb_only():
    for widget in image_frame.winfo_children():
        widget.grid_forget()
    rgb_label.grid(row=0, column=0, padx=10)


def show_thermal_only():
    for widget in image_frame.winfo_children():
        widget.grid_forget()
    thermal_label.grid(row=0, column=0, padx=10)



def show_both():
    for widget in image_frame.winfo_children():
        widget.grid_forget()
    rgb_label.grid(row=0, column=0, padx=10)
    thermal_label.grid(row=0, column=1, padx=10)



button_frame = tk.Frame(top_frame, bg=THEME_BG)
button_frame.pack(side="left", expand=True)
tk.Button(button_frame, text="RGB Only", command=show_rgb_only, font=default_font, bg="white", fg="black").pack(side="left", padx=5)
tk.Button(button_frame, text="Thermal Only", command=show_thermal_only,font=default_font, bg="white", fg="black").pack(side="left", padx=5)
```

```
tk.Button(button_frame, text="Show Both", command=show_both, font=default_font, bg="white", fg="black").pack(side="left", padx=5)


# Dropdown Menu

def on_dropdown_change(event):

    global drone_selected

    selection = dropdown.get()

    log_message(f"[Dropdown] Selected option: {selection}")

    # Add any specific behavior for each choice here

    if selection == "Drone A":

        drone_selected = 1

    elif selection == "Drone B":

        drone_selected = 3

    elif selection == "Drone C":

        drone_selected = 2


dropdown_values = ["Drone A", "Drone B", "Drone C"]

dropdown = ttk.Combobox(button_frame, values=dropdown_values, font=default_font, width=12)

dropdown.set("Select Drone")  # default text

dropdown.bind("<<ComboboxSelected>>", on_dropdown_change)

dropdown.pack(side="left", padx=5)



#Log panel
```

```
def log_message(msg):
    def _log():
        log_text.config(state="normal")      # Temporarily enable editing
        log_text.insert(tk.END, f"{msg}\n")
        log_text.see(tk.END)
        log_text.config(state="disabled")    # Disable editing again
    log_text.after(0,_log)


# --- Helper to update images ---
def update_image_on_label(label, img):
    img = cv2.cvtColor(img, cv2.COLOR_BGR2RGB)
    height, width = img.shape[:2]
    # Calculate new dimensions while maintaining aspect ratio
    max_width = 320  # Increased from 320
    max_height = 240  # Increased from 240
    scale = min(max_width/width, max_height/height)
    new_width = int(width * scale)
    new_height = int(height * scale)
    img = cv2.resize(img, (new_width, new_height))
    pil_image = Image.fromarray(img)
    tk_img = ImageTk.PhotoImage(pil_image)
    label.imgtk = tk_img
    label.config(image=tk_img, width=new_width, height=new_height)


# --- Image Decoder ---
```

```python
def process_image(img_type, rgb_received_chunks):
    try:
        sorted_data = b''.join(rgb_received_chunks[k] for k in sorted(rgb_received_chunks.keys()))
        rgb_received_chunks = {}
        with tempfile.NamedTemporaryFile(suffix='.jpg', delete=False) as temp_file:
            temp_name = temp_file.name
            temp_file.write(sorted_data)
        try:
            img = cv2.imread(temp_name)
            if img is not None:
                if img_type == 0:
                    update_image_on_label(rgb_label, img)
                elif img_type == 1:
                    update_image_on_label(thermal_label, img)
        except Exception as e:
            print(f"Error reading image: {e}")
        finally:
            # Clean up the temporary file
            rgb_received_chunks = {}
            print("Cleaned up chunks array")
            try:
                os.unlink(temp_name)
            except:
                pass
    except Exception as e1:
```

```
        print(f"Error in processing images: {e1}")



def serial_thread():
    global base_gps_label
    while True:
        try:
            received_data = ser.readline().decode('utf-8').strip()
            if "Latitude" in received_data and "Longitude" in received_data:
                parts = received_data.split()
                lat = float(parts[1])
                lon = float(parts[3])
                base_gps_label.config(text=f"Base GPS: {lat:.6f}, {lon:.6f}")
            if "Battery" in received_data:
                part = received_data.split()
                life = int(part[1])
                update_battery(life)

        except Exception as e:
            print(f"[UART] Error parsing base GPS: {e}")

# --- MAVLink Thread ---
def mavlink_thread():
    global rgb_expected_packets, rgb_received_chunks, thermal_expected_packets, thermal_received_chunks
```

```
    t = ""

    messages = ["DATA_TRANSMISSION_HANDSHAKE", "ENCAPSULATED_DATA",
"GLOBAL_POSITION_INT", "HEARTBEAT"]

    while True:

        msg = connection.recv_match(type=messages, blocking=False)

        if not msg:

            continue

        print(msg.get_type())

        sys_id = msg.get_srcSystem()

        if sys_id == 1:

            drone = "A"

        elif sys_id == 3:

            drone = "B"

        elif sys_id == 2:

            drone = "C"

        if msg.get_type() == 'DATA_TRANSMISSION_HANDSHAKE':

            img_type = msg.height

            t = "Regular Image" if msg.height != 1 else "Thermal Image" # img_height used to tag
image type

            if img_type == 0:

                rgb_expected_packets = msg.packets

                rgb_received_chunks.clear()

                info = f"[HANDSHAKE] Expecting {rgb_expected_packets} packets. Type: {t}"

            elif img_type == 1:

                thermal_expected_packets = msg.packets
```

```
        thermal_received_chunks.clear()
        info = f"[HANDSHAKE] Expecting {thermal_expected_packets} packets. Type: {t}"
    print(info)
    log_message(info)

elif msg.get_type() == 'ENCAPSULATED_DATA':
    if sys_id == 1:
        print(f"Got chunk {msg.seqnr} from Regular Camera")
        #if msg.seqnr in rgb_received_chunks:
            #continue
        rgb_received_chunks[msg.seqnr] = bytes(msg.data)
        if len(rgb_received_chunks) == rgb_expected_packets:
            rgb_expected_packets = 0
            info = f"[IMAGE] Received complete image of type Regular"
            print(info)
            log_message(info)
            process_image(0, rgb_received_chunks)
    elif sys_id == 3:
        print(f"Got chunk {msg.seqnr} from Thermal Camera")
        #if msg.seqnr in thermal_received_chunks:
            #continue
        thermal_received_chunks[msg.seqnr] = bytes(msg.data)
        if len(thermal_received_chunks) == thermal_expected_packets:
            thermal_expected_packets = 0
            info = f"[IMAGE] Received complete image of type Thermal"
```

```
            print(info)
            log_message(info)
            process_image(1, thermal_received_chunks)

    elif msg.get_type() == 'HEARTBEAT':
        log_message(f"[HEARTBEAT] Received from drone {drone}.")

    elif msg.get_type() == 'GLOBAL_POSITION_INT':
        if sys_id != drone_selected:
            continue

        if drone_selected == 1:
            gps_drone = "A"
        elif drone_selected == 3:
            gps_drone = "B"
        elif drone_selected == 2:
            gps_drone = "C"

        lat = msg.lat / 1e7
        lon = msg.lon / 1e7
        gps_label.config(text=f"Drone {gps_drone} GPS: {lat:.6f}, {lon:.6f}")
        log_message(f"[GPS] Drone {gps_drone}: {lat:.6f}, {lon:.6f}")
```

```
# --- Start Thread ---

threading.Thread(target=mavlink_thread, daemon=True).start()

threading.Thread(target=serial_thread, daemon=True).start()

# --- GUI Loop ---

show_both()

root.mainloop()
```

Jetson AGX Orin MAVProxy Command Line:

```
mavproxy.py --master=/dev/ttyTHS1,57600 --out=udpout:127.0.0.1:14552 --
out=udpout:127.0.0.1:14550
```

STM32F103C8T6 PCB Code:

```
#include <Wire.h>

#include <HardwareSerial.h>

#include <TinyGPS++.h>


#define NUM_LEVELS 11

HardwareSerial Serial1(USART1);

HardwareSerial SerialGPS(USART3);  // PB10 and PB11 (TX and RX)

TinyGPSPlus gps;

unsigned int iteration = 0;


void setup() {

  // put your setup code here, to run once

  Wire.begin();

  Serial1.begin(115200);  // For Jetson UART forwarding

  SerialGPS.begin(9600);
```

```
while (!Serial1);
while (!SerialGPS);

pinMode(PA4, OUTPUT);  // Set PA4 as output
pinMode(PA5, OUTPUT);  // Set PA5 as output

// Set thresholds
writeRegister(0x06, 0x0f, 0xe7);
writeRegister(0x07, 0x0f, 0x00);
writeRegister(0x08, 0x00, 0x1a);
writeRegister(0x09, 0x0f, 0x00);
writeRegister(0x0a, 0x0f, 0xff);
writeRegister(0x0b, 0x0f, 0x00);
writeRegister(0x0c, 0x00, 0xff);
// writeRegister(0x0d, , );
writeRegister(0x0e, 0xff, 0xff);
//writeRegister(0x0f, , );
writeRegister(0x10, 0xff, 0xff);
writeRegister(0x11, 0x00, 0xff);
writeRegister(0x12, 0x00, 0xff);

// enable bits
//writeRegister(0x00, , );
writeRegister(0x01, 0x00, 0x7f);
//writeRegister(0x03, , );
```

```
  writeRegister(0x04, 0x1a, 0xbf);

  writeRegister(0x23, 0x20, 0x00);
  writeRegister(0x24, 0x10, 0x00);

  writeRegister(0x02, 0x0f, 0xe3);

  delay(1000);

  Serial1.println("Finished Writing to Battery Cells");
}

void loop() {

  // blink LEDs
  digitalWrite(PA4, HIGH);  // LED ON
  digitalWrite(PA5, HIGH);  // LED ON
  delay(500);               // wait 500ms
  digitalWrite(PA4, LOW);   // LED OFF
  digitalWrite(PA5, LOW);   // LED OFF
  delay(500);               // wait 500ms
  if (iteration % 5 == 0) {
    readBattery();
  }
```

```
  if (SerialGPS.available()) {
    String nmeaSentence = SerialGPS.readStringUntil('\n');  // Read full NMEA sentence
    if (nmeaSentence.length() > 0) {                        // Check if something is received
      Serial1.println(nmeaSentence);
    } else {
      Serial1.println("Waiting for GPS data...");
    }

    for (char c : nmeaSentence) {
      gps.encode(c);
    }

    if (gps.location.isUpdated()) {
      Serial1.print("Latitude ");
      Serial1.print(gps.location.lat(), 6);
      Serial1.print(" Longitude ");
      Serial1.println(gps.location.lng(), 6);
    }
  }

  iteration += 1;
  iteration %= 10;
}

void writeRegister(uint8_t reg, uint8_t msb, uint8_t lsb) {
```

```
  Wire.beginTransmission(0x49);
  Wire.write(reg);
  Wire.write(msb);
  Wire.write(lsb);
  Wire.endTransmission();
}

const int voltage_levels[NUM_LEVELS] = {
  4000, 3900, 3800, 3750, 3650, 3580, 3500, 3435, 3350, 3250, 3000
};

const int battery_percentages[NUM_LEVELS] = {
  100, 90, 80, 70, 60, 50, 40, 30, 20, 10, 0
};

int voltage_to_percent(int mv) {
  for (int i = 0; i < NUM_LEVELS; i++) {
    if (mv >= voltage_levels[i]) {
      return battery_percentages[i];
    }
  }
  return 0;  // Default to 0% if below the lowest threshold
}

int avg_battery_percent(int battery_mv_array[]) {
```

```
  int total = 0;
  int percent = 0;
  for (int i = 0; i < 5; i++) {
    percent = voltage_to_percent(battery_mv_array[i]);
    total += percent;
  }
  return total / 5;
}

void readBattery() {
  int battery_mv[5];
  int battery_shift = 600;  // mV value which the read voltage levels are shifted up by
    for (int i = 0; i < 5; i++) {
    Wire.beginTransmission(0x49);
    Wire.write(0x21 + i);                        // Write to the register address
    byte error = Wire.endTransmission(false);  // Send stop condition
    Wire.requestFrom(0x49, (uint8_t)2);
    if (Wire.available()) {
      byte data1 = Wire.read();
      byte data2 = Wire.read();
      uint16_t data = ((data1 << 8) | data2) & 0x0fff;
      battery_mv[i] = data + battery_shift;
    } else {
      Serial1.println("Error: Incomplete data received\n");
      battery_mv[i] = 0;
```

```
    }
  }
  int battery_array_percent = avg_battery_percent(battery_mv);
  char buffer[50];
  sprintf(buffer, "Battery %d", battery_array_percent);
  Serial1.println(buffer);
}
```

Appendix C - ChatGPT Responses

Case Study #1

Prompt: “What should I consider when placing components onto a drone?”

ChatGPT Response:

When placing components onto a drone, there are several important considerations to ensure optimal performance, stability, and safety. Here's what you should keep in mind:

1. **Center of Gravity (CG)**
   - **Balance:** Ensure that the drone's center of gravity is as close to the geometric center as possible. This helps maintain stable flight and reduces the workload on the motors.
   - **Symmetry:** Distribute the weight symmetrically around the center to prevent the drone from tilting or requiring constant correction during flight.
2. **Weight Distribution**
   - **Component Weight:** Heavier components like batteries should be placed closer to the center to minimize the moment of inertia, which improves maneuverability.
   - **Motor Placement:** Motors should be positioned symmetrically to ensure equal thrust distribution.
3. **Accessibility**
   - Maintenance: Position components like the battery, flight controller, and GPS in a way that allows easy access for maintenance, repairs, and battery swapping.
   - Connections: Ensure that all wiring and connections are secure but accessible for troubleshooting or replacement.

4. **Vibration Isolation**

   - Flight Controller: Mount the flight controller on vibration-dampening pads to minimize interference from motor vibrations, which can affect sensor readings and flight stability.

   - Sensitive Components: Components sensitive to vibrations, such as cameras or sensors, should also be isolated or mounted on vibration-dampening materials.

5. **Antenna Placement**

   - GPS Antenna: Place the GPS antenna away from other electronics and metal components to minimize signal interference. Ideally, it should be on the top of the drone with a clear view of the sky.

   - Radio and FPV Antennas: Position these antennas to avoid interference from the frame or other electronics, and orient them to maximize range and signal strength.

6. **Cooling and Ventilation**

   - ESCs and Motors: Ensure that electronic speed controllers (ESCs) and motors have adequate airflow for cooling. Overheating can lead to performance degradation or failure.

   - Heat Dissipation: Position heat-generating components where they can dissipate heat effectively, avoiding enclosed spaces.

7. **Wiring Management**

   - Cable Length: Keep wiring as short as possible to reduce weight and minimize electromagnetic interference (EMI).

   - Secure Wiring: Use zip ties, heat shrink, or other methods to secure wiring and prevent it from moving during flight, which could lead to wear or disconnection.

8. **FPV Camera and Gimbal Placement**

   - Forward View: Position the FPV camera at the front with a clear, unobstructed view.

   - Gimbal Stability: If using a gimbal, mount it securely and ensure it is properly balanced to maintain stable video footage.

9. **Battery Placement**

   - Center of Gravity Adjustment: The battery is often the heaviest component, so its placement is crucial for balancing the drone. Consider using a sliding battery tray for fine-tuning the CG.

- Secure Mounting: Ensure the battery is securely mounted to avoid it shifting during flight, which could disrupt balance.

10. Environmental Considerations

- Weatherproofing: If the drone will be used in various weather conditions, consider weatherproofing components or placing them inside protective enclosures.

- Environmental Sensors: Ensure sensors like barometers or compasses are placed away from components that could interfere with their readings, such as magnets or electronics.

11. Aesthetics and Aerodynamics

- Streamlined Design: Position components to minimize drag and improve the drone's aerodynamic profile.

- Visibility: If needed, consider the placement of LEDs or other markers for better visibility during flight.

- Considering these factors will help you achieve a well-balanced, stable, and reliable drone. (ChatGPT, 2024)

Copilot Response:

When placing components onto a drone, there are several important factors to consider to ensure optimal performance and safety:

Weight Distribution: Ensure that the weight is evenly distributed across the drone to maintain balance and stability during flight. Uneven weight distribution can cause the drone to tilt or become difficult to control.

Center of Gravity: The center of gravity should be as close to the center of the drone as possible. This helps in achieving stable flight and better maneuverability.

Component Placement: Place heavier components, such as the battery and motors, closer to the center of the drone. Lighter components, like sensors and cameras, can be placed further out. This helps in maintaining the drone's balance.

Accessibility: Ensure that critical components, such as the battery and flight controller, are easily accessible for maintenance and replacement. This will save time and effort during repairs or upgrades.

Vibration Dampening: Use vibration dampening materials or mounts for sensitive components like the flight controller and camera. This helps in reducing vibrations that can affect the performance and quality of the drone's output.

Cooling and Ventilation: Ensure that components that generate heat, such as the motors and electronic speed controllers (ESCs), have adequate cooling and ventilation. Overheating can lead to component failure.

Wiring and Connections: Keep the wiring neat and secure to prevent any loose connections or interference with moving parts. Use zip ties or cable organizers to manage the wires effectively.

Safety Precautions: Always follow the manufacturer's guidelines and safety precautions when assembling and placing components on your drone. This includes wearing protective gear and working in a safe environment123.

By considering these factors, you can ensure that your drone is well-balanced, safe, and performs optimally. Do you have any specific components or configurations in mind for your drone? (Copilot, 2024)

Gemini Response:

Factors to Consider When Placing Components on a Drone

When placing components on a drone, consider the following factors to ensure optimal performance, stability, and safety:

Weight Distribution

- Balance: Ensure the drone is balanced to prevent it from tilting or spinning uncontrollably.
- Center of Gravity: Place heavier components closer to the center of the drone to maintain stability.
- Payload: If carrying a payload, consider its weight and distribution when placing components.

Center of Lift

- CoL: The center of lift is the point where the drone's lift force is concentrated.
- Alignment: Align the center of lift with the center of gravity to minimize pitching and rolling.

Propeller Interference

- Clearance: Ensure components are positioned to avoid interference with the propellers.
- Safety: Prevent objects from being struck by the propellers, which can cause damage or injury.

Electrical Interference

- EMI: Avoid placing components near sensitive electronics that could be affected by electromagnetic interference (EMI).
- Shielding: Use shielding or grounding techniques to minimize EMI.

Aerodynamic Considerations

- Drag: Minimize drag by placing components in a streamlined manner.
- Lift: Consider how components can affect the drone's lift generation.

Component Compatibility

- Size and Shape: Ensure components fit within the frame and do not obstruct other parts.
- Power Requirements: Verify that the drone's power supply can handle the combined power draw of all components.
- Compatibility: Ensure that components are compatible with each other and with the drone's overall design.

Safety and Regulations

- Regulations: Adhere to local and national regulations regarding drone operations.
- Safety Features: Consider incorporating safety features like redundancy, failsafe mechanisms, and emergency landing systems.

Additional Tips:

- Plan Ahead: Create a layout or diagram before assembling the drone.
- Experiment: Test different component placements to find the optimal configuration.
- Documentation: Keep detailed records of your component placement decisions.

By carefully considering these factors, you can build a drone that is well-balanced, stable, and safe to operate. (Gemini, 2024)

Case Study #2

Prompt: "What safety considerations should I consider when selecting a battery for a drone controller?"

ChatGPT Response:

When selecting a battery for a drone controller, it's important to consider the following safety considerations to ensure reliable performance and avoid hazards:

1. **Battery Chemistry**
    - Lithium Polymer (LiPo) batteries are popular due to their high energy density, but they are also sensitive to improper handling.
    - Lithium-Ion (Li-Ion) is safer but may not provide as high power output as LiPo batteries.
    - Nickel-Metal Hydride (NiMH) or Alkaline batteries are safer but less common due to lower energy density and shorter runtime.
    - Ensure the battery chemistry is appropriate for your specific controller and usage.
2. **Voltage Compatibility**
    - Ensure the battery voltage matches the required input of your drone controller. Over-voltage can damage internal components, while under-voltage may cause the controller to fail during operation.
    - Controllers typically specify an operating voltage range (e.g., 3.7V–12V).
3. **Capacity (mAh)**

- Choose a battery with sufficient capacity to last the duration of your drone flights. Using an under-capacity battery may lead to mid-flight failures.
- Avoid overloading the controller with a battery that’s too large, as this can lead to overheating.

4. **Discharge Rate (C-Rating)**

- The C-rating indicates how quickly a battery can safely discharge. Make sure the discharge rate matches the power demands of the controller.
- A mismatch in discharge rates can cause overheating or damage the controller.

5. **Battery Protection Features**

- Look for batteries with built-in overcharge, over-discharge, and short-circuit protection to prevent accidents.
- Some high-end batteries may also have thermal protection to shut down if they overheat.

6. **Battery Quality and Brand**

- Use reputable brands that are known for quality and safety. Avoid counterfeit or low-cost knock-offs, as they may not meet safety standards.
- Check for certifications like UL, CE, or RoHS to ensure compliance with safety regulations.

7. **Charging Considerations**

- Use a compatible charger designed for the specific battery type. Mismatched chargers can lead to overcharging, overheating, or fire risks.
- Never leave batteries unattended while charging, especially LiPo batteries, as they are more prone to catching fire if something goes wrong.

8. **Storage and Handling**

- Store batteries in a cool, dry place away from direct sunlight or extreme temperatures.
- Use fireproof storage bags or containers for LiPo batteries, which are prone to swelling or combustion if damaged.
- Avoid physical damage, punctures, or dropping the battery, which could cause internal short circuits.

9. **Cycle Life**

- Keep track of charge cycles (the number of times the battery has been charged and discharged). Batteries wear out over time, and old batteries can become unstable and pose safety risks.
- Replace the battery once it shows signs of degradation (e.g., swelling, reduced capacity).

10. **Environment and Usage Conditions**

- Extreme heat or cold can impact battery performance and safety. Avoid exposing the battery to harsh conditions, as this can cause swelling, reduced capacity, or even thermal runaway.
- Make sure the battery isn't exposed to moisture or water unless it is specifically rated as waterproof.

By considering these factors, you can minimize the risk of accidents and ensure safe and reliable operation of your drone controller.

Copilot Response:

When selecting a battery for your drone controller, it's crucial to consider several safety factors to ensure optimal performance and longevity:

1. **Battery Type:** Most drone batteries are Lithium-Polymer (LiPo) due to their high energy density. Ensure the battery type is compatible with your drone controller.

2. **Capacity and Voltage:** Choose a battery with the appropriate capacity (mAh) and voltage (V) for your drone controller. Higher capacity and voltage can provide longer flight times but may also require more robust safety measures.

3. **Charging Safety:** Use only the manufacturer-recommended chargers and cables. Avoid overcharging and interruptions during charging, as these can lead to battery damage or even fire hazards.

4. **Storage Conditions:** Store batteries in a cool, dry place away from direct sunlight and heat sources. High temperatures and humidity can degrade battery performance and safety.

5. **Physical Protection:** Protect the battery from physical impacts and water damage. A damaged battery can pose significant safety risks.

6. **Discharge Levels:** Avoid over-discharging the battery. Most LiPo batteries have a low-voltage cutoff to prevent damage, but it's good practice to monitor and maintain proper discharge levels.

7. **Short Circuit Prevention:** Ensure proper insulation and avoid exposing the battery terminals to conductive materials to prevent short circuits.

By keeping these considerations in mind, you can help ensure the safe and efficient operation of your drone controller.

Gemini Response:

When choosing a battery for your drone controller, consider the following safety factors:

1. Battery Type:

- **Lithium Polymer (LiPo) batteries:** While they offer high energy density, they can be prone to overheating and potential fires if mishandled. Ensure you purchase reputable brands and follow charging and storage guidelines.

- **Lithium-ion (Li-ion) batteries:** These are generally safer than LiPo batteries but might have lower energy density.

2. Voltage and Amperage:

- **Voltage:** Ensure the battery's voltage matches the controller's requirements. A higher voltage might provide longer flight times but could also be more dangerous if mishandled.

- **Amperage:** A higher amperage can provide more power but might also increase the risk of overheating. Choose a battery with an amperage rating suitable for your controller's specifications.

3. Battery Protection Features:

- **Overcharge protection:** This prevents the battery from being charged beyond its capacity, reducing the risk of overheating and fire.

- **Overdischarge protection:** This prevents the battery from being discharged too low, which can damage it.

- **Short circuit protection:** This safeguards the battery from short circuits that can cause rapid discharge and potential fires.

4. Charging Practices:

- **Dedicated chargers:** Use chargers specifically designed for LiPo or Li-ion batteries.

- Safe charging environment: Charge batteries in a well-ventilated area away from flammable materials.

- **Supervision:** Never leave charging batteries unattended.

5. Storage:

- **Proper storage:** Store batteries in a cool, dry place. Avoid extreme temperatures.

- **Storage bags:** Consider using fire-resistant battery storage bags to minimize risks.

6. Manufacturer Reputation:

- **Reputable brands:** Purchase batteries from well-known manufacturers with a good reputation for quality and safety.

By following these guidelines, you can significantly reduce the risk of accidents and ensure a safer flying experience

Case Study #3

Prompt: "What are important parameters to consider when selecting sensors for a search and rescue drone?"

ChatGPT Response:

"When selecting sensors for a search and rescue (SAR) drone, it is crucial to consider a balance between the technical capabilities of the sensors and the specific mission requirements. Here are key parameters to consider:

1. **Environmental Conditions**
    - **Operating temperature range:** The sensors need to withstand the temperatures and weather conditions of the target environment (extreme cold, heat, humidity, etc.).
    - **Ingress Protection (IP) rating:** Sensors should be resistant to dust, water, and other environmental hazards, especially if they will be used in rugged or unpredictable conditions like forests, mountains, or flood zones.
2. **Detection Capabilities**
    - **Sensor type and purpose:** Different sensors serve different purposes in SAR operations:
        - **Thermal cameras** detect heat signatures from people or animals.
        - **RGB cameras** provide visual imagery for navigation and identification of key landmarks.
        - **LiDAR** can map terrain or dense vegetation for navigation in difficult-to-reach areas.
        - **Ultrasonic or infrared sensors** help avoid obstacles in environments with low visibility.
    - **Range:** Ensure that the sensor's detection range is appropriate for the intended altitude and distance at which the drone will operate.
    - **Resolution and precision:** For cameras, higher resolution improves image quality, while for range sensors (LiDAR, ultrasonic), precision is key to detecting small objects.
3. **Weight and Size**
    - **Payload capacity:** Drones have limited weight capacities, so sensors must be lightweight to avoid reducing the drone's flight time or maneuverability.

- **Compactness:** Smaller sensors reduce overall space consumption, allowing more sensors or other equipment to be mounted on the drone.

4. **Power Consumption**

- **Battery life:** High power-consuming sensors (like LiDAR or high-resolution cameras) drain the drone's battery faster, reducing flight duration. Low-power sensors are preferable when long missions are required.

- **Voltage compatibility:** Ensure that sensors can operate with the power supply provided by the drone without requiring complex power management systems.

5. **Data Transfer and Processing**

- **Interface compatibility:** Sensors need to communicate efficiently with the drone's onboard systems. Common interfaces include USB, SPI, I2C, and UART. Data transfer speed should be fast enough to process real-time information during rescue missions.

- **Processing power:** Ensure the drone's onboard processor (like the Jetson Orin in SPARROW's case) can handle the data from all sensors without excessive delay.

6. **Field of View (FOV)**

- **Coverage area:** Cameras and LiDARs need a wide enough field of view to cover a large area during a single pass. In SAR operations, large area coverage helps in scanning quickly.

- **Adjustable FOV:** Some applications benefit from adjustable FOV (such as zoom capabilities) for both broad scanning and detailed close-ups.

7. **Durability and Reliability**

- **Shock and vibration resistance:** Drones are exposed to physical stress during takeoff, landing, and flight. Sensors should be robust enough to handle these conditions without losing calibration or breaking down.

- **Reliability in diverse terrains:** Sensors must perform consistently in various terrains, such as forests, mountains, urban environments, and even during night or low-visibility conditions.

8. **Cost**

- **Budget constraints:** While high-end sensors provide superior capabilities, they come at a high cost. It is important to balance cost and performance. Consider more affordable options that meet the minimum requirements for the SAR mission (as with SPARROW's choice of the ELP-SUSB1080P01-LC1100 camera).

- **Maintenance and replacement:** Sensors that are prone to damage or wear may require frequent replacement or maintenance, increasing long-term costs.

9. **Latency**

   - **Real-time feedback:** In SAR operations, timely information is crucial. Ensure that the sensor can deliver real-time or near-real-time data with minimal latency to aid in decision-making during critical operations.

10. **Integration and Compatibility**

   - **Ease of integration:** Sensors that are easy to integrate with the drone's onboard system and software (e.g., ROS, PX4) save time during the design and testing phases.

   - **Modular design:** Modular sensors allow for easier upgrades or replacements if the mission parameters change in the future.

These parameters help ensure that sensors selected for a SAR drone are capable of performing the intended tasks efficiently while being reliable and cost-effective. For SPARROW's project, factors like weight, power consumption, range, and cost were key in selecting their camera and GPS systems." (ChatGPT, 2024)

Copilot Response:

"When selecting sensors for a search and rescue drone, several key parameters should be considered to ensure effective and efficient operations:

1. Resolution and Range: High-resolution sensors can capture detailed images and videos, which are crucial for identifying survivors and assessing damage. The range determines how far the sensor can detect objects or heat signatures.

2. Thermal Imaging: Thermal cameras are essential for detecting heat signatures, especially in low-visibility conditions or at night. They can help locate survivors who might be hidden from plain sight

3. LIDAR (Light Detection and Ranging): LIDAR sensors can create detailed 3D maps of the terrain, which is useful for navigating through complex environments and identifying obstacles.

4. Obstacle Detection: Sensors that can detect and avoid obstacles are crucial for safe navigation, especially in cluttered or disaster-stricken areas.

5. Light Sensitivity: Sensors should perform well in various lighting conditions, including low-light and nighttime operations.

6. Size and Weight: The sensors should be lightweight and compact to not hinder the drone's flight capabilities and battery life.

7. Integration with AI: Sensors that can be integrated with artificial intelligence and machine learning algorithms can enhance the drone's ability to autonomously identify objects of interest and alert human operators.

8. Durability and Weather Resistance: Sensors should be durable and able to withstand harsh environmental conditions, such as rain, dust, and extreme temperatures.

9. Battery Life: The power consumption of the sensors should be optimized to ensure the drone can operate for extended periods without frequent recharging.

10. Cost: Budget constraints may also play a role in sensor selection, balancing performance with affordability.

These parameters will help ensure that the search and rescue drone is equipped to handle various challenges and perform its mission effectively. Do you have a specific scenario or environment in mind for the drone's use?" (Copilot, 2024)

Gemini Response:

"**Important Parameters for Selecting Sensors for a Search and Rescue Drone**

When selecting sensors for a search and rescue drone, it's crucial to consider factors that will optimize the drone's effectiveness in locating and assisting individuals in distress. Here are some key parameters to keep in mind:

1. **Sensor Type and Capabilities:**

    - **Visual Cameras:** High-resolution cameras for clear identification of objects and people.
    - **Thermal Cameras:** Detect heat signatures, making them invaluable for nighttime search and rescue operations and locating individuals trapped in collapsed structures.
    - **LiDAR (Light Detection and Ranging):** Create 3D maps of the terrain, aiding in navigation and obstacle avoidance.
    - **Infrared Sensors:** Similar to thermal cameras, but detect infrared radiation.
    - **Multispectral Sensors:** Capture images across multiple wavelengths, providing additional information about the environment.

2. **Range and Resolution:**

    - **Range:** The distance at which the sensor can effectively detect and identify objects.
    - **Resolution:** The level of detail the sensor can capture. Higher resolution is crucial for identifying individuals and small objects.

3. **Payload Capacity:**
    - The drone's ability to carry the weight of the sensor(s) and any additional equipment.
4. **Power Consumption:**
    - The sensor's energy usage should be compatible with the drone's battery life.
5. **Environmental Factors:**
    - Temperature: Sensors should be able to operate in a wide range of temperatures, especially in extreme conditions.
    - Weather: Consider factors like rain, fog, and dust, which can affect sensor performance.
6. **Data Processing and Transmission:**
    - The sensor's ability to process data in real-time and transmit it to the operator.
7. **Cost**
    - The initial cost of the sensor and any ongoing maintenance or operating expenses.
8. **Ease of Use:**
    - The sensor's user interface and how easily it can be integrated with the drone's system.
9. **Reliability and Durability:**
    - The sensor's ability to withstand harsh conditions and provide consistent performance.

Example of a Sensor Combination:

For a search and rescue drone, a combination of a high-resolution visual camera, a thermal camera, and a LiDAR sensor could be ideal. This setup would provide the ability to identify individuals in both day and night conditions, navigate challenging terrain, and create detailed maps of the search area.

By carefully considering these factors, you can select sensors that will optimize the capabilities of your search and rescue drone and increase its effectiveness in saving lives." (Gemini, 2024)

Case Study #4

Prompt: "What are some important things to consider when wanting to select wireless communication hardware and protocols?"

ChatGPT Response:

Selecting wireless communication hardware and protocols involves several key considerations to ensure compatibility, reliability, and efficiency. Here are some important factors to consider:

1. Application Requirements

Data Rate: Determine the required data transfer rate for your application. Higher data rates are needed for applications like video streaming, while lower rates may suffice for simple sensor data.

Range: Assess the required transmission distance. Different protocols have varying ranges, from a few meters to several kilometers.

Latency: Consider the acceptable delay in data transmission. Low-latency communication is critical for real-time applications.

2. Environment

Interference: Evaluate the potential for interference from other wireless devices or physical barriers (e.g., walls, buildings). This affects the choice of frequency band and modulation technique.

Outdoor vs. Indoor: Different hardware may be optimized for outdoor conditions (weather-resistant) or indoor settings (better signal through walls).

3. Power Consumption

Battery Life: For battery-operated devices, consider low-power protocols like Bluetooth Low Energy (BLE) or Zigbee, which are designed for energy efficiency.

Power Supply: If the devices will be powered by mains electricity, higher power consumption may be acceptable.

4. Scalability

Ensure the chosen solution can accommodate future growth in device numbers or data volume. Some protocols support large networks better than others.

5. Security

Evaluate the security features of the protocols, such as encryption methods and authentication mechanisms. This is crucial for protecting sensitive data.

6. Cost

Consider both the initial cost of hardware and ongoing operational costs. Some protocols may require more expensive hardware or maintenance.

7. Compatibility and Standards

Ensure that the hardware and protocols are compatible with existing systems and adhere to industry standards to facilitate integration.

8. Ease of Use

Look for hardware and protocols that are user-friendly and have good documentation and community support. This can reduce development time and costs.

9. Protocol Characteristics

Understand the strengths and weaknesses of various wireless protocols (e.g., Wi-Fi, Zigbee, LoRa, Cellular, etc.):

Wi-Fi: High data rates, good for local networks but higher power consumption.

Zigbee: Low power, suitable for mesh networks, ideal for IoT applications.

LoRa: Long-range, low-power, suitable for sensor networks.

Cellular: Good for long-range communication and mobility, but may incur higher costs.

10. Regulatory Compliance

Ensure compliance with local regulations regarding wireless communication, including frequency bands and power limits.

Conclusion

Choosing the right wireless communication hardware and protocols involves balancing these factors according to the specific needs of your application. Conducting a thorough analysis of these considerations will help you make an informed decision.

Copilot Response:

Selecting the right wireless communication hardware and protocols is crucial for ensuring efficient and reliable communication. Here are some important factors to consider:

1. Data Transfer Speed: Depending on your application, you may need high-speed data transfer (e.g., Wi-Fi) or lower speeds for simpler tasks (e.g., Bluetooth Low Energy).

2. Range: Consider the distance over which the devices need to communicate. Some protocols like Wi-Fi offer several kilometers of coverage, while others like Bluetooth are better for short-range communication.

3. Power Consumption: Evaluate the power requirements of your devices. Low-power protocols like Bluetooth Low Energy or Zigbee are ideal for battery-operated devices.

4. Interference and Reliability: Assess the environment where the devices will operate. Some protocols are more susceptible to interference from other devices and networks

5. Compatibility: Ensure that the chosen protocol is compatible with existing devices and systems. This is especially important in environments with multiple device manufacturers.

6. Security: Consider the security features of the protocol to protect data from unauthorized access. Protocols like Wi-Fi and Bluetooth have built-in security measures, but additional security layers may be needed.

7. Cost: Evaluate the cost of the hardware and any licensing fees associated with the protocol. This can vary significantly between different options.

8. Scalability: Think about whether the protocol can handle the number of devices you plan to connect. Some protocols are better suited for large-scale networks than others.

Gemini AI Response:

When selecting wireless communication hardware and protocols, several key factors should be carefully evaluated to ensure optimal performance and suitability for your specific application.

1. Range and Coverage:

- **Distance:** How far do you need the signal to travel?
- **Environment:** Will there be obstacles like walls, trees, or bodies of water that can interfere with the signal?
- **Coverage Area:** How large of an area do you need to cover?

2. Data Rate and Bandwidth:

- **Throughput:** How much data needs to be transmitted per unit time?
- **Latency:** How quickly does data need to be transmitted?
- **Bandwidth:** What is the required bandwidth for your application?

3. Power Consumption:

- **Battery Life:** If using battery-powered devices, how long should the battery last?
- **Power Efficiency:** How efficient is the hardware in terms of power consumption?

4. Cost:

- **Hardware Cost:** What is the initial cost of the hardware (e.g., transmitters, receivers, antennas)?
- **Operating Costs:** Are there any ongoing costs associated with the technology (e.g., licensing fees, network access fees)?

5. Security:

- **Encryption:** Does the protocol provide adequate encryption to protect data from unauthorized access?
- **Authentication:** How are devices authenticated to prevent unauthorized access?

6. Interference:

- **Frequency Interference:** Are there other wireless devices operating on the same frequency that could interfere with the signal?
- **Noise:** Is there any environmental noise that could affect the signal quality?

7. Regulatory Compliance:

- **Licensing:** Does the technology require any specific licenses or permits?
- **Standards:** Does the technology comply with relevant industry standards (e.g., FCC, CE)?

8. Scalability:

- **Capacity:** Can the system handle an increasing number of devices or data traffic?
- **Flexibility:** Can the system be easily expanded or modified to meet future needs?

9. Reliability:

- **Error Rates:** How often do errors occur during transmission?
- **Fault Tolerance:** Can the system recover from failures or interruptions?

10. Ease of Use and Maintenance:

- **Complexity:** How easy is it to set up, configure, and maintain the system?
- **Support:** Is there adequate technical support available?

By carefully considering these factors, you can select the most appropriate wireless communication hardware and protocols for your specific needs.

Case Study #5

Prompt: "What should the team consider when developing a detection algorithm?"

ChatGPT Response:

When developing a detection algorithm, your team should consider the following aspects:

1. **Accuracy and Precision**: Ensure the algorithm can accurately identify the target objects or features while minimizing false positives and false negatives. Fine-tuning the model to achieve high accuracy is crucial, especially for search and rescue operations where missing a target could be critical.

2. **Speed and Efficiency**: The algorithm should process data quickly, especially if it's intended for real-time detection. Optimize for computational efficiency to handle high-resolution images or video feeds without significant lag.

3. **Scalability**: The algorithm should be adaptable to different scenarios or environments. For instance, it should perform well regardless of varying lighting conditions, weather, or terrain that may be encountered in the field.

4. **Robustness**: Ensure the detection algorithm can handle noisy data, occlusions, varying object sizes, and different orientations. It should be resilient to changes in image quality or other unpredictable factors that could interfere with detection accuracy.

5. **Hardware Constraints**: Consider the computational resources available on the drone or controller, such as processing power, memory, and battery life. The algorithm should be optimized to run efficiently within these limitations, especially if deployed on drones with limited onboard processing capabilities.

6. **Training Data Quality**: Use a diverse and representative dataset to train the algorithm. Include various examples of the objects or patterns to be detected under different conditions, so the model generalizes well to new scenarios.

7. **Integration with Other Systems**: Ensure seamless integration with your existing hardware, communication systems, and the overall drone control system. The algorithm should work alongside other modules, such as computer vision, GPS, and communication protocols.

8. **Adaptability and Learning**: Consider implementing machine learning techniques that allow the algorithm to improve over time. For example, it could adapt to changes in the environment or learn from false detections to enhance accuracy.

9. **Battery and Power Consumption**: Optimize the algorithm to minimize power usage, especially if it's intended to run on battery-powered drones. Efficient processing can extend operational time in the field.

10. **Legal and Ethical Considerations**: Ensure compliance with privacy laws, safety regulations, and ethical guidelines, particularly if the algorithm captures or processes sensitive data.

These factors are essential to developing a robust, efficient, and effective detection algorithm tailored to your project's requirements. (ChaptGPT, 2024)

Copilot Response:

When developing a detection algorithm, there are several important considerations that the team should keep in mind:

1. Data Quality and Diversity:

- **High-quality data**: Ensure that the training data is accurate, relevant, and representative of the problem domain.
- **Diverse data**: Include diverse examples to avoid bias and improve generalization.

2. Algorithm Selection:
    - Choose an appropriate algorithm based on the problem type (e.g., classification, regression, anomaly detection).
    - Consider trade-offs between accuracy, interpretability, and computational complexity.
3. Feature Engineering:
    - Select relevant features that capture essential information.
    - Normalize or scale features to ensure consistent behavior across different scales.
4. Model Evaluation:
    - Use appropriate evaluation metrics (e.g., precision, recall, F1-score) to assess model performance.
    - Validate the model on a separate test dataset to avoid overfitting.
5. Bias and Fairness:
    - Detect and mitigate biases in the data and model.
    - Ensure fairness by considering protected attributes (e.g., gender, race) during model development.
6. Interpretability:
    - Choose models that provide interpretable results.
    - Use techniques like feature importance analysis or SHAP values to understand model decisions.
7. Scalability and Real-Time Processing:
    - Design for scalability to handle large datasets efficiently.
    - Optimize memory usage and consider distributed processing.
    - Implement online learning for real-time detection.
8. User Trust and Feedback:
    - Provide clear explanations of model decisions.

- ○ Use effective visualizations to enhance interpretability.
- ○ Foster trust by incorporating user feedback for continuous improvement.

Remember that developing a robust detection algorithm is an iterative process that requires expertise in both threats and machine learning. The model's effectiveness heavily depends on data quality and continuous adaptation to new and evolving threats12345. 🚀

https://www.forasoft.com/blog/article/machine-learning-algorithims-anomaly-detection

https://link.springer.com/article/10.1007/s11831-024-10134-2

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https://www.brookings.edu/articles/algorithmic-bias-detection-and-mitigation-best-practices-and-policies-to-reduce-consumer-harms/ (Copilot, 2024)

Claude AI Response:

When developing a detection algorithm, there are several important factors the team should consider:

1. Data quality and quantity:

- Ensure you have a large, diverse, and representative dataset

- Consider data cleaning and preprocessing steps

- Address any class imbalance issues

2. Algorithm selection:

- Choose appropriate algorithms based on the problem type (e.g. classification, anomaly detection)

- Consider both traditional machine learning and deep learning approaches

- Evaluate pros and cons of different algorithms for your specific use case

3. Feature engineering:

- Identify relevant features that capture important signals

- Create new features if needed

- Consider dimensionality reduction techniques if dealing with high-dimensional data

4. Performance metrics:

- Select appropriate evaluation metrics (e.g. accuracy, precision, recall, F1-score)

- Consider the costs of false positives vs false negatives in your specific domain

5. Computational resources:

- Assess available hardware and runtime requirements

- Consider scalability for real-time or large-scale deployment

6. Interpretability:

- Determine if model interpretability is important for your use case

- Consider using explainable AI techniques if needed

7. Robustness and generalization:

- Test on diverse datasets to ensure the algorithm generalizes well

- Consider potential adversarial attacks or edge cases

8. Ethical considerations:

- Assess potential biases in the data or algorithm

- Consider privacy implications and data protection regulations

9. Deployment and maintenance:

- Plan for model versioning and updates

- Consider monitoring and retraining strategies

10. Domain expertise:

- Incorporate domain knowledge into the algorithm design

- Consult with subject matter experts throughout the development process

Would you like me to elaborate on any of these points or discuss a specific aspect of detection algorithm development in more detail? (Claude, 2024)

Case Study #6

ChatGPT Response:

To live demonstrate human detection using both a regular camera and a thermal camera from a drone, you'll need to carefully plan the technical and practical aspects of the demo to show the system's capabilities in real-world conditions. Here's a step-by-step guide:

1. Pre-Demonstration Setup

- Test Environment: Choose a location that simulates a search and rescue scenario, such as a large open field, wooded area, or mock disaster zone. Ensure that it has different terrains and obstacles to highlight the effectiveness of both cameras.
- Drone Preparation: Mount both the regular RGB camera and the FLIR Boson thermal camera on the drone. Ensure that the cameras are properly calibrated, and the gimbal system is stabilized to provide smooth footage.
- Data Transmission Setup: Ensure the drone has real-time video feed transmission capabilities. You'll need to stream both the RGB and thermal camera feeds to a ground station (laptop or tablet) for live display.
- Software Preparation: Set up software to display side-by-side live feeds from both cameras. This could be done using MAVLink for drone communication and a custom app for video streaming (or a software like QGroundControl if using Pixhawk or similar).

2. Demonstration Introduction

- Overview of Objectives: Briefly explain the context—how human detection is crucial in search and rescue missions and why using both RGB and thermal cameras enhances the system's effectiveness in different environments.
- Camera Capabilities: Describe the capabilities of each camera:
- The RGB camera is for standard visual identification.
- The thermal camera detects heat signatures, especially in low-light or obstructed environments.

3. Live Drone Flight Demonstration

- Drone Takeoff: Start by flying the drone over the demonstration area, maintaining a height where both cameras have a clear view of the ground. For human detection, keep the altitude low enough (around 50-100 feet depending on camera resolution) to ensure accuracy.
- Real-Time Feed Display: On a large screen (or multiple screens), display the live feed from both the RGB and thermal cameras side by side, allowing the audience to see the contrast between the two.
- On the RGB feed, you'll see regular visual data.
- On the thermal feed, heat signatures should be visible as people or objects with distinct temperature differences.
- Human Presence Detection: Have a few volunteers move through the area, both in open spaces and behind obstacles (like trees or structures). Show how the RGB camera detects humans visually, while the thermal camera detects heat signatures, even if the volunteers are partially obstructed.
- Detection Highlighting: Use computer vision algorithms (like YOLO for RGB and thresholding for thermal) to detect humans in real-time. Highlight detected humans by bounding boxes in both feeds, showing how the system accurately detects people across different environments.

4. Demonstrate Camera Fusion and AI Integration

- Camera Fusion: If your system supports it, show how data from both the thermal and RGB cameras are fused to confirm human presence. This can involve overlaying the thermal data on the RGB feed or triggering alerts when both cameras detect a human presence simultaneously.
- For example, as volunteers walk into shaded areas or behind partial obstacles, demonstrate how the thermal camera continues to track their heat signature when the RGB camera might lose visibility.
- AI-Assisted Detection: If you're using AI, demonstrate how the AI processes the combined data from both cameras to increase detection accuracy. Show how the system reduces false positives by cross-verifying the detection from both sensors.

5. Scenario-Based Demonstration

- Day and Night Conditions: To showcase the thermal camera's advantage in low-light conditions, start the demo during the day and continue it into dusk or night. The RGB camera's effectiveness will decrease in low light, while the thermal camera will continue to detect heat signatures, proving its value in night operations.
- Search and Rescue Example: Create a scenario where a person is "lost" in an area with obstacles. Fly the drone over the area and demonstrate how the system detects the person using both the regular and thermal cameras, highlighting how the thermal camera excels at detecting humans hidden by debris or low visibility.
- Dynamic Human Tracking: Have the volunteers move, and show how the system continues to track them in real-time using both cameras. The drone should autonomously or manually follow the detected person, showing the system's responsiveness.

6. Post-Processing and Analysis

- Live Metrics: Display detection metrics such as accuracy, range, and latency in real-time on the screen. This helps the audience understand the technical performance of the detection system.
- Comparison of Results: After the live demo, provide a quick comparison of how well each camera performed in different scenarios:
- RGB camera: Great for daylight detection, color-based identification.
- Thermal camera: Excellent in low light, detecting humans behind obstacles (heat signatures).
- Real-World Application: Discuss how this dual-camera setup could be used in real-world operations, highlighting its practical benefits for search and rescue missions.

7. Conclusion and Q&A

- Summarize the key takeaways from the demonstration, emphasizing the strengths of combining regular and thermal cameras for human detection.
- Open the floor for questions to explain technical details or challenges the system addresses. (ChatGPT, 2024)

Copilot Response:

Demonstrating human detection via both a regular camera and a thermal camera from a drone can be an impressive and practical showcase. Here's a step-by-step guide to help you set up and execute this demonstration:

1. Equipment Setup

- Drone: Choose a drone capable of carrying both a regular camera and a thermal camera. DJI Matrice 300 RTK is a good option as it supports multiple payloads.
- Regular Camera: Use a high-resolution camera like the DJI Zenmuse X5S.
- Thermal Camera: A thermal camera such as the FLIR Vue Pro R is suitable for capturing thermal images.

2. Software and Algorithms

- Object Detection Models: Use YOLO (You Only Look Once) for real-time object detection on the regular camera feed1.
- Thermal Detection Models: Use a model like ThermalYOLO, which is fine-tuned for thermal images2.

3. Integration and Synchronization

- Data Fusion: Integrate the data streams from both cameras. This can be done using software like ROS (Robot Operating System) to synchronize and process the data in real-time3.
- Edge Computing: Use an onboard computer like the NVIDIA Jetson Orin to run the detection algorithms directly on the drone4.

4. Live Demonstration Setup

- Location: Choose an open area with clear visibility and minimal obstructions.
- Safety Measures: Ensure all safety protocols are in place, including a safe flight path and emergency procedures.

5. Execution of the Demonstration

- Pre-Flight Checks: Verify that both cameras are functioning correctly and that the detection algorithms are running smoothly.
- Flight Path: Plan a flight path that allows the drone to capture both regular and thermal images of the target area.
- Real-Time Detection: Stream the live feed from both cameras to a display screen. Run the detection algorithms to identify humans in real-time.
- Comparison Display: Show the outputs from both cameras side-by-side to highlight the differences and advantages of each type of detection. Emphasize how thermal imaging can detect humans in low visibility conditions, such as darkness or smoke5.

6. Applications and Use Cases

- Security: Demonstrate how the system can be used for perimeter security, detecting intruders even in complete darkness.
- Search and Rescue: Show how thermal imaging can help locate people in disaster scenarios where visibility is poor.
- Smart Environments: Explain how this technology can be integrated into smart homes or buildings for enhanced safety and monitoring. (Copilot, 2024)

Gemini Response:

Demonstrating Human Detection via Camera and Thermal Camera from a Drone

Here's a step-by-step guide on how to demonstrate human detection using both a camera and a thermal camera mounted on a drone:

1. Equipment Setup:

- Drone: Choose a drone with a payload capacity to carry both cameras.
- Cameras: Select a high-resolution camera and a thermal camera that are compatible with the drone.
- Software: Ensure you have appropriate software for image processing, object detection, and data analysis.

2. Flight Planning:

- Location: Choose a location with varied terrain and potential human activity (e.g., park, beach, outdoor event).
- Flight Path: Plan a flight path that covers different angles and distances to test the cameras' detection capabilities under various conditions.

3. Camera Calibration:

- Calibration: Ensure both cameras are properly calibrated to align their images and provide accurate measurements.
- Sensitivity: Adjust the sensitivity settings of both cameras to optimize human detection in different lighting conditions.

4. Data Collection:

- Flight: Fly the drone along the planned path, collecting data from both cameras simultaneously.
- Data Storage: Store the collected images and data for analysis.

5. Image Processing and Analysis:

- Object Detection: Use image processing algorithms to detect human-shaped objects in both camera images.

- Feature Extraction: Extract relevant features from the detected objects (e.g., size, shape, movement).
- Classification: Classify the detected objects as humans or non-humans based on the extracted features.
- Data Fusion: Combine the results from both cameras to improve detection accuracy and robustness.

6. Visualization and Evaluation:

- Visualization: Visualize the detected humans on the camera images and overlay bounding boxes or labels.
- Evaluation: Evaluate the performance of the detection system using metrics like accuracy, precision, recall, and F1-score.

7. Demonstration:

- Presentation: Present the collected data, analysis results, and visualizations to demonstrate the effectiveness of human detection using both cameras.
- Live Demonstration: If possible, conduct a live demonstration by flying the drone and showing real-time human detection.

Key Considerations:

- Lighting Conditions: Test the cameras under different lighting conditions (e.g., day, night, low light).
- Environmental Factors: Consider factors like temperature, humidity, and background clutter that can affect detection accuracy.
- Ethical Considerations: Ensure compliance with privacy regulations and ethical guidelines when collecting and analyzing data.
- Real-World Scenarios: Test the system in real-world scenarios to assess its practical performance.

By following these steps and addressing the key considerations, you can effectively demonstrate the capabilities of human detection using both camera and thermal camera mounted on a drone. (Gemini, 2024)