Low-Cost Passive Aircraft Detection System & Super Resolution Image Device

A means to do surveillance and increase security for less!

Group 2

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Chapter 1: Executive Summary

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Chapter 2: Project Description

2.1 Motivation & Background

RF Device

Along the borders of many different countries, it is very hard for radar and air traffic controllers to detect aircraft. The reason being that it is generally far too expensive for many countries to place large high-power radar systems all over their country. These systems can cost tens of millions of dollars and require advanced infrastructure to implement. As a result, certain locations become dead zones, areas where there are no effective means of surveillance. These so-called "dead zones" make it very easy for illegal activity to happen such as illegal immigration, drug smuggling, or drone surveillance. Not only that, these aircraft may not be using a transponder of any form in order to avoid detection from air traffic control or similar systems. Naturally, this makes it an issue for governments all over the globe. Our project aims to provide a cost-effective and stealthy solution in an effort to help increase security and give governments the peace of mind they are seeking.

As aspiring engineers, senior design projects are a cornerstone of our education and provide several key benefits which include but are not limited to, hands-on application of knowledge, real world problem solving, collaboration and teamwork, and portfolio development. As a group, we must learn to problem solve underpressure, work as a collective unit toward a common goal, and design and showcase a functional product using an innovative approach. With that said, we wanted to work on a project that addressed a significant, real-world challenge.

We knew we had an incredible opportunity before us and a chance to solve a real world problem that incorporated our unique skills and expertise. This problem was introduced to us by Roy H. Wubker Jr. who, through the Department of Defense's Southern Command (SOUTHCOM) is sponsoring this project. Based on the introduction from our sponsor we knew we had an incredible opportunity before us and a chance to solve a real world problem that incorporated our unique skills and expertise. Our sponsor's initial recommendations for solving this problem involved RF detection which led us to brainstorm more ideas, especially those that involved optics and photonics.

This problem poses many challenges but has widespread impact which is why our group decided to take on this project. From this project, we will learn about how to implement a solution to this kind of system and optimize the strengths of our solution. Our group will try to make our solution as low cost as possible and, simultaneously, as stealthy as possible. The harder it is to detect, the longer our proposed solution can relay vital information. Longevity in this case, will also help keep the replacement cost down.

Active radar is a modern radar technique that is used all over the globe to track the direction, altitude, and speed of airplanes. It works by sending out a Radio Frequency beam from an antenna to the desired target direction; The RF beam bounces off of the desired object and then makes its way back to the antenna which is listening for the reflection. Based on the time-of-flight of the signal, it can determine how far the object is, its speed, direction, and more.

Our solution, however, will be to use passive radar. This will not only lower the cost but it will also provide a more simplistic solution as compared to an active radar counterpart. Passive radar works by instead of sending out a beam of RF energy, which requires lots of power, space, and infrastructure, it uses existing RF signals in the environment, and listens for those RF signals to bounce off of the desired object. RF signals in the environment appear in the form of things like FM Radio, GPS, or even the natural resonance of an airplane's motor. By only listening to the radio signals that are reflected off of the object, the amount of power consumed will be cut down. Furthermore, the system will be much harder to find as there was no RF beam emitted from the system to be tracked by enemy countermeasures. It will essentially be completely hidden to any aircraft.

Camera Array

High-resolution imaging systems play a crucial role in various applications, including aerial observations, environmental monitoring, and remote sensing. Traditional high-performance cameras capable of capturing detailed images from long distances are often expensive, with prices reaching $10,000 or more. This cost barrier limits accessibility to advanced imaging capabilities for smaller organizations and research initiatives.

To address this challenge, we propose the development of a cost-effective alternative utilizing an array of low-cost cameras. By leveraging multiple cameras priced at approximately $15 each, we aim to achieve high-resolution imaging comparable to expensive systems while maintaining affordability. The key innovation in this project lies in the strategic arrangement of these cameras, specialized lens systems, a phase corrector plate, and advanced image processing techniques to synthesize a single high-resolution output.

The core of this project is the design and implementation of a curved camera array. Different array configurations, such as circular, rectangular, and elliptical layouts, will be explored to determine the optimal design for capturing and stitching images with minimal distortions. The curved platform will ensure proper alignment of the individual camera fields of view, enabling seamless image stitching and resolution enhancement.

Additionally, a phase corrector plate will be integrated into the system to compensate for wavefront distortions caused by environmental factors, particularly Florida’s high temperature and moisture levels. Over long distances, atmospheric variations can introduce aberrations that degrade image quality. The phase corrector plate will help mitigate these effects, ensuring sharper and more accurate imaging.

Another significant aspect of this project involves optimizing the lens systems used in each camera. Given the low cost of individual cameras, ensuring high optical quality through proper lens selection and calibration will be essential for achieving the desired resolution. Various lens configurations and focal lengths will be tested to maximize image clarity and field of view while minimizing distortions.

The project also involves significant computational work, including image alignment, stitching, and enhancement. By employing advanced image processing techniques, such as super-resolution algorithms, we aim to refine the final output, creating a high-quality image from the combined data of multiple low-cost cameras. The processing pipeline will need to account for differences in individual camera characteristics, such as exposure and optical distortions, to produce a seamless and accurate final image. Additionally, camera synchronization will be another challenge as this system will have to take images of moving objects. If the cameras take their individual images seconds apart, the final image, after processing, will be unusable because the same moving object may appear in multiple areas of the image.

This system has the potential to revolutionize cost-effective imaging solutions for aerial applications. By making high-resolution imaging more accessible, it could benefit fields such as agriculture, disaster response, surveillance, and scientific research. For example, in agricultural monitoring, such a system could provide farmers with detailed crop health data at a fraction of the cost of traditional imaging solutions. In disaster response, the ability to deploy affordable aerial imaging systems could assist emergency teams in assessing damage and planning relief efforts more effectively, such as during hurricanes or fires.

Furthermore, the success of this project could serve as a foundation for future innovations in scalable imaging systems. Demonstrating that high-quality results can be achieved without relying on prohibitively expensive hardware opens up new opportunities for research and development in the field of photonics and imaging science. As technology advances, the principles developed in this project could be extended to other applications, including space-based imaging and autonomous vehicle vision systems. By reducing costs and improving accessibility, this project could contribute to a broader adoption of high-resolution imaging technologies across various industries.

2.2 Existing Products & Related Works

2.2.1 Hensoldt TwInvis

The TwInvis system by Hensoldt is a passive radar that leverages signals in the environment, such as those from FM radio, digital television, or mobile communication devices. It does not emit any signals itself, making it undetectable by traditional radar-detection systems. The TwInvis system monitors reflections of the aforementioned signals off objects, including aircraft, to detect and track their movement. TwInvis passively listens to ambient RF signals emitted by sources in the area, processes how they bounce off objects in the environment, and with an array of these devices, can determine the speed and trajectory of the aircraft.

This technology is very similar to the solution we are proposing and can be applied in stealth aircraft detection, civil air traffic monitoring, and even compliments active radars when integrated with military systems. Since it does not emit its own signals, it avoids detection and interference from hostile forces and makes use of already existing infrastructure which simultaneously allows for wide regional coverage in areas dense with RF signals. However, in areas in which the density and quality of ambient RF signals is poor, this technology is not of much use. In addition, this system requires advanced algorithms to separate useful data from just noise, which increases computational demands.

A key difference between the TwInvis and our proposed solution is the integration of optical components. TwInvis can only function in areas where RF signals are dense enough and only works using RF detection. Our project incorporates an optical component in the form of an infrared camera. This approach can provide a more complete picture of the environment that is being monitored. By implementing an optical component, we can introduce a sort of 2-step verification system to reduce false positives and provide more accurate results. Not only that, capturing video of the aircraft could help the user determine the threat level and could clue the user into the intentions of the aircraft entering their airspace.

2.2.2 Thales Elvira

The Elvira system by Thales is a multisensor electronic support system designed for detection, classification, and tracking of aircraft. It integrates RF signal detection with additional tracking systems, such as optical or infrared sensors. This approach provides a holistic view of the airspace. Elvira detects emissions from communication devices, radars, or other onboard systems of aircraft. It then correlates RF data with other inputs, such as infrared tracking, to improve target identification and accuracy. In a broader sense, Elvira can use advanced algorithms to analyze emission types, origin, and even determine threat level.

This system is ideal for border surveillance as it operates covertly without filing flight plans or transponders. It can also be integrated into ground stations or shipboard systems to enhance situational awareness. By integrating multiple sensors, it is able to minimize false positives and improves tracking in challenging environments. The issue is the cost. The integration of advanced sensors and processing units makes it very expensive to both deploy and maintain. Since the main method of gathering data is the RF system, it could be susceptible to jamming or other countermeasures. In addition, the system is not simple and would require specific training to be effective.

This system, although more complex, does have many similarities to our proposed solution. Both the Elvira system and our project work based on already available RF signals in the area. Using the already existing infrastructure of radio towers, television stations, and mobile devices is a great way to maintain stealth while obtaining the information you seek. However, Elvira systems main trigger is based on RF detection with the secondary trigger being the infrared search and track system. Our project aims to use the RF detection method as the main trigger and the infrared camera system as a means to verify the detected anomaly. With this approach, we could reduce the power consumption of the device which would make for a more effective system overall.

2.2.3 Dedrone RF-300

The Dedrone RF-300 is a passive network-attached radio frequency (RF) sensor designed to detect, classify, and locate drones and their remote controls. It is capable of detecting consumer, commercial, and hobbyist drones by analyzing the RF signals they emit. While primarily focused on drone detection, its capabilities can extend to other aircraft emitting RF signals.

Some key features of this system are the ability for the RF-300 to identify communication between drones and their controllers including both Wi-Fi and non-Wi-Fi drones. It classifies drones by their manufacturer, model, and unique ID. Through internal digital signal processing, the RF-300 is also able to determine the direction of signals from drones and pilots. With multiple RF-300 units, it can triangulate and pinpoint the exact location of both the drone and its operator. Each RF-300 sensor covers a 120-degree area, requiring 3 units to achieve a full 360-degree coverage zone. The typical detection range is up to 1000 km, which can be extended to 1500 km under ideal conditions. The system is also built for extreme environments and can operate between -20 degrees to 55 degrees Celsius. Finally, to power the device, it must be connected via ethernet connection.

In addition to the key features listed, the RF-300 integrates with Drones DroneTracker software, a platform that aggregates and analyzes data from multiple sensors to provide comprehensive airspace security. The integration of this software enables real-time monitoring and alerts and when paired with a camera, offers advanced video analytics to enhance detection and tracking capabilities. The software can catalog all alerts, flight paths, and video footage of drone threats, which can be easily exported. Moreover, the software incorporates a classification engine that recognizes drones of all types. The system makes use of a sophisticated machine learning system trained on millions of data points.

This product, while much more advanced, has many similar components and restrictions as our project. One key thing to notice is that multiple units of the RF-300 are required to have a complete view of the airspace in question. Not only that, multiple units are required in order to determine crucial information like speed and direction of travel. One of the main goals of our project is to eventually be able to detect those key parameters so we have to keep in mind that we’ll need multiple units to be able to do that. We also do not have the software, nor the capabilities to re-produce a similar piece of software so our project will mainly focus on detecting aircraft rather than classifying them. Eventually, a database could be implemented with software that could reference previous images and detection signals.

2.2.4 Summary

Overall, there is a lot of insight to be gained from the systems that exist already today. Given that RF technology has been around for a while, we can see many different interactions of RF detection implemented to many detection systems already due to its stealth capabilities and relative simplicity. Most of these systems also require multiple units to determine localization information. Our project will likely also need to incorporate that if we hope to get accurate location readings. In most cases, we see that RF detection, if enhanced with an optic, usually involves infrared imaging. While IR allows for a more detailed view, it is still susceptible to environmental factors such as rain. For this reason, we chose to use visible light rather than IR. This will prove to be cheaper and will allow for better imaging during the day and can be optimized for different weather conditions in the future. Most of these systems also feature some sort of pan-tilt motor setup to move the camera in the direction of the aircraft. This proves to be a difficult addition and makes things much more complex, especially since our group does not feature a mechanical engineer. For our solution, we aim to only include one mechanical system which will mainly focus on shifting the lenses in the telephoto lens system. This will keep things much simpler and will keep total cost down for the optical enhancement.

2.3.1 Goals & Objectives

RF Device Basic Goals

- Build a unit of similar ability to the ones discussed at a very low cost
- The successful detection of a metal sphere using passive detection. The reason for a metal sphere is due to its ease of detection by radar.
- Measure antenna radiation pattern and classical range measurement.

RF Device Advanced Goals

- The system should be able to detect an aircraft in flight. This will prove that our passive detection system is working as intended.
- The system should be self-sustaining. If the system were to be deployed in the field, it should be able to provide its own power. This may be done via solar, wind, or other types of power generation depending on the deployment location.
- The time it takes to deliver the information from the system to the user should be relatively quick. This will ensure that our system is actually viable and worth implementing.

RF Device Stretch Goals

- The system will be easily implemented and easily manufacturable. The main goal of this project is to provide a low-cost solution which means ease of use and construction is important to consider.
- The system should be connected with other systems to form an array. This will allow for accurate localization and will help the user determine the speed, direction, and location of any aircraft within the detection distance.
- The system should be completely autonomous. This will allow the user to “set it and forget it” and will alert them of possible incursions within their airspace.
- The system should incorporate a false alarm feature.

- Create or utilize a database that can characterize aircrafts and identify the type of plane or drone that is entering the range of the antenna. The system should have the ability to easily install and uninstall enhancements depending on the user's needs. This will be vitally important when it comes to selling the unit. Depending on the user's needs or surrounding environment, they may or may not want certain add-ons or enhancements.

Camera Array Basic Goals

- Arrange 3-9 low cost cameras in an array configuration.
- Capture an image at a distance of 1, 10, and 20 meters and effectively enhance the resolution of the image using image processing techniques.
- Design a simple and stable holder for the camera array configuration.
- Find the simplest way to connect the cameras together to the main computer so that image processing may be done.
- Use code to do image processing and to create a super resolution image.
- Design a lens system and ensure that it has the proper characteristics required for our final desired distance of 100 yards.

Camera Array Advanced Goal

- Arrange a larger number of low cost cameras into the most effective configuration and integrate them into a larger cohesive system.
- Capture an image at a distance of 100 yards and effectively demonstrate that the resolution is enhanced and provides more detail for the viewer.
- Design a lens system for each camera that allows for effective image capture at a distance of 100 yards.
- Design a housing for the lens system that allows for easy swapping in case the object is at a different distance
- Incorporate a phase correction plate to account for any aberrations due to the environment

Camera Array Stretch Goals

- Design multiple, easy to install, lens systems that can be used depending on the desired image capture distance.
- Design a sturdy, stable, and environmentally protected housing for the entire device.
- Design a connecting unit that allows the unit to be attached to a vehicle, such as an airplane, for mobile image capture

2.3.2 Objectives

RF Device Objectives for Basic Goals

- Research, select, and buy quality and cost effective materials and components to create the device
- Ensure proper calibration of spectrum analyzer
- Test all components once they have arrived to ensure they function properly.
- Measure range of detection by using a second antenna.
- Use a second antenna to find the effective beam pattern of the antenna.

RF Device Objectives for Advanced Goals

- Create an algorithm that differentiates noise from aircraft.
- Test the prototype at Dade Collier Airport to see if we can detect passively
- Research means to power the unit autonomously and integrate it (phase 2)
- Test the amount of computer power and latency to process data.
- Increase efficiency of detection algorithms to decrease power draw.

Camera Array Objectives for Basic Goals

- Research and purchase low cost, low resolution cameras to include in the array and ensure they can easily be integrated with our devices.
- Test multiple array configurations and shapes and observe which configuration and camera spacing results in the best image after image stitching.
- Use wood, cardboard, or foam to put the camera array on so we can ensure that they are aligned properly and stable.
- Connect the cameras to a computer via a USB connection.
- Write and test code using python to do image processing techniques and create a higher resolution image out of the many that were captured.
- Use Zemax to design a lens system that will allow for quality image capture at 100 yards and account for possible aberrations that we may encounter.

Camera Array Objectives for Advanced Goals

- Purchase more of the low cost, low resolution cameras to arrange into a larger array configuration.
- Research a way to effectively connect all the cameras into a more cohesive system.
- Use the sign outside of the L3 Harris building on campus to test our camera array at a distance of 100 yards and see if we can produce a more clear image at that distance.
- Based on the separations of the cameras in the array, design a housing for multiple lens systems that can be easily attached to the array and are properly aligned.

- Research and work with CREOL professors to understand how a phase correction plate works and how to properly incorporate it into our design to produce the best possible image.

2.4 Features & Functionalities

RF Device

The unit is designed for those who purchase it to be able to detect aircraft via the passive detection of waveforms rather than via an active radar. They want it to be able to detect aircraft in radio and radar “dead zones” which have no active radars to detect aircraft, as well as no nearby infrastructure that would be able to detect aircraft in other ways. A common example of this would be an airplane that illegally passes through borders by flying into dead zones that don’t have radars to detect it, or by flying under the radars that would normally be able to actively detect it. This unit should be able to passively detect any such aircraft and with the use of multiple, be able to make an array of them that can be used to triangulate the position of any such aircraft based on the signal strength picked up by each of the devices in a way that can be shown on a phone or computer via starlink. Furthermore it has been requested that the data be livestreamed so that people can take appropriate action based on the data found.

Camera Array

The camera array device will allow the user to capture an image at a desired distance and be able to discern large amounts of detail that is typically only able to be done by very expensive cameras. Our device, since it will be made up of cheap cameras and affordable lens systems, will allow for clarity at a cheaper cost. The design is also meant to be scalable which will allow for even more precision and clarity depending on the user's needs. By its nature, the array will be able to capture a wide field of view while maintaining its high pixel density through image fusion. With the configuration, blind spots are also eliminated which also allows for a much clearer image. With a large amount of cameras in the array, it may also be possible to estimate depth which is vital when it comes to surveillance scenarios. Additionally, the device uses off the shelf components which verifies that ITAR restrictions are met. Finally, due to the systems design, the device has a natural fault tolerance meaning that if a camera happens to stop working, the remaining cameras can still effectively produce the desired outcome.

2.5 Engineering Specifications

Below are some specifications that were derived with the consideration of our project objectives, constraints and limitations of other similar products and projects, and quality versus cost analysis. The tables are also split into categories, namely those for the RF device and those for the camera array device.

Table 2.5.1 Prototype Specifications and Features

Parameter	Specification
Signal receive and detection time	**5 min or less**
Airspace coverage	10-12 miles at 12,000 feet
Wide frequency detection range	300MHz to 3GHz
Detection Range	50m to 50km
Detection Accuracy	RCS $\geq$ 3m^2
Size	<1m^2
Cost	<$6500

Table 2.5.2 Unit Components Specifications

Component	Parameter	Specification
Log Periodic Antenna	Antenna radiation pattern	180 degrees
Battery	Power	>600W
Spectrum Analyzer	Dynamic range	-158dbm to 10dbm
Android Phone	Power consumption	<10W
Portable solar panel	Power	>60W

Table 2.5.3 Camera Array Design Components Specifications

Component	Parameter	Specification
Camera(s)	FOV Pixel Count Frame Rate	110 degrees 3MP 15 fps
Camera Array	**Effective FOV** **Image Overlap**	**150-180 degrees** **~20-30%**

Post Fusion Image	**Pixel Density**	**At least 10 pixels/cm at 10 meter**
Lens System	**Focal Length** **Aperture**	**~50-75 mm** **f/2.8 - f/4.0**
Entire Unit	Weight Operating Temperature	Less than 5 kg 10-30 degrees Celsius

Chapter 3: Research

RF Device
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Camera Array
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Chapter 4: Standards & Design Constraints

RF Device
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Camera Array
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Chapter 5: Comparison of ChatGPT With Other Similar Platforms

RF Device
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Camera Array
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Chapter 6. System Design

6.1 Hardware Block Diagram

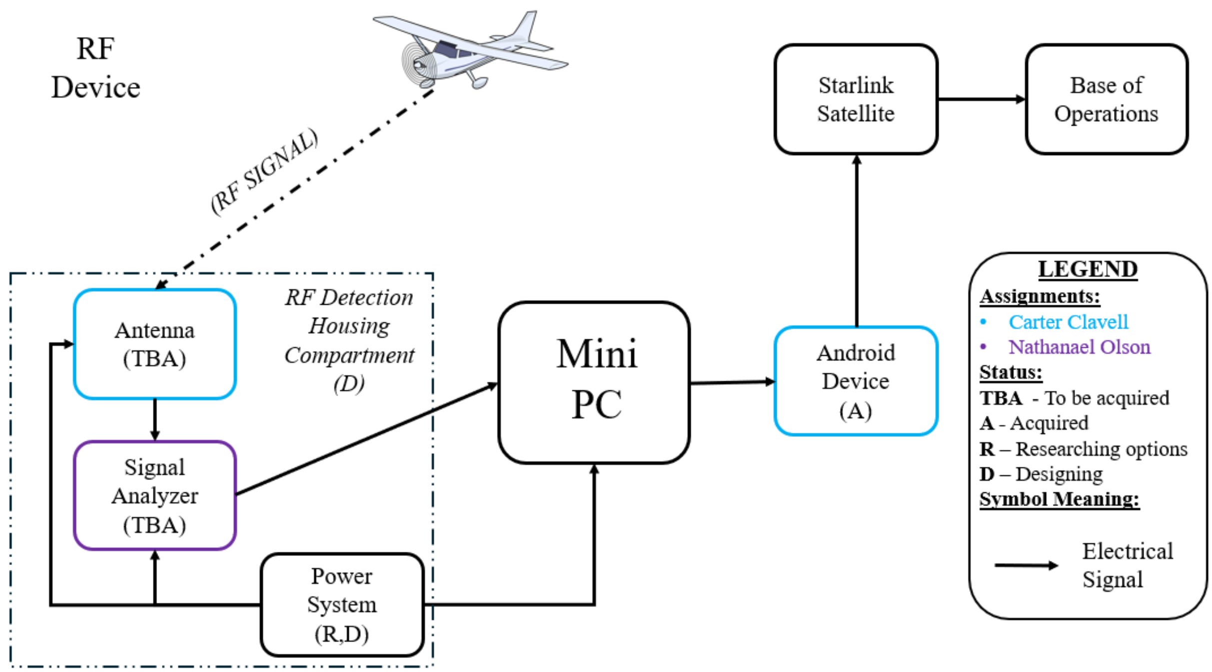


Figure 6.1 Hardware Block Diagram (Note: Still being worked on!)

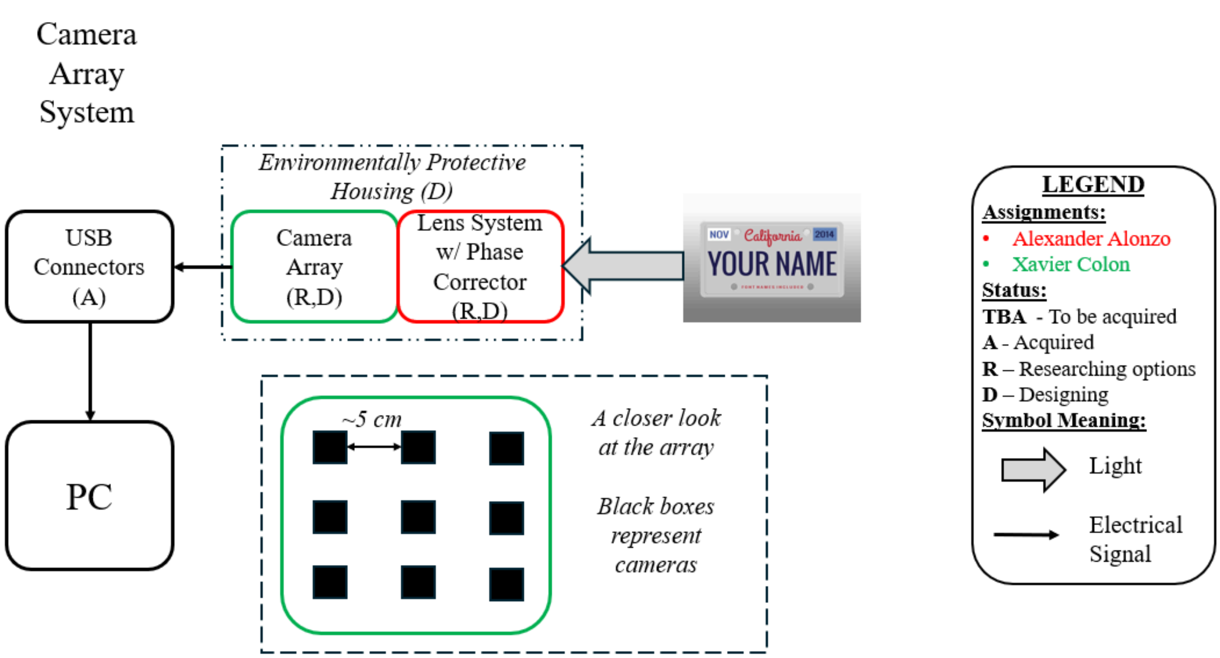


Figure 6.2 Optical System (Extension of Figure 6.1) (Note: Still being worked on!)

The hardware diagrams above illustrate some of the basic components that our project will implement and whose responsibilities they are. Further additions, either by our sponsor's request or by other groups on this project that are not in our senior design section may need to be accounted for. We currently do not know if other divisions, like the computer science team, will need different hardware parts or housing units yet. Moreover, the PCB requirement from senior design was voided for this project which is why it is not illustrated in the diagram.

The second diagram serves as an optical system schematic and shows how the optical systems interact. A closer look at the camera array is provided and a more detailed version will be uploaded once specific measurements and arrangements are figured out.

6.2 Software Block Diagram

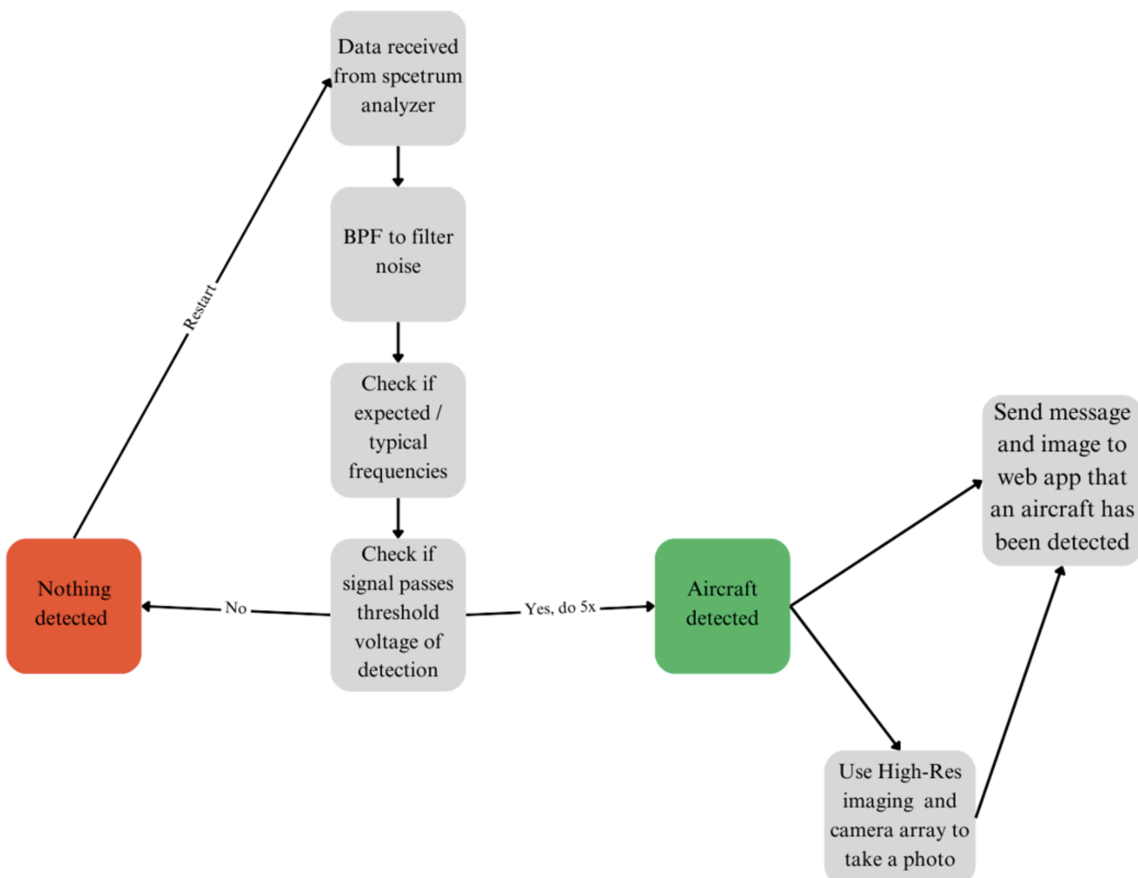
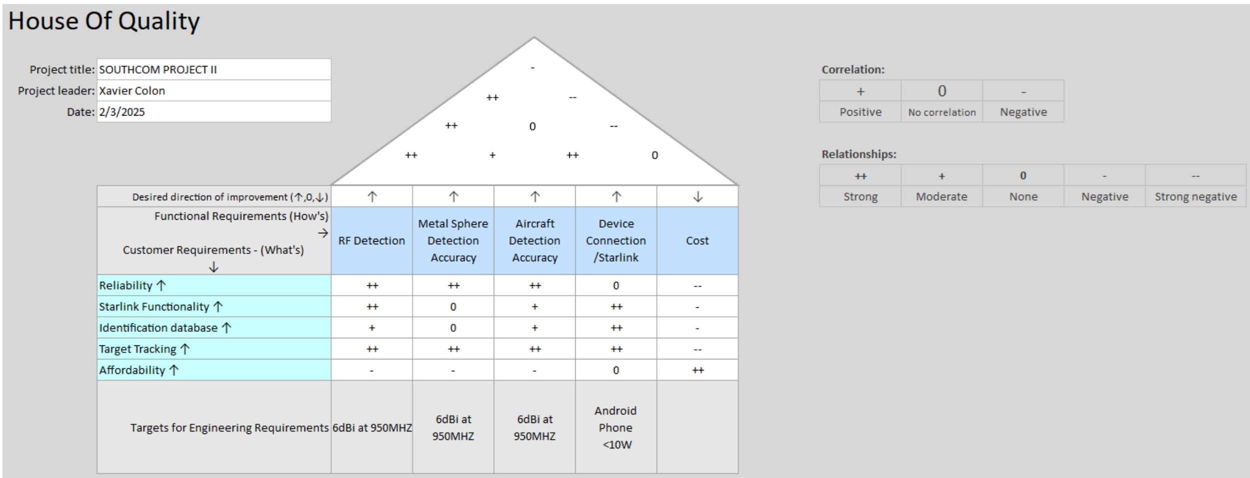


Figure 6.3 Software Block Diagram (Need to adjust for new project route)

6.3 House of Quality



Functional Requirements (How's) → / Customer Requirements - (What's) ↓	RF Detection	Metal Sphere Detection Accuracy	Aircraft Detection Accuracy	Device Connection /Starlink	Cost
Desired direction of improvement (↑,0,↓)	↑	↑	↑	↑	↓
Reliability ↑	++	++	++	0	--
Starlink Functionality ↑	++	0	+	++	-
Identification database ↑	+	0	+	++	-
Target Tracking ↑	++	++	++	++	--
Affordability ↑	-	-	-	0	++
Targets for Engineering Requirements	6dBi at 950MHZ	6dBi at 950MHZ	6dBi at 950MHZ	Android Phone <10W	

Chapter 7: System Testing & Evaluation

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Chapter 8: Administrative Content

8.1 Finances

Table 8.1 Preliminary Budget Table for RF Device

Item	Approximate Price
Antenna(x1)	$450 each
Motors(x2)	$10 each ($20 total)
Signal Analyzer	$4000
Solar / Power System	$420
Android Phone	$600
PC/laptop	$200

Total:	$7,040

Table 8.2 Preliminary Budget Table for Camera Array

Item	Approximate Price
Cameras (x3)	$15 each
Lens System (x3)	$25 each
USB Connector	$20
Material for Housing	$30
PC/laptop	$400
Total:	$570

The budget for this project is set by our sponsor, Roy H. Wubker. The goal of this project is to create a cost-effective solution. Components that require a higher standard of quality were allocated a larger portion of the total funds. As it currently stands, many of the components could be subject to change based on quality versus cost assessments or customer standards. In addition, the solar power system may not end up being part of the final product, but we have funds allocated for it in the case that it does become a part of the system.

While this project is sponsored, the optical components may or may not be covered depending on the sponsors willingness to provide the equipment. As was mentioned earlier, the sponsor's main focus is an RF detection device. However, since the optical project would pique the interest of the same customers as the RF device, it may be possible to justify the sponsorship of the optical contributions of this project.

The cost per unit comes out to around $7000. This price, which is flexible based on optimization and inclusion or exclusion of the optical enhancement portion, is a much more appealing price especially since the user would need multiple to localize effectively. Compare this to radar systems from big companies that do contract work with the government. Our device is much more affordable while still providing essential information. While we do not want our device to cost the user anywhere near the price of a radar system, there are a lot of potential enhancements that can be made to elevate the quality of the unit.

8.2 Project Timeline

Below we have created both a table and Gantt chart to help organize our group and get a clearer view of the approaching deadlines. We have currently set up our schedule in even increments of about 3 weeks per step. This may turn out to be unrealistic as certain milestones may take more or less time to achieve. The main idea, however, is to give us insight into the quick turnaround we will need to have, especially going into the summer session of senior design 2.

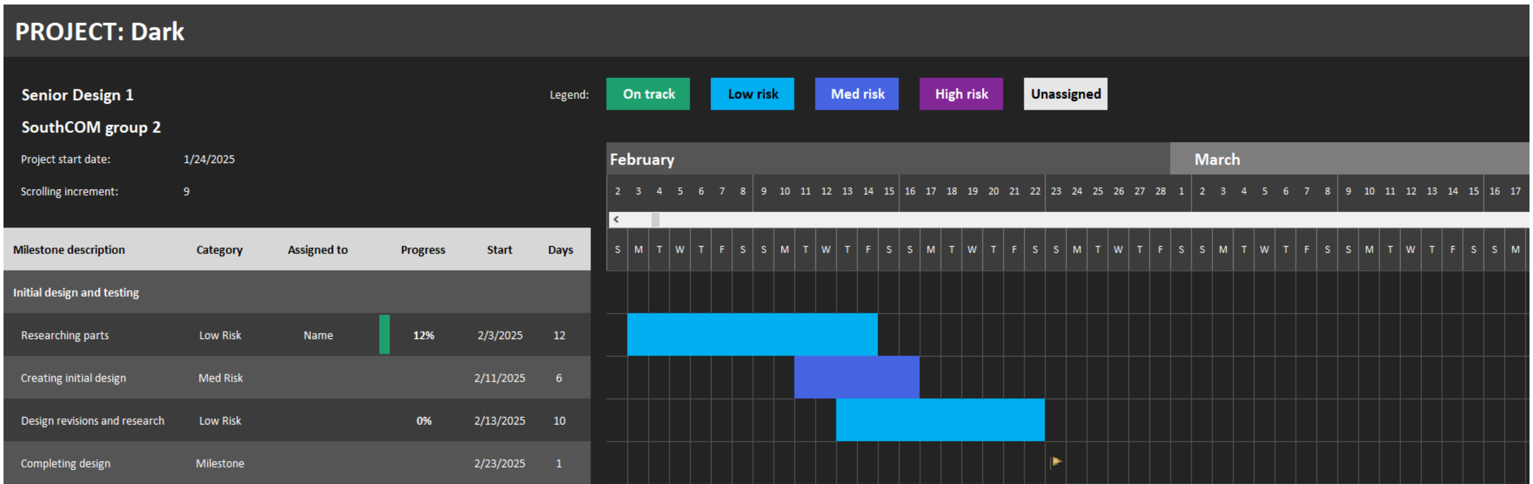
Table 8.2 Senior Design I Milestones

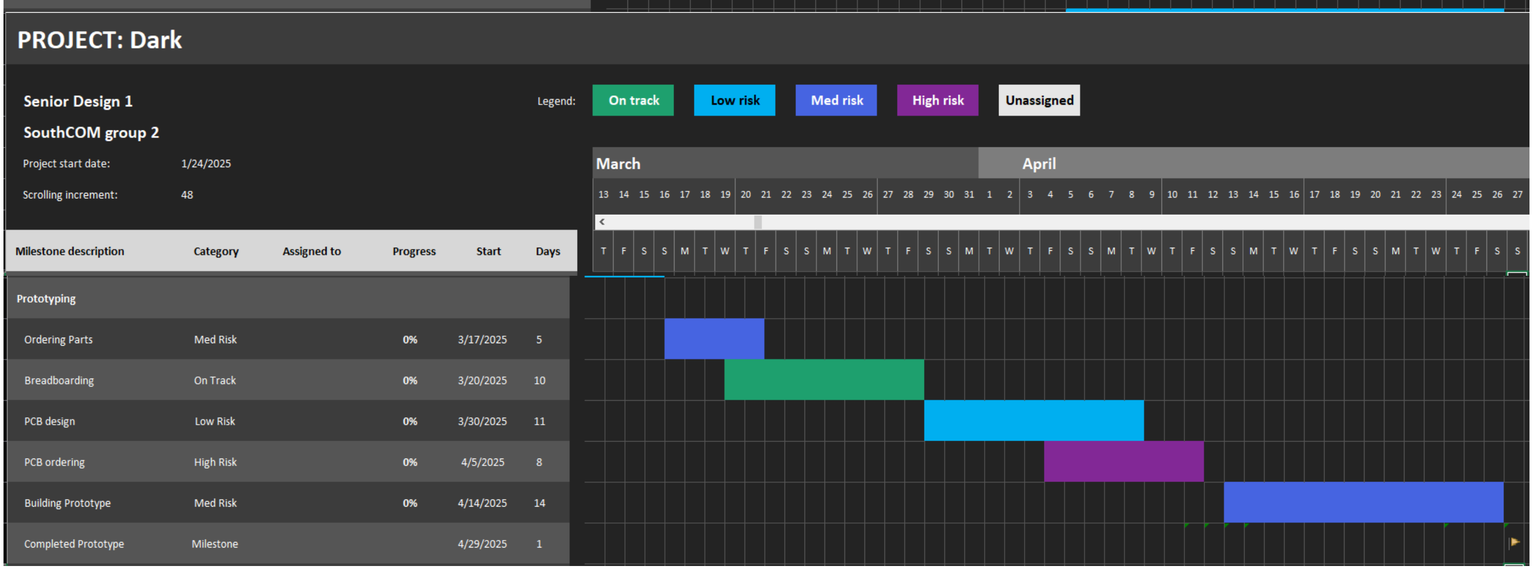
Milestone	Expected Start	Expected End	Duration
System Design	02/03/2025	02/23/2025	3 weeks
System Testing	02/24/2025	03/16/2025	3 weeks
Breadboard Prototyping	03/17/2025	03/30/2025	2 weeks
Finished Prototype	03/31/2025	04/29/2025	4 weeks

Table 8.3 Senior Design II Milestones

Milestone	Expected Start	Expected End	Duration
Multiple prototypes made	05/19/2025	06/16/2025	4 weeks
Designing Array setup	06/02/2025	06/22/2025	3 weeks
Testing Array	06/23/2025	07/20/2025	4 weeks
Final Product Completed	07/21/2025	08/23/2025	2 weeks

Gantt Chart for Schedule:





Chapter 9: Conclusion

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Appendix:

DeDrone RF-300

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Thales Elvira

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TwInvis Information

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