Low-Cost Passive Aircraft Detection System

A means to increase security for less

Group 2

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Project Description

1. Motivation & Background

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 is 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.

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. ~~Roy is an engineer with a technical background. Roy is excellent and has a deep understanding of the problem he wants solved.~~ Initial recommendations from our sponsor for how to solve this problem involved RF detection which led us to brainstorm more ideas, especially those that involved optics and photonics. We knew we had an incredible opportunity before us and a chance to solve a real world problem while also working with, and being guided by, a member of the SOUTHCOM team.

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 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 back to control towers. This 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.

In addition to our passive radar system using an array of antennas, we will also be incorporating a set of camera systems. The first system will be a wide-lens detection type of system. This system will aim to estimate the aircraft's altitude using angular measurements. By seing the distance the aircraft has moved and determining the corresponding angle, we can get a rough idea of how high the aircraft is flying. Once the altitude is determined, the second system comes into play. The second system, the telephoto camera system, will aim to take a picture of the aircraft. This system will feature something similar to a variable optic. By having a variable optic, we can change the zoom of the lens, which will be dependent on the altitude reading from the wide-lens system, and will result in a clearer, higher quality image of the aircraft. This allows us to only require one mechanical system which keeps complexity down.

2. Goals & Objectives

~~The main idea for this project is to design and build a device that uses both RF detection and 2 camera systems to detect aircraft in a given airspace, gather necessary data, and then communicate that data to a base station unit via a Starlink constellation. Some of the main goals and objectives are listed here below.~~

2.1 Basic Goals

- ~~One of the most basic goals of our system is that it will be able to successfully detect a metal sphere using passive detection means. The reason for a metal sphere is because it is the easiest thing for a radar to detect. This will show that we were able to implement our system in the most basic way possible.~~
- ~~Another one of our most basic goals will be to successfully capture an image of the object using the aforementioned camera system. If we are able to capture an image of an object using the wide-lens detection system and the telephoto camera system approach, we will know that our 2-step system was a successful enhancement to the unit.~~
- ~~Design a wide-lens camera system and a variable lens camera system that can adapt its zoom level to gain information such as altitude and an image of the aircraft.~~
- ~~Make 1 functional prototype unit.~~

2.2 Advanced Goals

- ~~We would like the system to be able to detect an aircraft in flight~~. With this, we will have proof that our passive detection system is working as it should. Not only that, but it should be self-sustaining, meaning energy will not have to be continuously poured into the system in order for it to work.
- We would also like for the system to be powered via a solar energy component. Our sponsor indicated that this requirement was not as important to them, but in terms of a long term idea, solar would provide the best means for power.
- We would also like the system response time to be generally quick. This will ensure that our detection device will actually be useful to the user.
- Connect everything into a more cohesive system, meaning we can connect it to similar devices and share the information to users using Starlink as the main form of information transfer.

2.3 Stretch Goals

- The system will be implemented and easily replicable. We would also like to further enhance the optic/photonics component to improve accuracy or provide a better system. This could be done via an infrared search and track system, a much more complex but effective solution.
- 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. This can be done by using the RF signature the plane reflects alongside the images from the infrared camera.

2.4 Objectives

2.4.1 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.
- Create code to differentiate noise from actual interference in radio frequencies.
- Design lens systems in Zemax and determine how to account for different types of aberrations and distortions.
- Create a housing unit for the lens system that can be easily incorporated into the main unit.

2.4.2 Objectives for Advanced Goals

- Test the prototype at a local airport like Dade Collier Airport to see if we can detect a plane
- Research means to power the unit autonomously and integrate it (phase 2)
- Test the unit and determine the travel time for the information.
- Identify the parts that cause delay and attempt to find a solution

3. Features & Functionalities

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.

The unit will also be enhanced with 2 lens systems. This system will feature 1 wide lens camera system whose purpose is to scan the airspace once the main detection method detects a disturbance and gain information such as an altitude estimation of the aircraft. Using a code that compares frames, we can determine if there is in fact an aircraft in the airspace and how high it may be. Using simple angular calculations will allow us to determine the aircraft's altitude using an x-y grid and angle approach. Once the system maps how high the aircraft is and possibly the direction of travel, it will send a signal to the motor controlling the second camera system. This second camera system's goal is to capture an image of the aircraft that was detected. After the location information is received from the first system, it will adjust the variable portion of the optic of the second system accordingly to capture the best image possible. This camera system will feature a more precise lens and larger aperture with a moveable group of lenses in order to produce a more clear image. The main limitation of this optical enhancement is, unfortunately, weather. However, this system has the potential to provide localization data with just one unit.

3.1 Market analysis

The selection of features and functionalities of the device are derived from requirements given by the client, as well as the abilities of other devices that are within the same niche. The main goal of this project of course being to build a unit of similar ability at a very low cost. Ideally, the unit should also be able to allow the user to ‘set it and forget it’, meaning it should be autonomous and may even be discardable after a period of use.

Main features include the ability to detect aircraft via its passive radar design, the ability to differentiate between aircraft and noise caused by other vehicles or similar things, the ability to have it work with starlink to transmit the data to the local base, and the ability to have multiple units working simultaneously in an array to determine the location of anything detected.

4. Existing Products & Related Works

4.1 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.

4.2 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.

4.3 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.

4.4 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.

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.

Table 5.1 Prototype Specifications ~~and Features~~

Parameter	Specification
Response Time	**5 min or less**
Airspace coverage	10-12 miles at 12,000 feet
Wide frequency detection range	VHF to UHF
Size	<1m^2
Power consumption	<100W

Table 5.2 Unit Components Specifications

Component	Parameter	Specification
Aventas Log Periodic Antenna	High Forward Gain	6dbi at 950MHz
Motorized Pan-Tilt System	**Angle**	**30 deg cone**
Battery	Power	>600W
Signal Hound BB60C Spectrum Analyzer	**Sample Rate (Accuracy)**	**312.5k to 40M samples / second**
Android Phone	Power consumption	<10W
Portable solar panel	Power	>60W

*Note for the antenna, more research needs to be done; Dr. Jones will be helping next week with it.

Table 5.3 Optical Design Components Specifications

Component	Parameter	Specification
Wide Lens System (Camera System 1)	**Field of View**	**Between 30-60 deg**
	Focal Length	6-16 mm
	Aperture	f/2-f/4 3-8 mm diameter
Telephoto Lens System (Camera System 2)	**Field of View**	**Between 1-5 deg**
	Focal Length	400-800 mm
	Aperture	f/8-f/11 50-100 mm diameter

*Will review this information with Dr. Pang and Dr. Eikenberry to get a better idea of what exactly we will need.

6. System Design

6.1 Hardware Block Diagram

Figure 6.1 Hardware Block Diagram

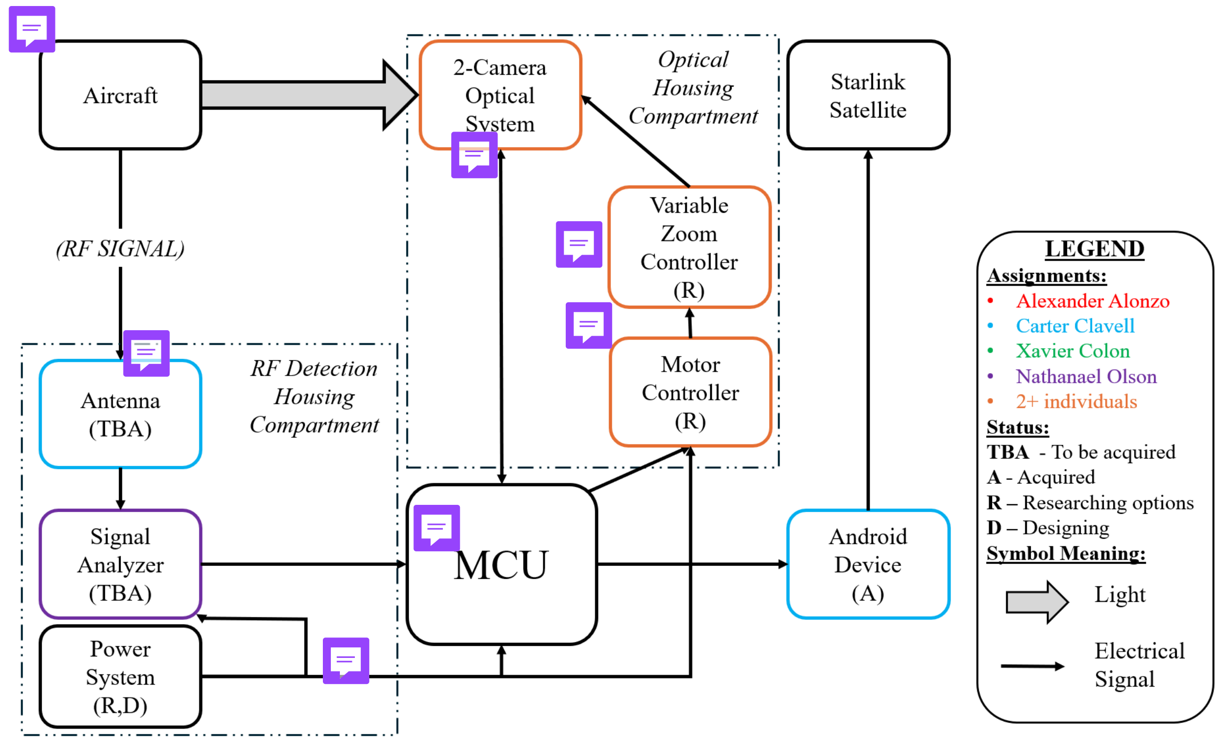
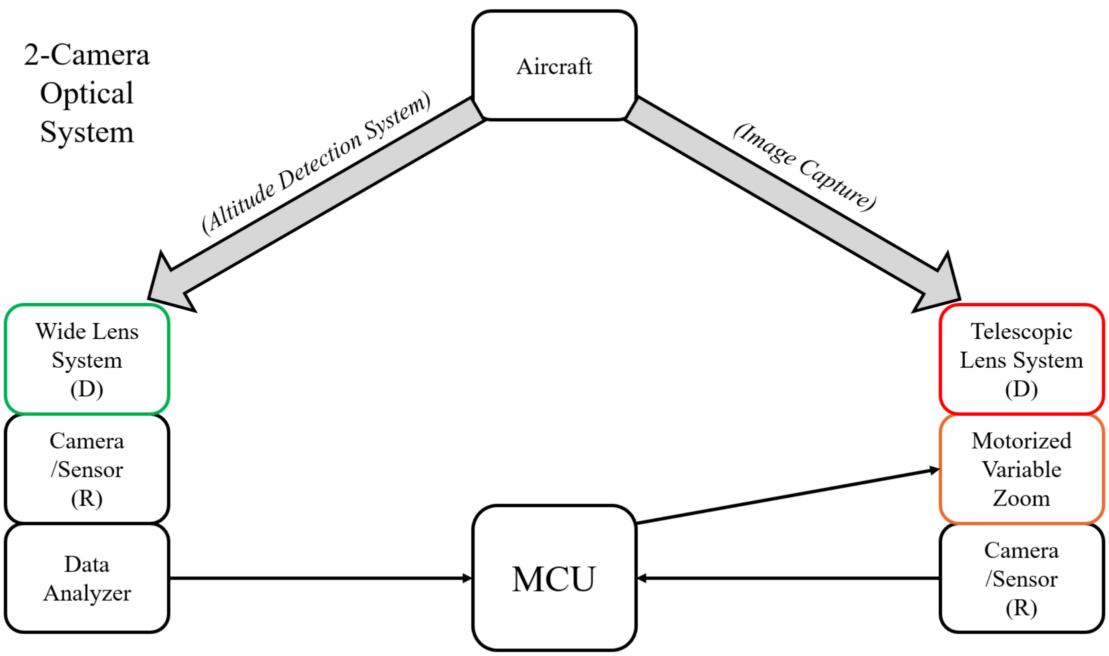


Figure 6.2 Optical System (Extension of Figure 6.1)

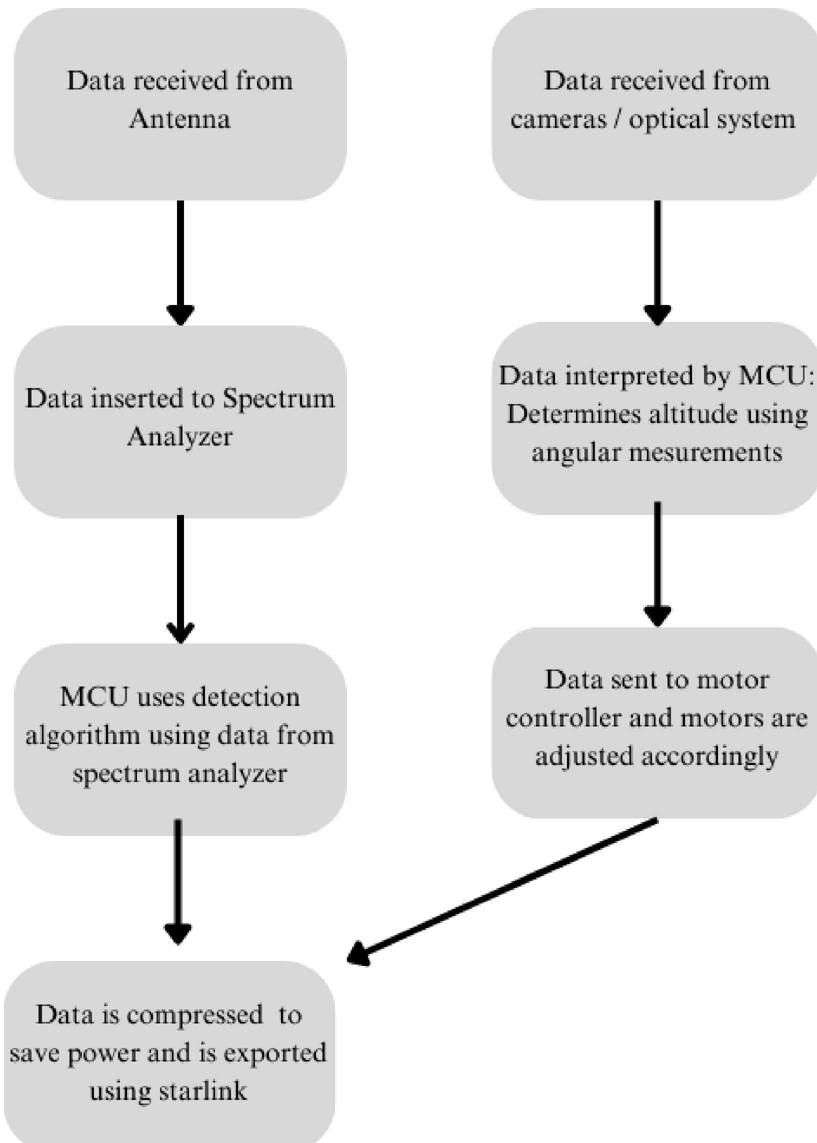


The hardware diagrams above illustrate some of the basic components that our project will implement and whose responsibilities they are. Further additions, either by our sponsor's request or by other groups on this project that are not in our senior design section may need to be accounted for. We currently 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. It uses the same legend as figure 6.1 since it is meant to be an extension of it for better visual clarity.

6.2 Software Block Diagram

Figure 6.3 Software Block Diagram



6.3 House of Quality

Project title:	SOUTHCOM PROJECT II
Project leader:	Xavier Colon
Date:	2/3/2025

++
0 ++
- 0 -
+ - - +

Desired direction of improvement (↑,0,↓)	0	↑	↑	↑	0
Functional Requirements (How's) → / Customer Requirements - (What's) ↓	RF Detection	Image Capturing	Energy Self Sufficiency	Device Connection /Starlink	Tracking
Able to detect Metal Sphere	++	0	0	+	+
Able to capture image of detected object	+	++	0		
Adaptable camera system	-	++	-	0	++
Able to detect aircraft	++	0	--	+	++
Able to be solar powered	0	0	++	0	0
Has starlink functionality	++	0	0	++	+
Identification database	+	+	0	++	++
Able to track targets	++	++	-	++	++
Low cost	0	-	-	0	--
Targets for Engineering Requirements	6dBi at 950MHZ	2 cameras 6-16mm and 400 -800mm focal lengths	>600W Battery >60W solar panel	Android Phone <10W	2 cameras 30-60 degree ROM and 1-5 degree ROM

Correlation:

+	0	-
Positive	No correlation	Negative

Relationships:

++	+	0	-	--
Strong	Moderate	None	Negative	Strong negative

7. Finances

Table 7.1 Preliminary Budget Table

Item	Approximate Price
Antenna(x1)	$450 each
Camera (x2)	$300
Lens System Components (x2)	$150
Motors(x2)	$10 each ($20 total)
Signal Analyzer	$4000
Solar / Power System	$420
Android Phone	$600

PC/laptop	$200
Total:	$7,040

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 large 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 enhancement components such as the optical components may be covered depending on the sponsors willingness to provide the equipment. As was mentioned earlier, the sponsor originally suggested an RF detection solution only and has been generous enough to provide us with most of the necessary equipment that will be required to implement this technique. The optical enhancement was our extension of this proposed solution and hence may require us to fund those parts ourselves.

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. 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 8.1 Senior Design I Milestones

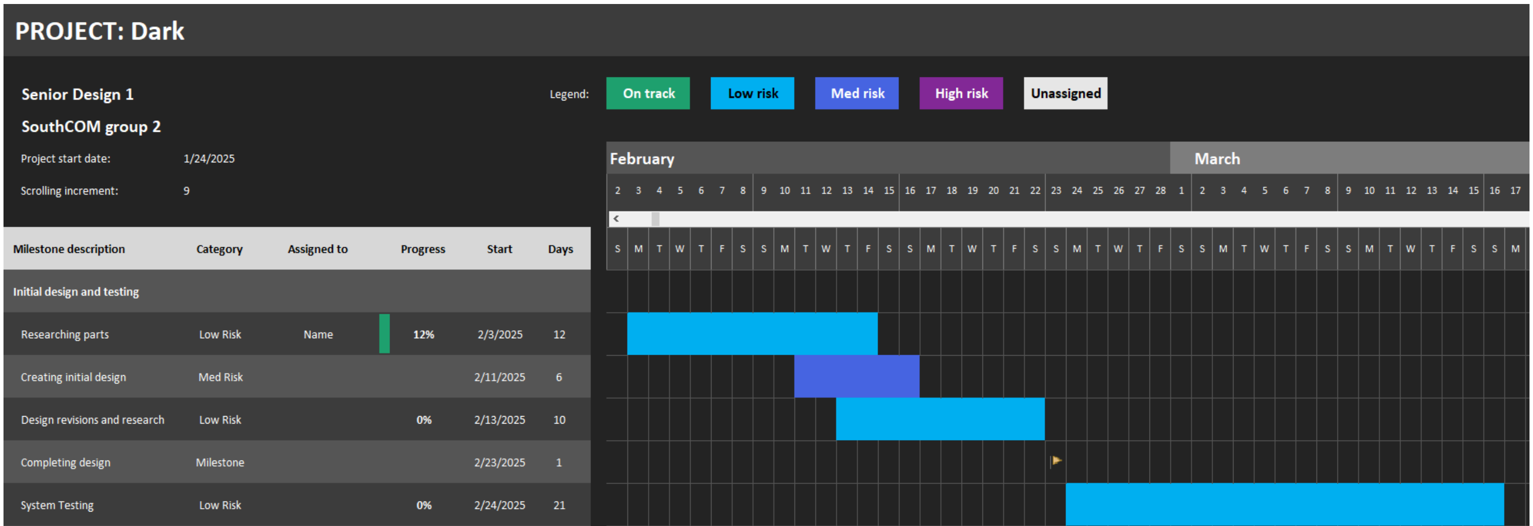
Milestone	Expected Start	Expected End	Duration
System Design	02/03/2025	02/23/2025	3 weeks
System Testing	02/24/2025	03/16/2025	3 weeks
Breadboard Prototyping	03/17/2025	03/30/2025	2 weeks

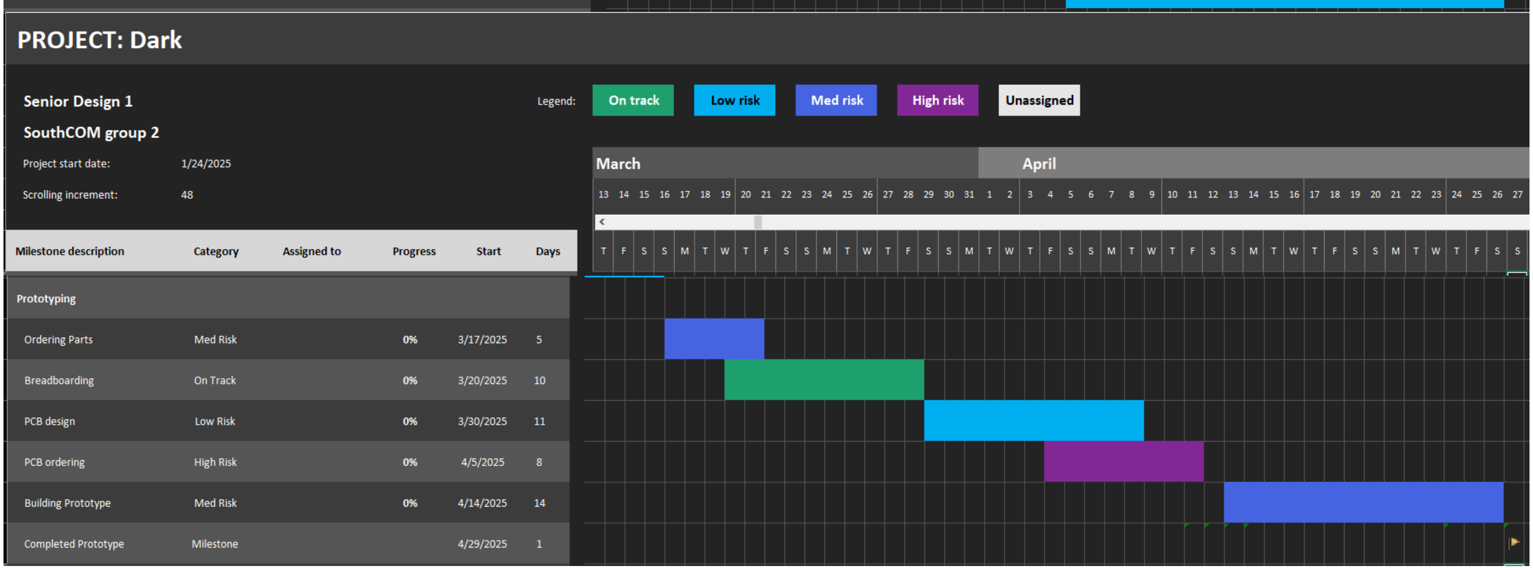
Finished Prototype	03/31/2025	04/29/2025	4 weeks

Table 8.2 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:





Appendix:

DeDrone RF-300

Dedrone, "Dedrone introduces localization technology to stop unauthorized drones," [Online]. Available: https://www.dedrone.com/press/dedrone-introduces-localization-technology-to-stop-unauthorized-drones. [Accessed: Jan. 23, 2025]

Dedrone, "RF Sensors Overview," [Online]. Available: https://www.dedrone.com/products/drone-detection/rf-sensors/overview. [Accessed: Jan. 23, 2025].

Thales Elvira

Robin Radar Systems, "ELVIRA Radar: 2D Drone Detection Radar," [Online]. Available: https://www.robinradar.com/products/elvira-radar. [Accessed: Jan. 21, 2025].

Robin Radar Systems, "Drone Detection Radar Solutions," [Online]. Available: https://www.robinradar.com/solutions/drone-detection-radar . [Accessed: Jan. 21, 2025].

TwInvis Information

Hensoldt, "TwInvis Passive Radar: Surveillance of noiseless objects," [Online]. Available: https://www.hensoldt.net/products/14/twinvis-passive-radar-surveillance-of-noiseless-objects . [Accessed: Jan. 20, 2025].

Defense News, "Hensoldt unveils a deployable package of its TwInvis passive radar," Aug. 10, 2023. [Online]. Available: https://www.defensenews.com/global/europe/2023/08/10/hensoldt-unveils-a-deployable-package-of-its-twinvis-passive-radar/. [Accessed: Jan. 20, 2025].