Mini-AWACS

Airborne Warning and Control System

Small UAS Airspace Domain Awareness RADAR Payload

Sponsored by U.S. Southern Command (SouthCom)

Group 3

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1. PROJECT NARRATIVE

BACKGROUND AND MOTIVATION

The military application of unmanned aircraft systems (UAS) has evolved since the initiation of their use by the US military. Although, larger UAS systems have the payload and cost to justify the integration of sophisticated sensor and radar systems. Smaller lower cost UAS do not. A long term goal expressed by our sponsor from US Southern Command (SouthCom) was to be able to deploy these UAS as functional drone swarms and to test other applications for these platforms. However, due to the size and cost of these smaller UAS platforms a full sensor and radar package is too costly and not feasible. This is a current barrier to the development of future capabilities as these UAS will have no collision avoidance systems to prevent accidents with each other or with other aerial assets. The only military asset that can provide the necessary radar information to solve this problem is the Airborne Warning and Control System (AWACS) which is a large plane with a long range radar system. However, AWACS are extremely costly and limited, thus they are not a viable solution for this problem. As a result the military requires a cheap, reliable, and easily deployable system that solves this issue so that the US military can continue to perform experiments and broaden the uses of UAS on the battlefield.

PROJECT FUNCTION

The overall function of this system is to be a deployable 100lbs sensor payload that can provide the necessary information to allow these smaller UAS systems to be used safely in environments where the necessary information for safe operation is not available. This will be done via radar and IR imaging which will provide the data needed for these UAS to operate safely. The end goal is for the product to function as a mini-AWACS. This system will be comprised of the following components:

Marine Radar: To keep the project cost low and develop a prototype for testing, a marine radar system will be repurposed to capture necessary radar information for the UAS to operate safely. The motion of the radar system will have to be modified to scan from a top down position. The radar system will provide long range spatial information to the UAS. The marine radar will also consist of a software development kit that will allow us to use the signal as desired with the reconfigured radar scanning pattern. This data will be fed into our central PC in order to communicate with the UAS via the Starlink System.

IR Imaging system: A scanning IR imaging system will be included on the payload to provide additional information and imaging to the UAS for safe operation. IR imaging can provide visualization of the given area during day and night and in varying weather conditions. In addition to visual information the IR system has the potential to provide better spatial resolution in comparison to the radar system. The IR system will consist of an IR camera, custom optical system providing magnification and wide field of view.

An optical encoder to give precise position information of the image in relation to the position of the aircraft the device is deployed on.

Starlink® Hardware: Starlink® module will be utilized to transmit the radar and IR imaging system information from the mini-AWACS via Starlink to a cell phone on the UAS to provide the UAS with the desired radar and IR information. This will allow the UAS to operate safely with other aerial assets allowing for further testing and research to develop the capabilities of these UAS.

Microcontroller: The microcontroller in the system will control the movement of the radar piston and the infrared camera motor. The microcontroller will operate partially as a feedback system for the IR motor, as the positional information from the motor will be used to determine the IR imaging in relation to the vehicle's position. The radar piston will operate on command only, cycling its whole range at a continuous speed.

Radar Angle Piston: The angle of the radar will be controlled by a piston-wheel system which will be calculated to move exactly ±30° from the neutral downwards position. The piston movement will be constant to facilitate the radar's clean and accurate sweep of the skies beneath it, so that it can be ensured the UAS training does not disrupt the airspace.

2. PROJECT OBJECTIVE, GOALS AND REQUIREMENTS

The overall objective of this project is to create a cost effective mini-AWACS which can be deployed on an aircraft to provide the US military's UAS the necessary radar and visual information required for safe operation. In order to meet this objective the mini-AWACS has to be able to gather Radar and IR information and provide this data to the UAS via Starlink® to a cellphone on the UAS as a proof of concept. If successful this will allow for continued development of the product. The final objective of this project is to provide the US military with a system that gives them the ability to safely test and develop its UAS capabilities.

Objectives:

- Determine the necessary mechanical components and configuration to allow the radar to move in the desired top/down 60 degree arc of motion.
- Utilize the software development kit to program the radar to provide useable data in its new physical configuration
- Determine desired encoder wheel configuration and optical components for the optical encoder to provide positional information in relation to the radars physical position during motion and provide data for image position in relation the aircraft
- Connect Starlink Mini Terminal to transmit data from mini-AWACS to cellphone
- Determine lens configuration for IR imaging system build lens system to operate in 900 nm-1700 nm range

Basic goals:

- Design and build the new motion platform for the marine radar so the radar field of view meets the specifications of the sponsor
- Have radar system operate properly on new motion platform
- Successfully transmit data from the mini-AWACS to the designated cellphone via Starlink®
- Design and build IR imaging system to provide images in short wave infrared wavelength (SWIR) at 900 nm to 1700 nm to provide imaging in varied weather conditions to compliment radar data
- Design and build optical encoder for radar system to provide positional information of radar system during arc of motion to improve resolution of radar information
- Design and build optical encoder for IR imaging system to provide positional information relating image to position of aircraft
- Total system must meet payload max weight of 100 lbs

Advanced goals:
- Deploy mini-AWACS on small aircraft to test prototype at 10,000ft for proof of concept (Sponsor goals)

Stretch goal
- Full prototype testing at high altitude “stratosphere” to determine if commercialization is feasible. (Sponsor goals)
- Full length test of the prototype for extended time at altitude on an unmanned air balloon. (Sponsor goals)

REQUIREMENTS

Specifications for each subsystem are listed below:

<u>Radar system</u>
- Modify Raymarine Cyclone 6 ft Open Array Radar Pack to operate in a top down laterally sweeping pattern vs. it’s original rotational scanning pattern
    - Design mechanical component which will provide new scanning motion of radar with desired scanning field of view of 60 degrees
- Able to operate for 1 week in a powered environment on an air balloon at high altitude

<u>System Shell</u>
- Able to withstand low pressures of about 8 psi
- Able to maintain functionality and structural integrity while traveling through up to 180 mph of air resistance
- Able to maintain functionality in regular weather (-20° C to 40° C)
- Should be at most 30 lbs

<u>Radar Rotation System</u>

- Able to move the Raymarine Cyclone radar 60° about its center, 30° each to the left and right from the neutral downwards facing position
- Able to accurately rotate in up to 30 mph winds at operational altitude
- Operates on a feedback system from the operating program to determine the angle at which the radar produces each of its signal responses
- Able to rotate the radar matching normal marine operating speeds, at the lowest around 72° per second or one direction in 0.8 seconds.
- Able to rotate the 30+ lb radar array smoothly

Starlink® Connection

- Accurately transmits information from the radar detection program through starlink to cell phone connections on drones
- Utilizes a standard (23,4 in x 15.07 in) Starlink® antenna mounted within the system shell

IR Imaging System

- The IR camera rotation system should rotate the IR camera uniformly and smoothly about a 360° pattern.
- Able to provide feedback into the PC algorithm to determine the position of the IR image in relation to the vehicle to provide imaging relating to its surroundings.
- Able to rotate the IR camera at a slow speed for reliable imaging, less than 10 rpm.
- The IR Camera needs to be able to take images in the short wave infrared spectrum from 900-1700 nm.

3. DESCRIPTION OF FEATURES AND FUNCTIONALITIES

The main and arguably most important feature in our project is the Raymarine Cyclone 6 ft Open Array Radar Pack which will be modified to scan in a top down sweeping mode instead of its original rotational scanning pattern. The radar will be converted into a top down sweeping radar to provide precise, real time coverage of the airspace below the host aircraft. This coverage ensures that the unmanned aircraft systems avoid potential air collisions.

Another feature of our project is the ability to send the scan data from the radar to the unmanned aircraft systems below. This is done using Starlink's high speed, low latency communication. Each unmanned aircraft will be equipped with a mobile phone that will receive the radar's data via Starlink. This data will allow the unmanned aircraft systems to track their surroundings and will act as a virtual radar for the small aircraft.

The system shell is another feature of our project that is required in order for the mounted radar to operate as intended. Its functionalities include but are not limited to the following. The system shell will be able to withstand low pressures of about 8 psi and will be able to maintain functionality and structural integrity while traveling through up to 180 mph of air resistance. It will also be able to maintain functionality in regular weather conditions (-20° C to 40° C).

Regarding the radar rotation system, it must be able to move the Raymarine Cyclone radar 60° about its center, 30° each to the left and right from the neutral downwards facing position. It must be able to accurately rotate in up to 30 mph winds at operational altitude. Lastly, it must be able to rotate the radar matching normal marine operating speeds, at the lowest around 72° per second or one direction in 0.8 seconds.

4. EXISTING PRODUCT, PAST PRODUCT, OR RELATED WORK

Although there is an existing product that can perform similar functions as the product we are designing, like the Airborne Warning and Control System (AWACS), our product will be significantly less expensive and more easily deployable. The AWACS, and other aircrafts that function similar to it, are extremely costly and not meant to be mass deployed. Our product will be the first of its kind that will be affordable, mass deployable, and in contrast to aircrafts mentioned earlier, it will be mounted to the bottom of private aircrafts which will allow for a large number of radars to be in the sky simultaneously.

Throughout the years there have been multiple planes with radars on them, for example the Lockheed EC-121 Warning Star and then the Airborne Warning and Control System (AWACS) after it. These systems are not directly comparable to our product, however they provide a background on how our product should work but on a smaller scale. A few other planes that incorporated the use of radars are the Boeing E-7 Wedgetail, the Grumman E-2 Hawkeye, and the Beriev A-50.

There is very little to no related work to our product as it has been assigned to us by the US Southern Command (SouthCom) to address an ongoing need to enable unmanned aircraft systems (UAS) to operate without the fear of an air collision during peacetime training. Existing air virtual radar systems have been designed mainly to be used for larger scale operations relative to what our product is aimed to do.

5. ENGINEERING SPECIFICATIONS

Table 1: Engineering requirements specification for the performance of the envisioned system

Specifications	
Parameter	Specification
Rotating wheel's rotation angle	60° range of motion, centered downwards
Piston's Rotation Speed	Should complete one 60° cycle in 0.7-1.0

	Seconds, 60°/s to 85°/s
Starlink connection communication time with UAS	Less than 3000 ms
Temperature resistance	-20° C to 40° C
Wind Resistance	Up to 180 mph from the front, up to 40 across the rotating axis
Length of continuous operation	1 week
Dimensions	No more than 2 ft x 2 ft x 6 ft

The highlighted specifications on the table are the specifications to be demonstrated during the demo of the project prototype.

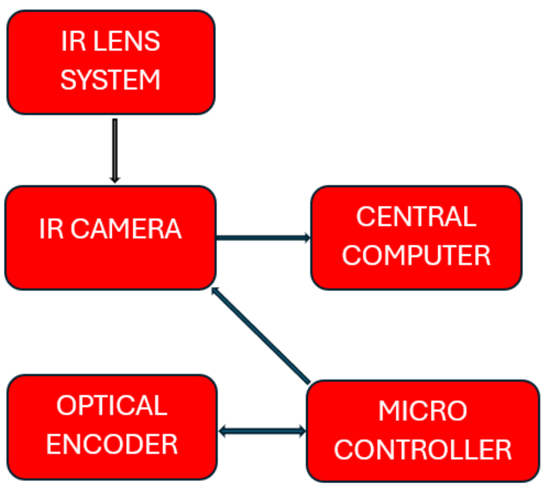
Table 2: Engineering requirements specification for the components that will be used in this project to build the IR Imaging system and optical encoders

Component	Parameter	Specifications	Unit
IR CMOS Camera	Operating wavelength	IR 900-2000	nm
Biconcave lens	Diameter Focal length Wavelength range	50.8 150 350-2000	mm mm nm
Planoconvex lens	Diameter Focal length Wavelength range	75 199.3 350-2000	mm mm nm
Biconvex lens	Diameter Focal length Wavelength range	50.8 100 350-2000	mm mm nm
Positive meniscus lens	Diameter Focal length Wavelength range	50.8 100 350-2000	mm mm nm
Photodiode ThorLabs FD11A	Wavelength range Capacitance Dark current Active area	200-1100 140 2.0 1.21	nm pF pA mm^2

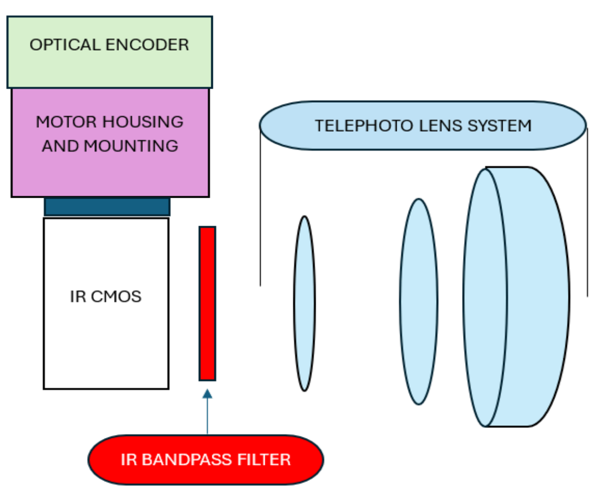
LED 5mm IR 940 nm	Wavelength Drive current	940 30 max	nm mA
IR BP Filter ThorLabs FGB67M	Wavelength	900-1375	nm

6. DETAILED HARDWARE DIAGRAMS

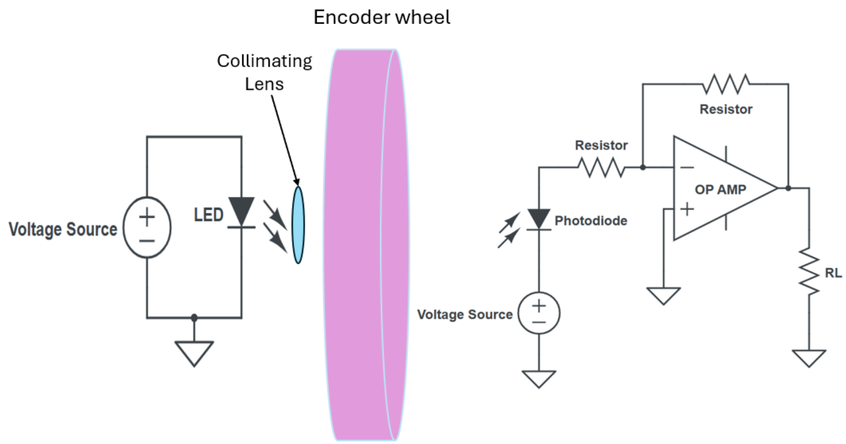
IR IMAGING SYSTEM BLOCK DIAGRAM



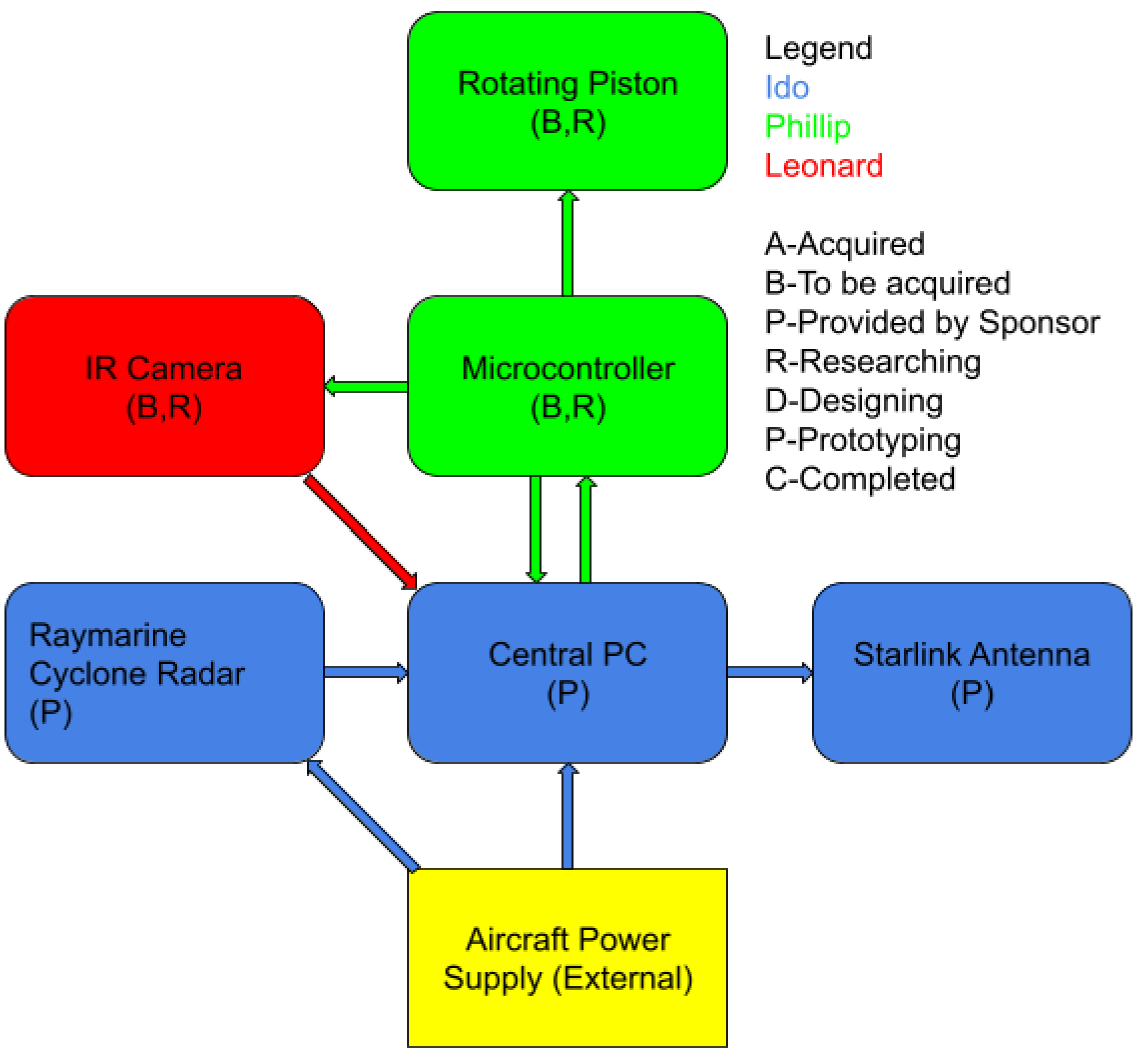
IR IMAGING SYSTEM SCHEMATIC DIAGRAM



OPTICAL ENCODER SCHEMATIC DIAGRAM

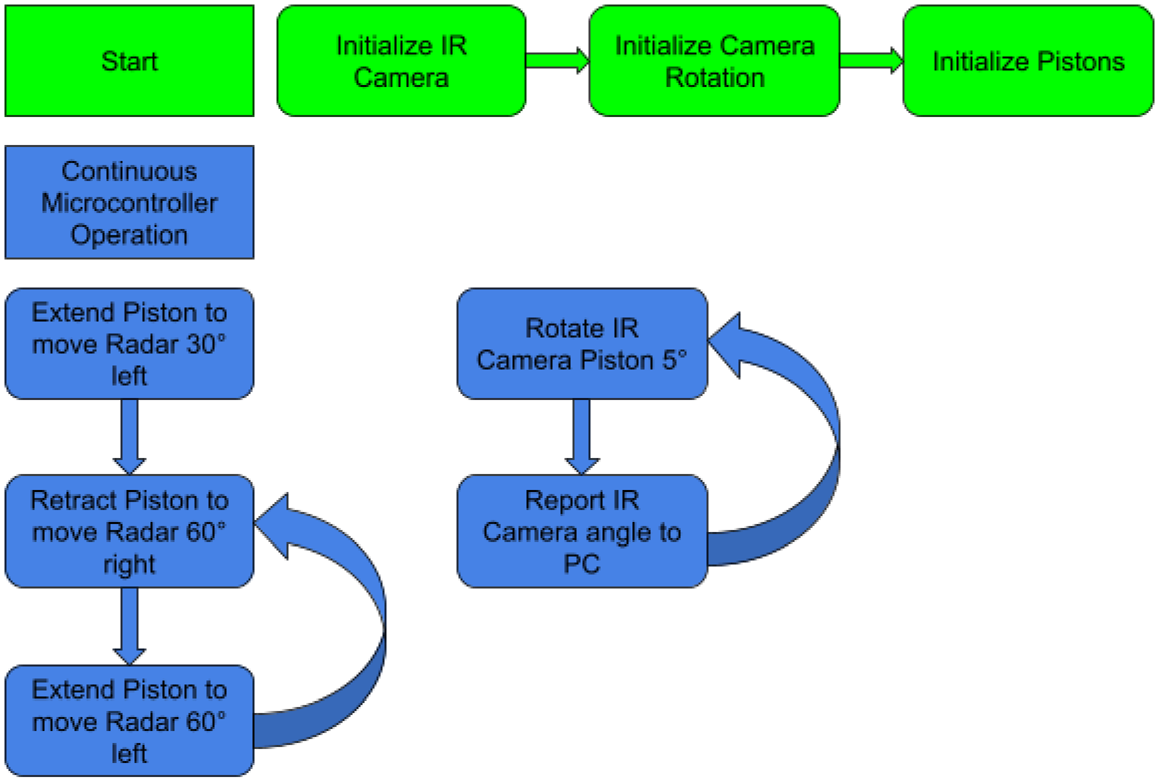


RADAR SYSTEM BLOCK DIAGRAM



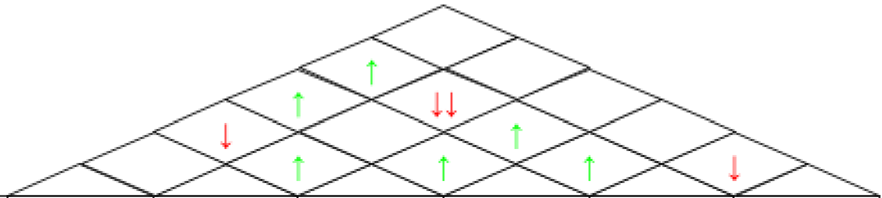
7. SOFTWARE DIAGRAM/FLOWCHART

The microcontroller software is going to be a continuous loop after initialization with one feedback process on the IR camera motor to report the position for the computer to recognize the plane's relative position.



8. HOUSE OF QUALITY

The house of quality is a speculative estimate of the tradeoffs for our engineering goals within the project versus other engineering goals and the marketing goals for our potential customers alongside desirable traits for the project for our sponsor.



	Engineering Requirements	Weight	Rotation Speed	Cost	Temperature Resistance	Operation Time	Rotation Angle
Marketing Requirements		-	+	-	+	+	+
Weight	-	↑↑		↑	↓		
Power Draw	-		↑↑			↓	
Cost	-		↓	↑↑	↓	↓↓	
Durability	+	↑	↓	↓	↑	↑	↓
Maintainability	+		↓	↓	↑		↓
Target		<100 lbs	>60°/s	<$10000	-20° C - 40° C	>1 week	60°

9. BUDGET AND FINANCING

Project to be sponsored and funded through SouthCom. Costs are estimates of key components of the project however additional items are likely to be added due to the custom nature of the mechanical and optical systems of this project.

Component	Name	Unit Cost	Quantity	Total
Radar System				
Radar	Raymarine Cyclone 6ft Open Array Radar Pack	$8250 (sponsor)	1	$8250
Radar software	Raymarine Software Dev Kit	$300 (sponsor)	1	$300
Data	Starlink Mini Terminal	$450 (sponsor)	1	$450

transmission				
Laptop PC	Provided by sponsor	$600 (sponsor)	1	$600
Portable power supply	Westinghouse portable power supply	$130 (sponsor)	1	$130
Mechanical System				
Linear actuator/piston	TBD	$50-$200	1	$200
Microcontroller	TBD	$50-$100	1	$100
Radar Housing	Custom	TBD	1	
IR Imaging System				
IR Camera	TBD	$200-$500	1	$350
Lenses		$60	3-4	$240
Lens system housing	Custom	$20-$50	1	$50
Optical Encoder				
LED	Ledsupply	$11	5	$55
Planoconvex lens	Thorlabs	$25-40	1	$40
Photodiodes	Thorlabs	$16	4	$64
Rotary wheel	3D printed	$10-20	2	$40
Motor	TBD	$50-100	1	$100

10. PROJECT MILESTONES FOR SD1 AND SD2

Senior Design 1 Project Milestones

TASK	START DATE	END DATE	DURATION
Project Brainstorming	1/6	1/10	1 Week
Sponsor Meeting	1/22	1/22	0 Weeks
Divide and Conquer Report	1/10	1/24	2 Weeks
Divide and Conquer Group Meeting	1/29	1/29	0 Weeks
Research Project Specifications	1/10	2/16	5 Weeks
Start System Design	2/17	4/15	8 Weeks
Midterm Report	1/10	3/24	11 Weeks
Midterm Report Group Meeting	3/26	3/28	0 Weeks
Finish System Design	2/17	4/15	8 Weeks
SD1 Final Report & Mini Demo Video	4/22	4/22	0 Weeks

Senior Design 2 Project Milestones

TASK	START DATE	END DATE	DURATION
Update 120 Page Report	5/12	5/12	0 Weeks
Begin System Assembly	5/12	7/14	9 Weeks
Test and Fix Prototype	6/2	6/9	1 Week
Optimize Prototype	6/9	6/30	3 Weeks
Complete Prototype	6/30	6/30	0 Weeks
Presentation Practice	6/30	7/13	2 Weeks
Final Presentation	7/14	7/14	0 Weeks

APPENDIX A:

References

[1] *E-3 Sentry (AWACS)*. (n.d.).
https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104504/e-3-sentry-awacs/

[2] Riedl, M. J. (2001). *Optical Design Fundamentals for Infrared Systems*. SPIE.

[3] Hansen, M. P., & Malchow, D. S. (n.d.). Overview of SWIR detectors, cameras, and applications. *Proc. of SPIE*, *6939*.

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