

Final Presentation

Sponsor: SOUTHCOM

Group 2

Alexander Alonzo

Xavier Colon

Carter Clavell

Nathanael Olson

Kai Doldan

Garrett Mosrie

P.A.D.S. ***(Passive Aircraft Detection System + Camera Array)***

Our Team



Carter Clavell

Electrical Engineering



Xavier Colon

Photonic Science and Engineering



Nathanael Olson

Electrical Engineering



Alexander Alonzo

Photonics Science and Engineering



Kai Doldan

Computer Science



Garrett Mosrie

Computer Science

Motivation & Background



- ◇ Border radar systems (\$20M+) are too costly, creating “dead zones” vulnerable to illegal activity (e.g., smuggling, drones).
- ◇ Our senior design project targets a low-cost, stealthy, reliable border security solution.
- ◇ Sponsored by Roy H. Wubker Jr. (DoD SOUTHCOM), with guidance on RF detection and optical alternatives.

Our Solution

- ◇ Active radars (which emit RF signals) are costly, both to buy, and maintain over time.
- ◇ We propose passive radar that listens to existing signals (e.g., FM radio, GPS) reflected from targets, making it harder to detect and requiring less power.
- ◇ Passive radars are also much cheaper and easier to maintain over time.
- ◇ To optically enhance the system, we propose a super-resolution three-camera array.
- ◇ This will combine the images of three cost-effective cameras, capturing far away objects, to produce an output with detail on par with expensive long-distance cameras.



Project Basic Goals



- ◆ The successful detection of a stationary metal object using passive detection.
- ◆ Measure antenna radiation pattern and classical range measurement
- ◆ Arrange 3 low-cost cameras in a simple and stable array configuration.
- ◆ Use code to do image processing and to create a super resolution image.
- ◆ Build a lightweight and reliable software system that connects the spectrum analyzer to a web interface that displays aircraft signal data in real time, including location, signal strength, and detection source.
- ◆ Develop a background service that runs independently to collect, clean, and store signal data from the SDK

Project Advanced Goals



- ◆ Should be able to detect a moving object
- ◆ The time it takes to deliver the information from the system to the user should be relatively quick
- ◆ System should be environmentally robust, primary focus on heat and humidity
- ◆ Camera array should have at least 3 lens systems with differing focal lengths
- ◆ System should be able to enhance objects at a distance effectively
- ◆ Super-resolution output should provide better edge detection than input images
- ◆ Cameras should all be aligned with overlap of at least 50%

Project Stretch Goals



- ◇ Easily implemented and easily manufacturable
- ◇ Connect with other systems to form an array.
- ◇ Completely autonomous
- ◇ False alarm feature.
- ◇ Create or utilize a database that can characterize aircrafts and identify the type of plane or drone that is within detection range
- ◇ Sturdy, stable, and environmentally protected housing for the entire device.
- ◇ Combine the RF device and camera array into a synergistic system for optimal performance in aircraft detection.
- ◇ Include signal classification features
- ◇ Design a connecting joint that allows the unit to be attached to a vehicle, such as an airplane, for mobile image capture.
- ◇ Incorporate a phase correction plate and adaptive optics to account for any aberrations due to the environment.
- ◇ Upgrade optical components to a higher quality to further improve the performance of the assembled system
- ◇ Build a simple database to log past detections and allow users to search or review older signal events
- ◇ Create a dashboard interface that summarizes total detections, time active, and any alerts or events



Project Objectives for Basic Goals

- ◆ Research and purchase affordable, quality parts. Ensure spectrum analyzer is properly calibrated.
- ◆ Test all hardware components and validate detection range and beam pattern using a second antenna.
- ◆ Acquire and configure low-cost, low-resolution cameras, and experiment with different array shapes and spacing.
- ◆ Use Python to develop and test image processing code to improve image resolution.
- ◆ Use Zemax to design lens systems that will allow for quality image capture at 100 feet away.
- ◆ Set up the server using Node.js and Express to support frontend connections.
- ◆ Design a responsive and readable UI using HTML, CSS, and JavaScript.
- ◆ Write code that pulls signal data from the SDK using a background service and sends it to the web interface.
- ◆ Test the real-time signal display.
- ◆ Keep the code organized with clear comments and folder.



Project Objectives for Advanced Goals

- ◆ Build algorithms that can separate aircraft signals from noise and make them more power-efficient.
- ◆ Validate passive detection at Orlando International Airport and test image clarity from 100 yards using the L3 Harris sign.
- ◆ Research autonomous power options and measure system latency and computational load.
- ◆ Test the amount of computer power and latency to process data.
- ◆ Add more low-cost cameras and develop better ways to interconnect and scale the camera array.
- ◆ Purchase more of the low cost, low resolution cameras to arrange into a larger array configuration.
- ◆ Design modular, aligned lens housings tailored to the camera layout.
- ◆ Collaborate with CREOL to integrate phase correction plates for better image quality.
- ◆ Link live spectrum analyzer data using its SDK, test signal filtering to reduce false positives, and implement WebSockets for real-time updates.
- ◆ Gather user feedback and refine the interface for better clarity and usability.

Project Objectives for Stretch Goals



- ◆ Develop a robust enclosure to protect the camera system from harsh environments.
- ◆ Integrate with an aircraft mounting system and optimize the system for aerial imaging.
- ◆ Conduct airborne tests.
- ◆ Create a larger array that has the capability to incorporate more cameras and lens systems to increase the potential of the super resolution system.
- ◆ Create a larger database of aircraft and drones that may be called upon when an anomaly appears in the area. This can be used to compare what was captured and detected with the camera array with previous detections or, if enhanced with AI, what the deep learning was trained on.



Engineering Requirements



Parameter	Specification
Signal receive and detection time	<5 minutes
Detection Range	0-5 Miles
Frequency range	300Mhz to 3000Mhz
Detection accuracy	>70%
Size	<1m ²
Cost	<\$6500

Engineering Requirement	Parameter	Specification
Camera(s)	Resolution	1 MP (1280x800)
	Pixel Size	3 um x 3 um
	Frame Rate	100 fps
	Color	Monochromatic
	Shutter Type	Global
Camera Density	# of Cameras	>= 3
Lens System	Focal Lengths	125 mm
		175 mm
		250 mm
	Diameter(s)	25.4 mm
		BK7
Inter-Camera Alignment	Image Overlap	>= 50%
Super-resolution Image	Resolution	>= 2x original
	FOV	>= 1 degree



House of Quality – EE/CS

House Of Quality

Project title: SOUTHCOM PROJECT II

Project leader: Xavier Colon

Date: 2/3/2025

Desired direction of improvement (↑,0,↓)	↑	↑	↑	↓	↓
Functional Requirements (How's) →	RF Detection	Large Plane Detection Accuracy	Small Plane Detection Accuracy	Device Connection	Cost
Customer Requirements - (What's) ↓					
Reliability ↑	++	++	++	++	--
Starlink Functionality ↑	0	0	0	++	-
Identification database ↑	++	+	+	++	-
Affordability ↑	-	-	-	-	++
Targets for Engineering Requirements	9kHz - 1.5GHZ	>60%	>50%	1 Starlink terminal	<\$10,000

Correlation:

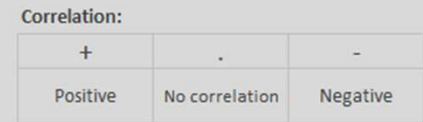
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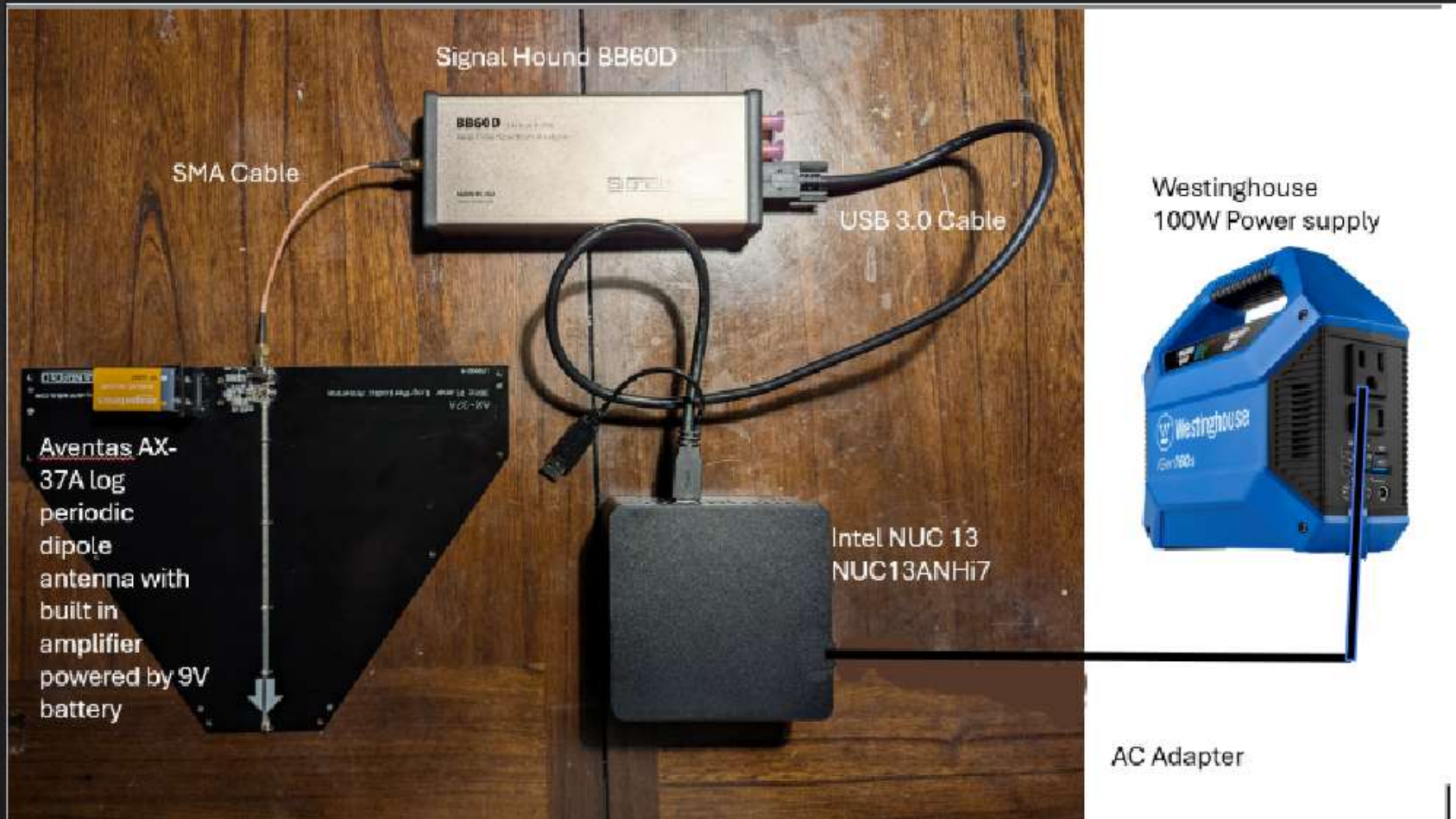
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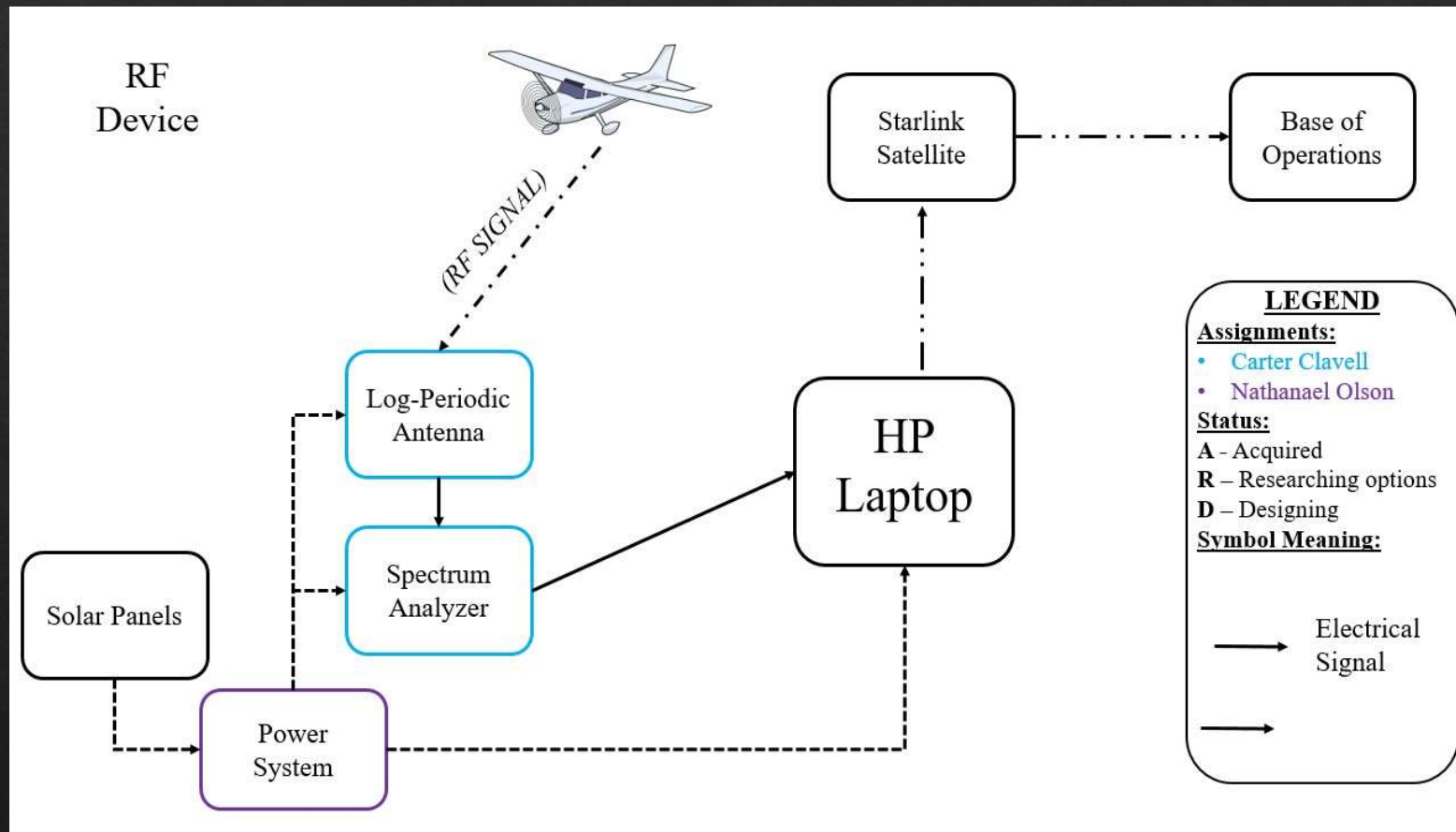
Project title:	SOUTHCOM PROJECT II
Project leader:	Xavier Colon
Date:	7/1/2025



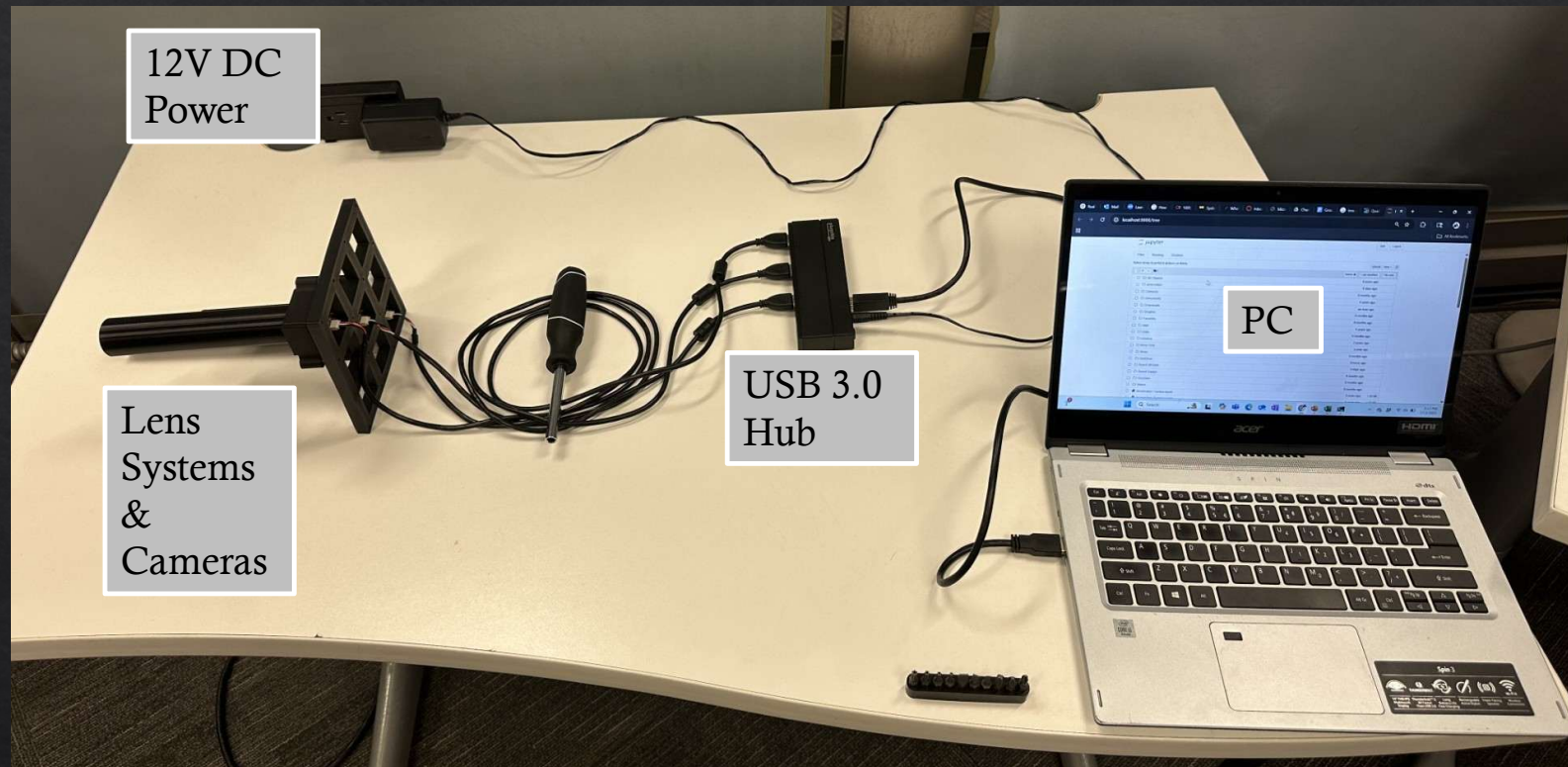
Physical Product – P.A.D.S.



Hardware Diagram



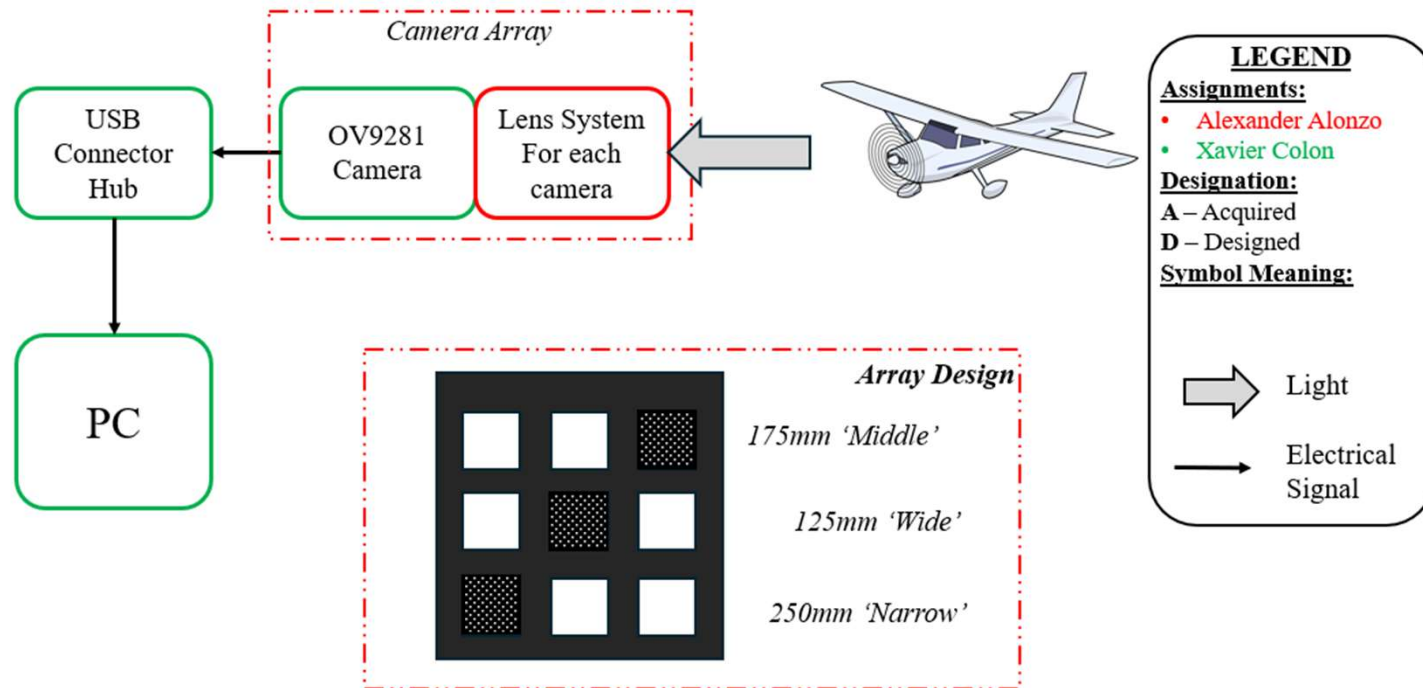
Physical Product – Camera Array



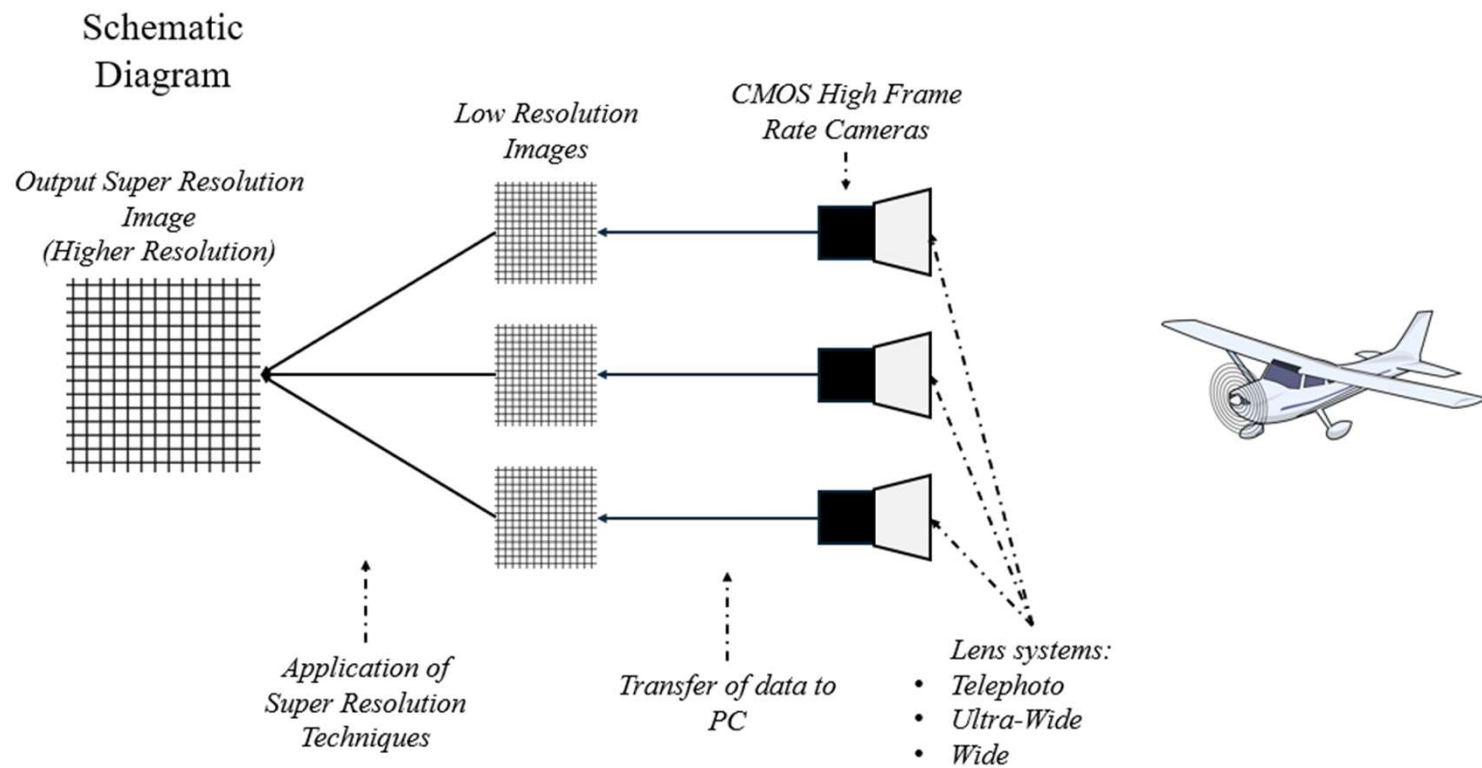


Hardware Diagram

Camera
Array
System



Camera Array Pipeline





Lens Design Calculations

- ❖ In imaging systems, angular resolution is defined as:

$$\text{Angular Resolution} \cong \frac{\lambda}{D}$$

- ❖ In practical camera systems, it can be interpreted as:

$$\text{Angle per Pixel} = \frac{\text{Pixel Pitch}}{\text{Effective Focal Length}}$$

- ❖ Differences in angular resolution between the cameras is key to achieving super-resolution!
 - ❖ We can achieve those differences using different focal length lenses!

Note:

- 206265 is the number of arcseconds in a radian
- 3600 arcsec/degree

Angular resolution for each camera:

$$\begin{aligned} \text{❖ } \frac{206265 * 3 \mu m}{125 \text{ mm}} &= 4950.36 \frac{\text{arcsec}}{\text{pixel}} \\ \text{❖ } \frac{206265 * 3 \mu m}{175 \text{ mm}} &= 3532.71 \frac{\text{arcsec}}{\text{pixel}} \\ \text{❖ } \frac{206265 * 3 \mu m}{125 \text{ mm}} &= 2475.18 \frac{\text{arcsec}}{\text{pixel}} \end{aligned}$$





FOV Design Calculations

- ❖ Field of view (FOV) is defined as how much an imaging system can see, usually defined in degrees

$$FOV = 2 * \arctan\left(\frac{x}{2f}\right)$$

- ❖ Variable Definitions:

- ❖ x = diagonal of sensor (in μm)

- ❖ Since our largest focal length is 250 mm, we used that value to find our limit

$$x = \sqrt{(1280 * 3 \mu m)^2 + (800 * 3 \mu m)^2} \cong 4.52 \text{ mm}$$

$$FOV = 2 * \arctan\left(\frac{0.00452 \mu m}{2} * 250 \text{ mm}\right) \left(\frac{180}{\pi}\right) \cong 1 \text{ degree}$$

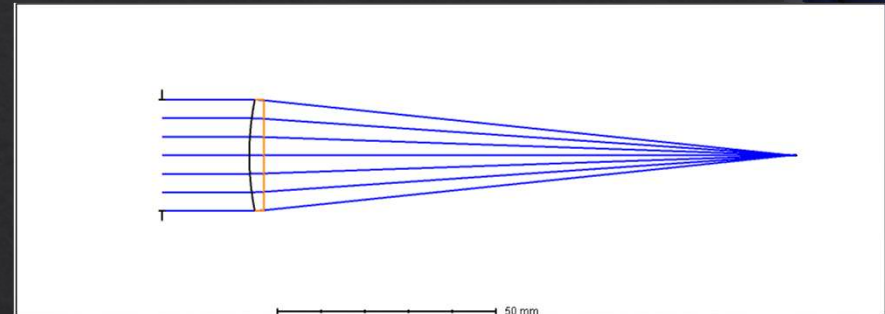
- ❖ With an approximate 1 degree field of view, we can use the equation used below to find our object size

$$Object \text{ Size} = 2d \sin\left(\frac{FOV}{2}\right) = 2(60 \text{ feet}) \sin\left(\frac{1}{2}\right) \cong 1 \text{ foot}$$

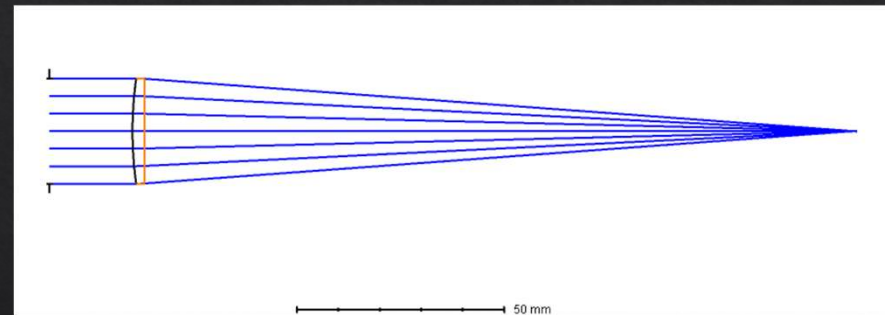
Lens Design



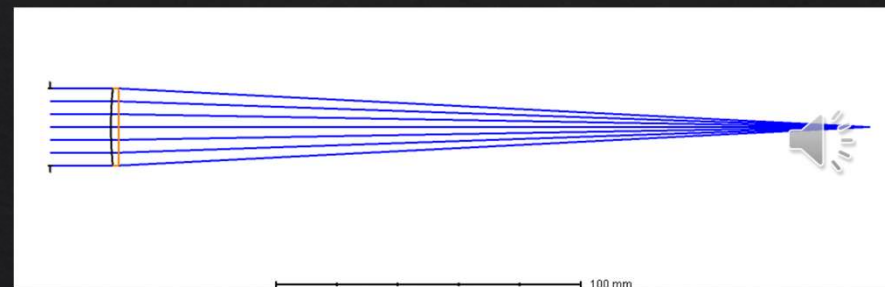
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1	STOP Standard ▾		Infinity	20.000	
2	Standard ▾	125 Lens 1 S1	64.400	3.300	BK7
3	Standard ▾	Lens 1 S2	Infinity	122.0...	M
4	IMAGE Standard ▾		Infinity	-	



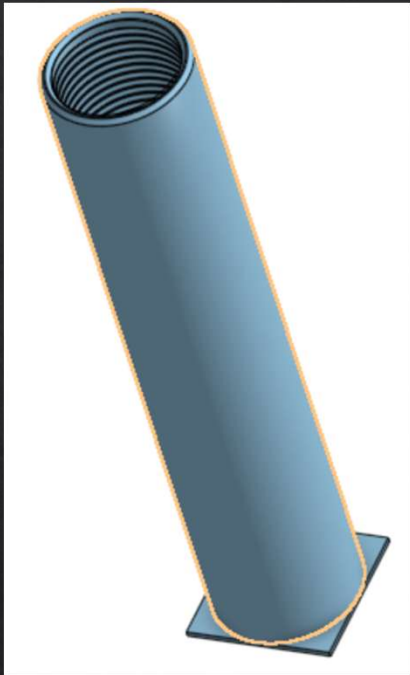
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3	Standard ▾	Lens 1 S2	Infinity	171.8...	M
4	IMAGE Standard ▾		Infinity	-	



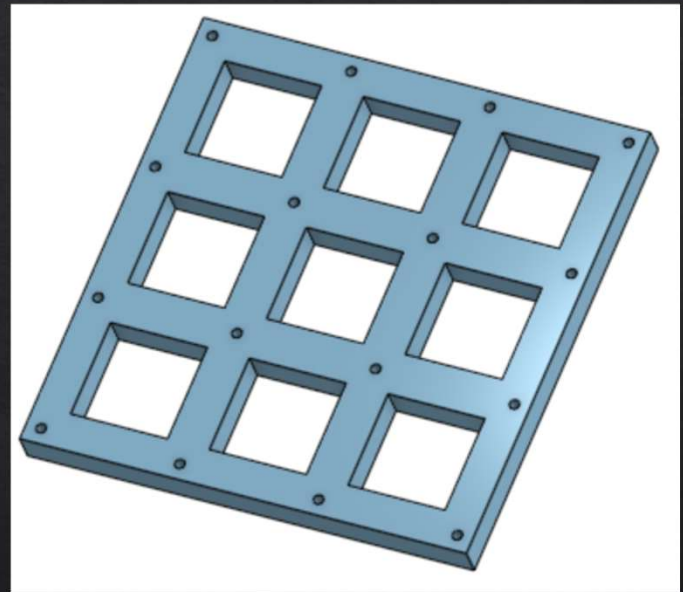
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1	STOP Standard ▾		Infinity	20.000	
2	Standard ▾	250 Lens 1 S1	128.800	2.600	BK7
3	Standard ▾	Lens 1 S2	Infinity	246.6...	M
4	IMAGE Standard ▾		Infinity	-	



Hardware Design – Lens Tube and Peg Board



Lens Tube



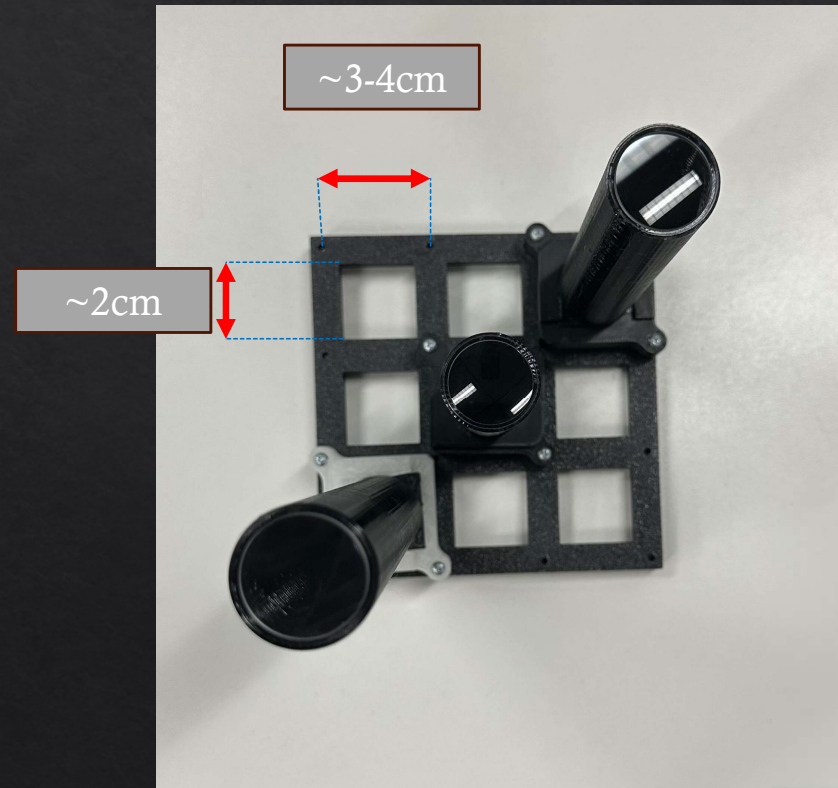
Peg Board





Visual of Lens Tubes & Peg Board

Each lens tube is slightly shorter than its corresponding lens focal length



Hardware Overview



- ◆ Log-periodic antennas (e.g., Aventas AX-37A):
 - Wide frequency range (300–3000 MHz)—ideal for unpredictable reflections.
 - Good forward gain and low noise for accurate detection.
 - Compact design and rugged construction suitable for challenging environments.
 - Selected as the best trade-off of performance, bandwidth, and size.

Antenna Type	Frequency Range	Beam Pattern	Gain (dbi)	Cost
<u>Half Wave</u>	3K to 300G	Omni	2.15	\$80.00 - \$200.00
<u>Half Wave Folded</u>	3K to 300G	Omni	4	\$509.00
<u>Microstrip</u>	915-930 Mhz	Broad	2	\$14.00
<u>Collinear</u>	896 - 970 Mhz	Omni	5	\$85.15
<u>Yagi-Uda</u>	880 - 960 Mhz	Omni	12.2	\$247.00
<u>Log Periodic</u>	300 - 3000 Mhz	Omni	6	\$0.00

Hardware Overview



- ◇ Signal Hound BB60D chosen due to:
 - Lowest cost, aligning with project budget constraints.
 - Compact, USB-powered, and low power consumption (6 watts).
 - Compatible with Linux for portable processing (e.g., Raspberry Pi, Nvidia Jetson).
 - Free software with SDK for advanced detection algorithms (e.g., AI/ML integration).
 - 27 MHz RTBW is acceptable for the targeted frequency range.
 - Good dynamic range and sensitivity for detecting low-power signals from aircraft.
 - Best trade-off of performance, portability, and cost for the project's needs.

Spectrum Analyzer	Frequency Range	DANL dBm/Hz	RTBW	Dynamic Range	Cost
Tektronix RSA306B	9 KHz to 6.2 Ghz	-160	40 MHz	-160 dBm to 20 dBm	\$6490
Siglent SSA3032X-R	9 KHz to 3.2 Ghz	-165	40 MHz	60 dB	\$6545
Signal Hound BB60D	9 KHz to 6 Ghz	-158	27 Mhz	-150 dBm to 10 dBm	\$0.00
Keysight N9023B PXA	2 Hz to 55 Ghz	-167dBm	2 Ghz	-170 dBm to 30 dBm	\$207292.56

Hardware Overview



- ◆ Intel NUC 13 NUC13ANHi7:
 - High-performance Intel Core i7 (12 cores, 16 threads) with 16GB RAM.
 - Fast 512GB NVMe SSD for high-speed data logging and analysis.
 - Supports complex software (e.g., MATLAB, GNU Radio) for RF analysis.
 - Excellent connectivity (USB, Thunderbolt 4, Ethernet) for integrating with RF equipment.
 - Compact form factor and power-efficient (~63W) for field deployment.
 - Expandable and versatile with Windows/Linux support and hardware acceleration (Iris Xe).
 - Chosen for its best mix of performance, portability, and compatibility with our signal processing needs.

Feature	Intel NUC 13 (NUC13ANHi7)	Raspberry Pi 5	NVIDIA Jetson Nano
Processor	Intel Core i7-1360P (12-core, 16-thread)	Quad-core Cortex-A76	Quad-core Cortex-A57
RAM	16GB DDR5	Up to 8GB LPDDR4X	4GB LPDDR4
Storage	512GB NVMe SSD	microSD or SSD (via adapter)	microSD or SSD (via adapter)
GPU	Intel Iris Xe Graphics	Broadcom VideoCore VII	NVIDIA Maxwell (128 cores)
Power Consumption	~63W	~5W	~10W
OS Support	Windows 11 Pro, Linux	Raspberry Pi OS, Linux	Ubuntu, Linux
Price	\$0	\$69.49	\$224.99
Best Use Case	High-performance data processing	Low-power, simple data collection	AI-enhanced RF processing

Hardware Overview



◇ Why Samsung Galaxy S24:

- **Direct-to-cell satellite messaging now**, future voice/data support for wider coverage.
- **High-performance Snapdragon 8 Gen 3 processor** and large, high-resolution display.
- **Long battery life** and future-proofed hardware for seamless aviation data tracking.
- **Best balance** of hardware, connectivity, and support for continuous access to flight data via Starlink.

Feature	Samsung Galaxy S24 Ultra	Apple iPhone 15	Google Pixel 8 Pro	Older Android/iPhones
Starlink Direct-to-Cell Support	Yes (Texting now, voice/data future)	Yes (Texting now, voice/data future)	No (Wi-Fi only)	No (Wi-Fi only)
Processor	Snapdragon 8 Gen 3	Apple A17 Pro	Google Tensor G3	Varies
RAM	12GB	6GB	12GB	4GB-8GB
Display	6.8" AMOLED (120Hz)	6.1" OLED (120Hz)	6.7" OLED (120Hz)	Varies
Battery Life	~14-16 hours	~13-15 hours	~12-14 hours	Lower than modern flagships
Starlink Wi-Fi Support	Yes	Yes	Yes	Yes
Price	\$0	\$729.99	\$599.99	<\$500

Hardware Overview



◆ Westinghouse 100-Watt Power Station:

- Lightweight (3.75 lbs) and highly portable for mobile radar deployment.
- Sufficient battery capacity (155Wh) for low-power radar needs.
- Affordable, making it cost-effective for prototyping and eventual deployment.
- Solar-ready for renewable, self-sustaining operation with continuous recharging.
- Multiple outputs (USB, DC, AC) for powering all necessary devices.
- Compact design and low output capacity match the system's modest energy requirements.
- Why Chosen: Provides the optimal balance of portability, cost, solar functionality, and power output for passive radar use.

Feature	Westinghouse 100W	EF ECOFLOW RIVER 2 Pro	EF ECOFLOW DELTA Max 2000	Jackery Explorer 300
Battery Type	Lithium-Ion	LiFePO4	LiFePO4	Lithium-Ion
Battery Capacity	155Wh	768Wh	2016Wh (Expandable)	293Wh
Power Output (Rated/Surge)	150W / Not specified	800W (1600W X-Boost)	2400W / 5000W	300W / 500W
Solar Input	Yes	220W max	800W max	100W max
Weight	3.75 lbs (Lightest)	17.2 lbs	48 lbs (Heaviest)	7.1 lbs
Price	\$0(cheapest)	\$379	\$1299(most expensive)	\$259
Dimensions (inches)	7.4 x 6.6 x 3.7	10.6 x 10.2 x 8.9	19.6 x 9.5 x 12	9.1 x 5.2 x 7.8
Best Use Case	Small devices, ultra-light travel	Mid-range power needs, tools, RVs	Home backup, high-power appliances	Camping, small device backup



Hardware Overview

◇ Lens System Types

- Imaging an object around ~60ft away.
- Small focal length to keep design compact
- ~ 1-degree FOV to create ~1 foot of object space

Feature	Telephoto Lens	Wide-Angle Lens	Adjustable Zoom Lens	Fisheye Lens	Aspheric and Custom Lenses
Focal Length Range	100mm-600mm	10mm-35mm	24mm-200mm	Wide-ranging	Wide ranging
Positive Features	Minimizes perspective distortion and high precision with long distances	Wide field of view to give peripheral information	Best used for moving objects	Field of view 180 degrees or more	Minimizes spherical and chromatic aberrations
Negative features	Narrow field of view	Barrel distortions and low magnification	Focal length changes causing image blur and chromatic aberrations	High distortions	Can be expensive 

Hardware Overview



◆ Arducam OV9281

- ◆ Good starting resolution (1280 x 800) 1MP Global shutter
- ◆ USB 3.0 connection
- ◆ Monochromatic
- ◆ 100 fps
- ◆ Around \$50 per camera

Feature	Arducam OV9281	IMX219 8MP	See3CAM_CU135	Rasp. Pi CM3
Resolution	1280x720	3280x2464	4208x3120	4608x2592
Shutter Type	Global	Rolling	Rolling	Rolling
Max Frame Rate	100 fps (720p)	30 fps (1080p)	60 fps (1080p)	100 fps (720p)
Pixel Size	3 um	1.12 um	1.1 um	1.4 um
Connection Type	USB 2.0	MIPI CSI	USB 3.0	MIPI CSI
Price	~\$50	~\$35	~\$100	~\$40
Best for Motion Detection	Yes, global shutter prevents motion blur	No, rolling shutter leads to motion blur	No, rolling shutter leads to motion blur	No, rolling shutter leads to motion blur
Super Resolution Feasibility	Good, multiple cameras with high frame rates	Possible, limited by rolling shutter	Possible, limited by rolling shutter	Possible, limited by rolling shutter

Wired Communications Protocol



❖ Pluggable 7-port USB Hub

- ❖ USB 3.0 connection
- ❖ Reduces bottlenecking effect when using cameras simultaneously
- ❖ Higher number of ports
- ❖ Easily connects to PC
- ❖ Provides 12 V DC power

USB Hub	# of Ports	Bandwidth	External Power	Bandwidth for each port	Best for multi-camera use	Price
Plugable 7-Port	7 - USB 3.0	5 Gbps	60 W	Highest stability for each port	Best for multiple camera setup	~\$40
StarTech 7-Port	7 - USB 3.0	5 Gbps	36 W	Higher stability for each port	Best if all ports are not used, 4-5 cameras	~\$60
Anker 10-Port	10 - USB 3.0	5 Gbps	60 W	Lower bandwidth per port	Lots of ports, but when all are in used, performance issues	~\$40
StarTech 4-Port	4 - USB 3.0	5 Gbps	None	Lower bandwidth and possible power issue risk		~\$35

Wired Communications Protocol



◆ USB (Universal Serial Bus):

- ◆ High data rates (USB 3.0: 5–10 Gbps), suitable for complex data.
- ◆ Provides power (up to ~5W), eliminating the need for separate power supplies.
- ◆ Robust, versatile, and standardized across platforms.
- ◆ Direct compatibility with the chosen spectrum analyzer and Intel NUC.
- ◆ Chosen for its superior bandwidth, versatility, and compatibility with our high-speed data needs.

Protocol	Power output	Bandwidth	Interface Compatible
I2C	1-5mW	400 KB/s	No
UART	3.3-150mW	10 Mbp/s	No
USB	.5-4.5W	5 - 10 Gbp/s	Yes

Wireless Communications Protocol



- ◇ Starlink (Low Earth Orbit Satellite Service):
 - Global coverage; operates on multiple bands (Ku, Ka, V) with high data rates and low latency.
 - Suitable for remote areas, eliminating need for cell towers or wires.
 - Drawbacks: Higher power consumption (10–100W) and rain fade susceptibility (weather interference).
 - Upcoming Starlink-to-Mobile Integration:
 - Direct satellite connection for modern smartphones—low power consumption, global reach.
 - Simplifies system design and reduces infrastructure needs.
 - Chosen Solution: Starlink offers the best balance of global coverage, speed, and future-proof connectivity despite higher power needs.

Protocol	Power Consumption	Download Speeds	Upload Speeds	Latency	Coverage
4G LTE	2 - 10 W	5 - 150 Mbps	1 - 50 Mbps	20 - 50ms	Near cell tower
Starlink	10 - 100 W	50 - 250 Mbps	10 - 40 Mbps	20 - 50ms	Worldwide

Software Overview



Front-end Frameworks

	Vanilla JS	React	Angular
Type	Language	Library	Framework
Complexity	Simple	Moderate, component-based	Complex, structured, and opinionated
Setup Needed	None	Moderate	High
Performance	Moderate, inefficient	High	Good
Ideal Use Case	Small Projects	Medium to large projects	Large-scale enterprise applications

React-

- Front-end Library
- Requires a bit of setup, but easy to develop with.
- Easy to expand web application with reusable components.
- Great performance for medium sized web applications.

Software Overview



Non-Relational Databases

	MongoDB	Cassandra	Redis
Efficiency	High	High	Very High
Scalability	Good for large datasets	Excellent	Limited (memory-based)
Flexibility	Dynamic schema	Wide column store	Key-value storage
Query Performance	Moderate	Limited	Minimal
Geospatial Support	Yes	No	No
Data Consistency	Eventual Consistency	Eventual Consistency	Not ACID-compliant

MongoDB-

- Document-based approach makes it easy to store and retrieve information.
- Scales well horizontally, which could help with storing information from multiple sensor nodes.
- Great geospatial indexing capabilities.
- Good balance between flexibility and performance.

Software Overview



Premade Web Stacks

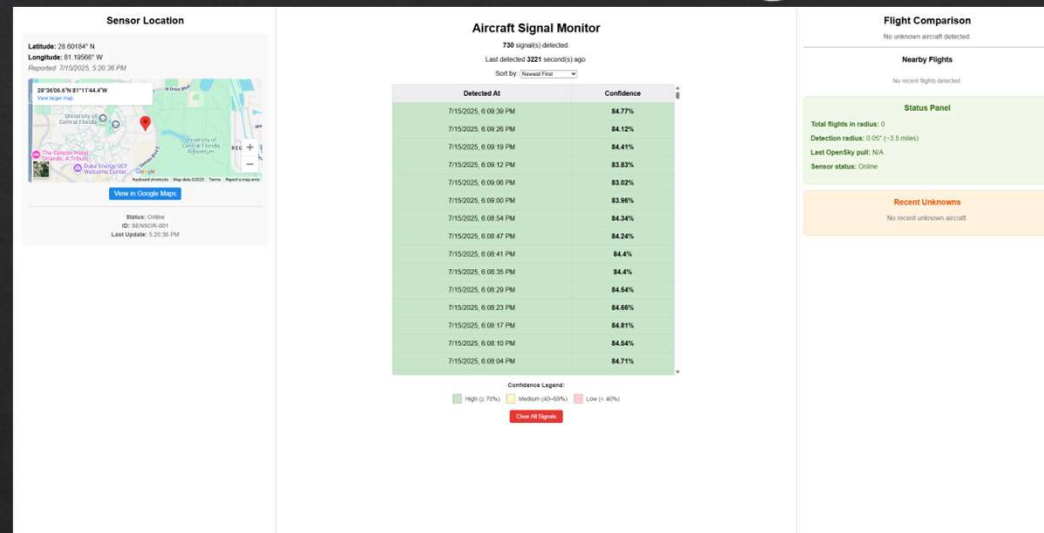
Web Stack Comparison

MERN	LAMP	MEVN	.NET STACK
MongoDB	Linux	MongoDB	ASP.NET Core
Express	Apache	Express	SQL Server
React	MySQL	Vue.js	React
Node.js	PHP	Node.js	Blazor

MERN-

- Since MERN includes both React and MongoDB, our choices for front-end and database, it made the most sense to use the commonly used MERN stack.
- Uses Node.js and Express for the back-end server.

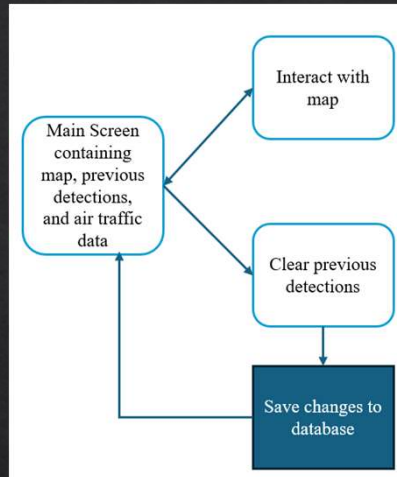
Software Design



Finished Web Application Layout

On the left is the information about the sensor, including the location and when it was last updated. There is also a map, so the user better understands the location. In the center is a log of all past detections and the associated time and confidence. On the right informs the user if there are any known flights in the area, and if the signal aligns with the known flights.

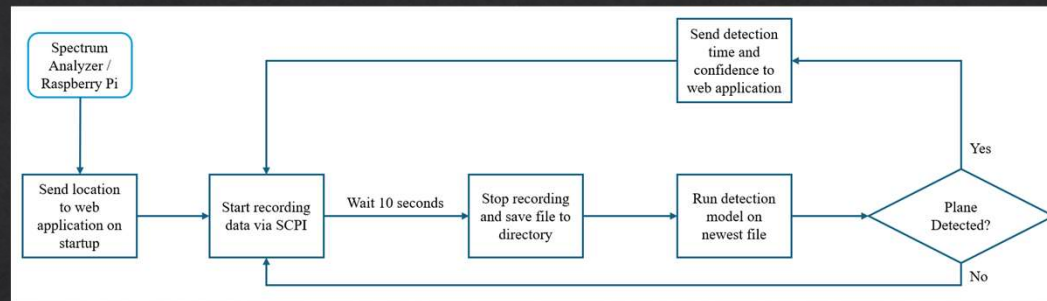
Software Design



User-Flow Diagram of Web Application

When opening the web application, the user lands on the main page, containing the location, previous detections, and known flights in the area. The user can interact with the map to get a better understanding of the location. The user can also clear all previous detections from the database.

Software Design



RF Signal Detection Flow

The sensor-side computer connects to the spectrum analyzer using the Spike SDK, utilizing SCPI commands. When the script runs, it first sends an API call to the website with the current location. Then, the script sends a command to start recording, waits for a specified amount of time, then stops the recording and saves the file. The model is then run on the file, and if an airplane is detected the script sends an API call with the time and confidence level.



Software Design

Multi-Image Super Resolution

- ❖ MATLAB & Python
- ❖ Doesn't require as much data as ESRGAN
- ❖ Back-Projection improves the output by minimizing reconstruction error — works better with multiple complementary inputs

Method	Type	Input	Computational Cost	Image Quality	Pros	Cons
Nearest Neighbor	Single Image, Interpolation	1 Image	Very Low	Poor	Fast, Simple, zero processing time	Blocky artifacts, jagged edges, poor detail retention
Bilinear	Single Image, Interpolation	1 Image	Low	Fair	Smooth results, slightly better than NN	Blurry, soft edges, still loss of detail
Bicubic	Single Image, Interpolation	1 Image	Moderate	Good	Smoother than bilinear, better edges	Blurs fine details, no resolution gain
Back-Projection (Multi-Image SR)	Multi-Image & Alignment	Multiple Images Aligned	High	Very Good	Uses actual new information from differences in angular resolution	Requires accurate image alignment, sync capture, more processing time
ESRGAN	Multi-Image & Deep Learning	Multiple Images Aligned	Very High	Excellent	Learns complex patterns, preserves fine details, robust to noise	Requires GPU, training data or pretrained model, sensitive to misalignment

Software Overview



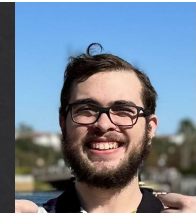
Image Object Detection Models

	TensorFlow	YOLO (You Only Look Once)	Detectron2	OpenCV
Speed	Moderate-High	Very High	Moderate	Very High
Accuracy	High	Moderate-High	Very High	Low-Moderate (Less accurate for complex scenes)
Ease of Use	Moderate (requires setup)	Moderate (if using pre-trained models)	Moderate-Easy	Easy, straightforward setup and deployment
Deployment Environments	Web, mobile, cloud	Embedded devices, desktop applications	Server, desktop, research environments (heavy computational demand)	Embedded systems, desktop applications
Ideal Use Case	Industrial automation, traffic surveillance, object tracking	Real-time video analysis, surveillance, frones	High-accuracy applications, scientific image analysis	Rapid prototyping, low-resource devices, simple detection tasks.

YOLO-

- Known for high performance and real-time object detection capability.
- Great where rapid-response times are crucial.
- Moderate ease of use using pre-trained models.
- High accuracy for our use-case.

Software Overview



Machine Learning Libraries for RF

	Scikit-learn	TensorFlow	PyTorch	XGBoost
Speed	Fast for small to medium datasets	Moderate, faster with GPU	Moderate, faster with GPU	Very fast
Accuracy	Good for classic models	High with deep learning models	High, good for experimentation	Extremely high on structured data
Ease of Use	Easiest	Steeper learning curve	Moderate	Moderate
Deployment Environments	Easy to deploy in lightweight apps	Great for embedded	Flexible	CLI, API, and cloud-compatible
Ideal Use Case	Prototyping traditional models	CNNs, RNNs, time-series detection	Custom detection networks & R&D	Handling large datasets for high accuracy

TensorFlow-

- Access to deep learning and neural networks.
- Works with Python, our main scripting language.
- Able to train with GPU, making training times faster.
- Works good for supervised learning with labeled datasets.

Testing – Hardware Testing



For our hardware testing, we needed a standard procedure. Data collection is the most important part of this whole project and detecting aircraft.

1. First, we needed to set the antenna high up so that we could get best results.
 - ◇ We put it on top of a 6 ft ladder and used an object to prop up the antenna about 5 degrees.
2. Next, we recorded and labelled data in accordance with whether there was an airplane or not.
3. We used guidelines around our test environment to help determine when an airplane was there.

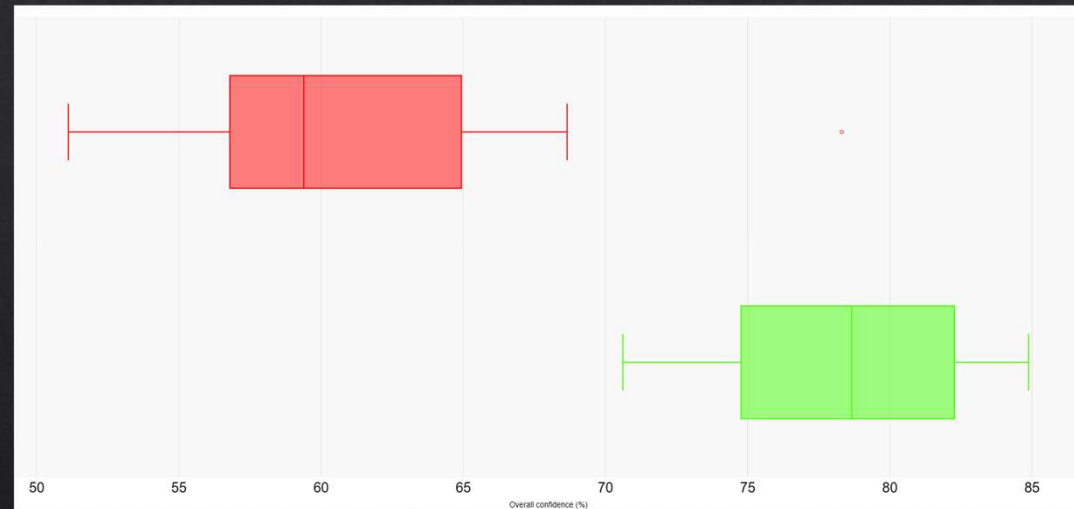


Image of the wonderful Kai on a test day

Testing – Performance Evaluation & Successes



- For our testing, we went to both MCO and Sanford International airport to gather plane data.
- Gathered over 1500 data points total.
- Succeeded in detecting airplanes
- Over 50 data points of varying distance
 - 76% accuracy with planes
 - 60% accuracy without planes
 - (Overall average for planes from 0 – 5 miles)
- Successful Starlink to website upload
- Confirmed solar power viability
- Successful radio detection
- Able to detect moving car (For live demo)



Box and whisker plot of overall confidence of aircraft presence.
(Red shows without plane green shows with plane)

Testing – Difficulties and Solutions

Difficulties

- No enclosure
- RF Environment changes drastically
- Inconsistent ML algorithm
- Issues with small aircraft

Solutions

- Prioritize detection over enclosure building
- Needs to be recalibrated and changed often
- Switched to Convolutional Neural Network and got much better results
- Explored dual switching antenna setup



Image of PSE and EE students working on final demo testing



Camera System Testing



- ❖ To test the cameras and lens systems we use a live feed from each camera
 - ❖ Checking for overall clarity sharpness
 - ❖ Exposure levels for each camera
- ❖ Once best possible image quality is achieved, we begin alignment
 - ❖ Region of interest must be within each cameras view



iPhone 14 Pro
(Result for
comparison)



Camera Capture



- ❖ These images are the inputs to our super-resolution code in MATLAB
- ❖ Note: Images are cropped here for viewer clarity
- ❖ Sync-capture still not achieved, stagger imaging used



Wide (125mm)



Middle (175mm)

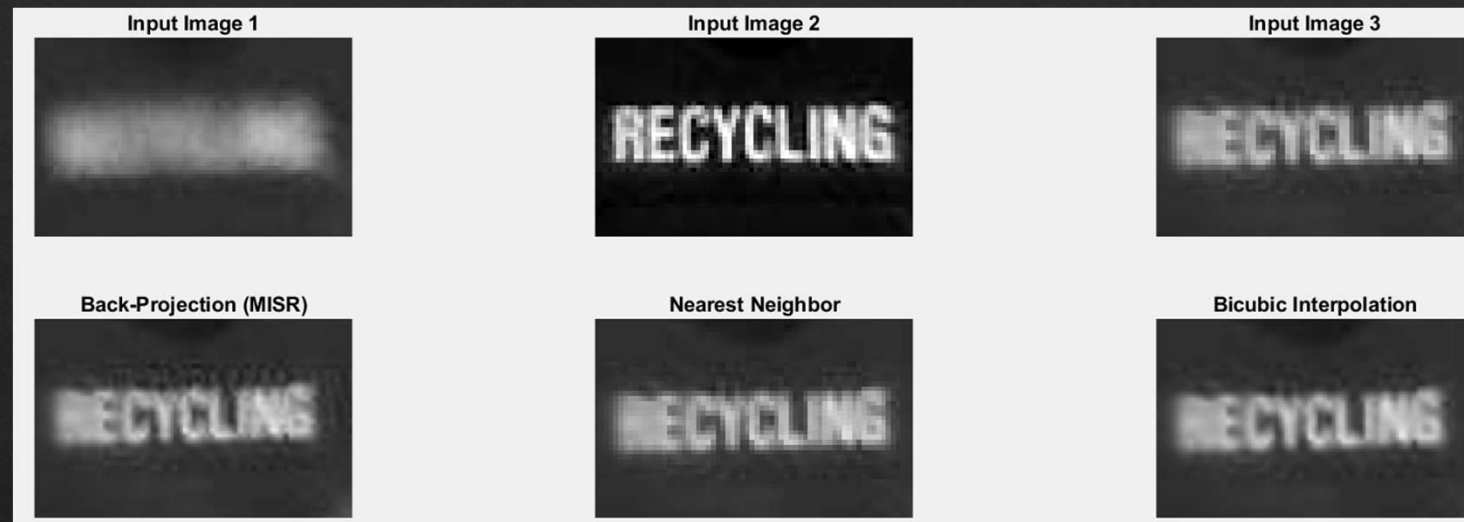


Narrow (250mm)



Super-Resolution Success Criteria

- ❖ Here we see 3 inputs and 3 versions of SR below them
- ❖ The bottom left is our SR algorithm
 - ❖ Artifacts from minimal misalignment and shaking during capture
 - ❖ More pixels within the ROI than our 3 inputs!



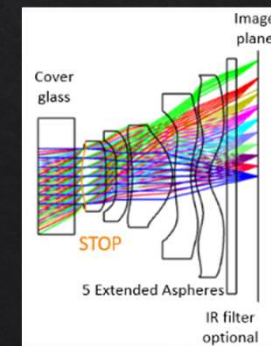
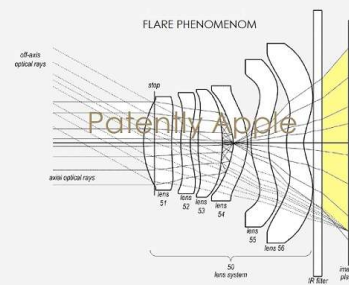


Comparison

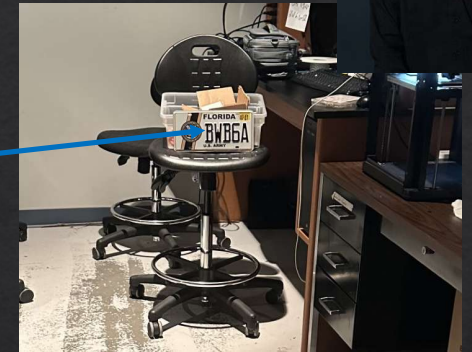
- ❖ It is very clear the iPhone14 Pro (\$\$\$\$) beats out our 3-camera array
- ❖ However, when more cameras are added and are finely tuned, the enhancement of the ROI will be much more noticeable

iPhone uses state of the art optics, cameras, and processors

We use 3 \$40 cameras and basic optical physics!



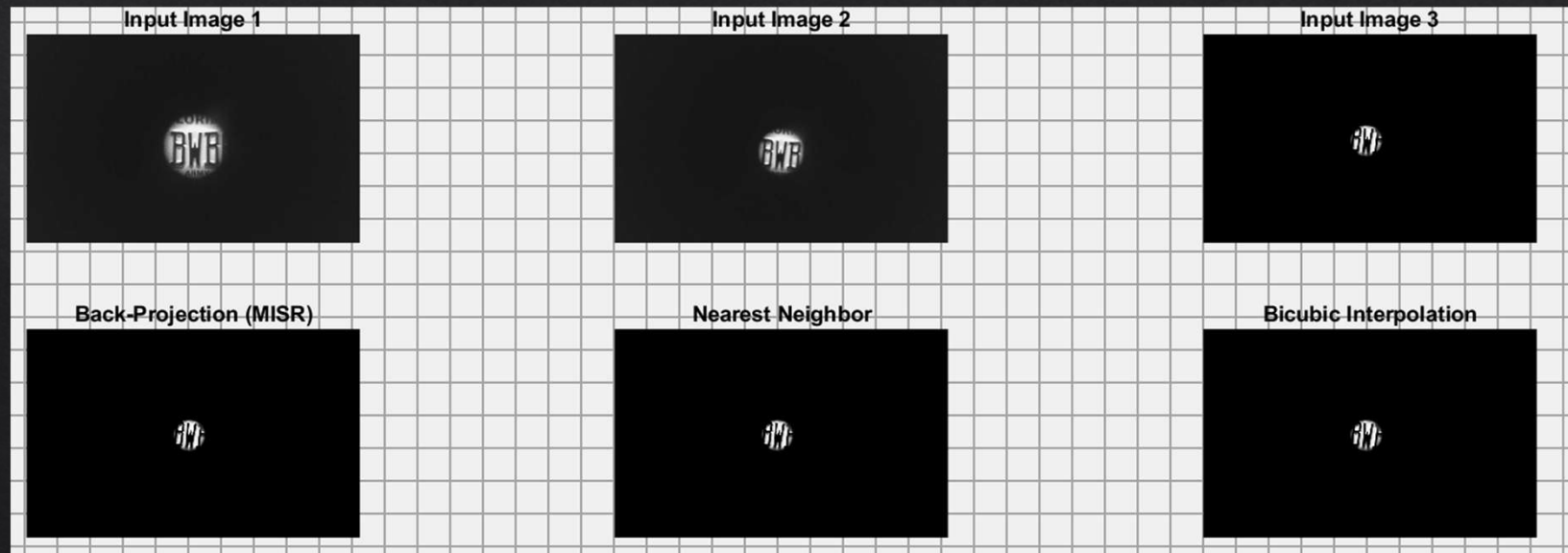
More Tests After Fine Tuning



~10ft away

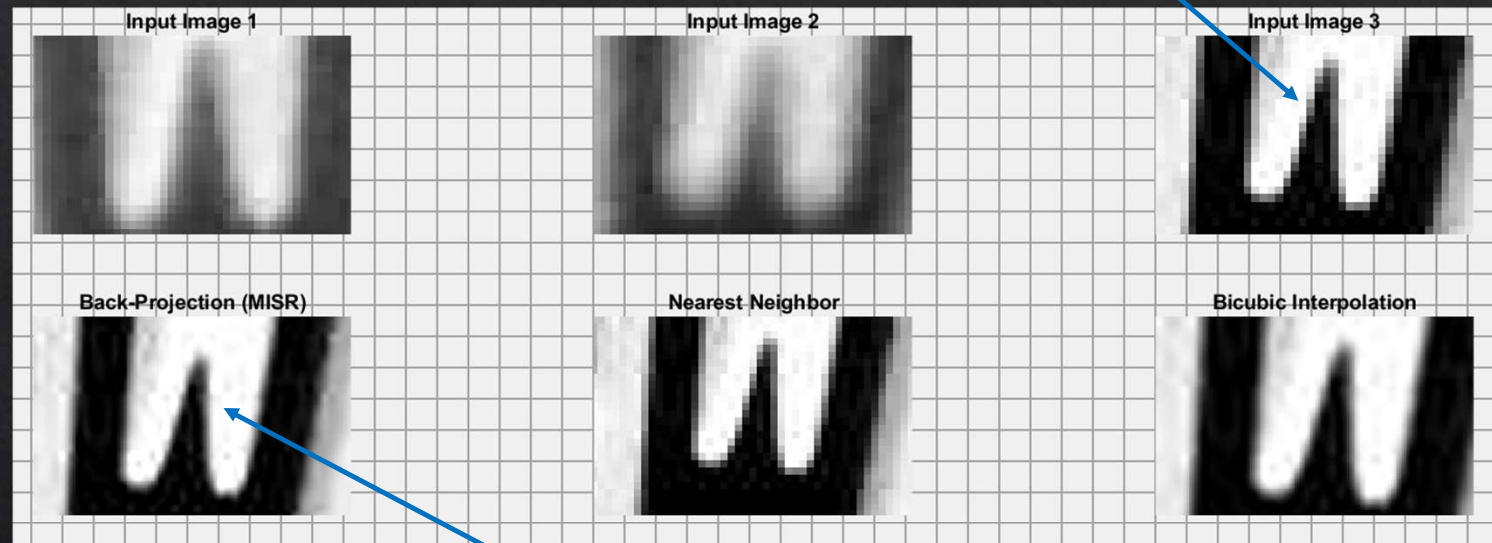
Focusing on "W"
- 7cm tall
- 2cm wide

- ❖ Here, we continued to fine tune each cameras quality
- ❖ Region of interest is "W"
- ❖ At first glance, output vs input looks the same but...



More Tests

- ❖ Let's take a closer look at the letter "W"
- ❖ Input images have little definition
- ❖ Output SR image has much better definition (6400x4000!)
- ❖ Once again, iPhone beats our system but (\$\$\$\$)



Middle part
of W is very
pixelated
here

More pixels
to define
that same
part!



Why is SR important?

- With better edges we are better able to detect objects in our scene such as a plane or a drone!
 - More definition for edges results in better detection
 - Future testing will involve aircraft and vehicles at farther distances to optimize object detection

Other possible applications:

- License plate imaging (Intersections)
- Facial imaging (Surveillance cameras)
- Biomedical Imaging (very fine details)
- Gaming (upscaling visuals in real-time)



Budget



Current Hardware	Price	Current Software	Future Hardware	Price
Spectrum Analyzer	\$4690.00		Power Supply/ Solar	\$449.00
Starlink Terminal	\$450.00	\$50.00 / month	Raspi 5	\$96.89
Aventas Antenna x2	\$920.00		2-way Power Divider	\$279.00
Android Phone	\$800.00	\$75.00 / month	Aarona Antenna	\$1146.96
Intel NUC	\$750.00			
Portable PSU	\$130.00			
			Misc. Cables / Motors etc.	\$150.00

*Note: All costs were
covered by
SOUTHCOM*

Work Distribution – P.A.D.S.



Necessary Element	Responsible Party
Antenna	Carter Clavell
Spectrum Analyzer	Carter Clavell
Power System	Nathanael Olson
Mini PC	Nathanael Olson
Detection Algorithm	Kai Doldan
Website	Garrett Mosrie

Budget



Component(quantity)	Cost	Vendor	Part Number
Plano-Convex Lens f=125mm(1)	\$23.40	Thor Labs	LA 1986
Plano-Convex Lens f=175mm(1)	\$22.61	Thor Labs	LA 1229
Plano-Convex Lens f=250mm(1)	\$22.14	Thor Labs	LA 1461
Arducam Global Shutter Camera(3)	\$40	Amazon	OV9281
Pluggable USB Hub(1)	\$40	Amazon	N/A

*Note: All costs were
covered by
SOUTHCOM*



Work Distribution – Camera Array



Necessary Element	Responsible Party
Lens System Design	Alexander Alonzo
Lens Research	Alexander Alonzo
Super-resolution Algorithm	Xavier Colon
Camera Research & Integration	Xavier Colon
Optimization	Alexander Alonzo & Xavier Colon



Progress and Plan for Completion



Achieved

- 1 mile Radio Detection
- Proof of aircraft detection
- Test setup and Procedure
- Web based server for data
- SDK Implementation of basic algorithm

Not yet Achieved

- Full range and accuracy results
- Implementation of advanced algorithm
- Full web app
- Autonomous Aircraft detection
- Optimized power use

Plan of Action

- ❖ More range testing
- ❖ Software Development time
- ❖ Testing at small quiet airports
- ❖ Data collection and labeling



Future Iterations & Improvements

- ❖ We were successfully able to apply super-resolution techniques!
- ❖ There are still areas for growth:
 - ❖ Wave-plates
 - ❖ Adaptive optics
 - ❖ Higher performance cameras
 - ❖ Better, larger sensors and pixel size, frame rate, color, CCD's instead of CMOS
 - ❖ Inclusion of more cameras
 - ❖ Synchronized capture
 - ❖ ESRGAN – AI/Machine learning assisted super-resolution
 - ❖ Requires GPU
 - ❖ Larger size array
 - ❖ Different shapes for array



Thank You!

