***Maritime Domain Awareness System***

*Multiplication of Radar Modules for Tracking Silent Vessels*

Initial Divide and Conquer Document

EEL4914 - Senior Design I

Group 4


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# Chapter 2: Project Description

## 2.1 Background

### The Importance of Maritime Border Security

The security and stability of the United States depend heavily on protecting its maritime borders. With over 95,000 miles of coastline and extensive shipping routes, the nation's waters serve as vital channels for trade, transportation, and national defense. However, these same waters are also exploited for illicit activities such as drug trafficking, human smuggling, illegal fishing, and unauthorized vessel entry. Traditional maritime security efforts rely on government-operated naval assets, but these resources are often stretched thin across vast oceanic regions, creating blind spots where illegal activities can go undetected.

To address these challenges, the U.S. has implemented Maritime Domain Awareness (MDA) initiatives, integrating surveillance technologies to monitor vessel activity in real time. The Maritime Domain is defined as "*All areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean, or other navigable waterway, including maritime-related activities, infrastructure, people, cargo, and vessels and other conveyances."* The Maritime Security Policy established the first-ever Maritime Security Policy Coordinating Committee to oversee the development of NSMS and eight supporting plans-the main one being a national plan to achieve MDA. This plan lays the foundation for all matters related to the maritime domain that could impact the security, safety, economy, or environment of the United States and also focuses on identifying threats as early and as distant from our shores as possible. A key component of MDA is the Automatic Identification System (AIS), which requires vessels to transmit their identity, position, speed, and course to prevent collisions and enhance navigational safety. AIS allows port authorities, coast guards, and naval forces to track legitimate vessels; however, ships engaging in illicit activities frequently disable or manipulate their AIS transponders to evade detection. This creates a significant gap in maritime security, as vessels without AIS cannot be easily identified or tracked using conventional methods.

### Project Motivation and Cost-Saving Measures

Given the limitations of current MDA strategies, there is a critical need for a cost-effective, scalable solution to detect and monitor non-cooperative vessels operating without AIS. Our project aims to deploy self-sustaining maritime surveillance units that integrate radar technology to track and transmit data on vessels operating without AIS transponders. These units will filter out compliant ships and focus on identifying unregistered or suspicious vessels, relaying this information to an inland server for analysis and military response.

A major innovation of this approach is leveraging commercial vessels as hosts for these radar systems. Rather than relying solely on government ships or satellite-based coverage, which are costly to operate and limited in number, deploying radar-equipped units on commercial vessels expands the military's radar network while significantly reducing operational costs. This not only increases the density of surveillance coverage but also ensures a more persistent and widespread monitoring capability. A critical aspect of this system is its ability to function independently from the host vessel. The radar unit is designed to be self-powered, ensuring minimal impact on the host's regular operations. The radar system is designed to be non-intrusive, increasing the acceptance from commercial operators to allow radar integration on maritime vessels. By integrating advanced radar systems with existing commercial fleets, this project enhances border security, resource efficiency, and military intelligence capabilities seamlessly without requiring additional government-operated vessels.

### 2.2 Review of Prior Related Work

To learn more about this project, research was conducted online to understand the requirements of similar solutions and gain insight into how to complete the objectives. This research led to a notable example of another commercial off-the-shelf (COTS)-based radar system. A surveillance systems company, Surface Search Radar Engineering, designed the AN/SPS-78 radar system to replace the aging AN/SPS-73 systems aboard U.S. Coast Guard vessels. Their project addresses reliability and obsolescence issues and details commercial requirements for the International Maritime Organization, along with capabilities necessary for tactical missions required by coast guards and navies. The new AN/SPS-78 is fully compatible with the U.S. Coast Guard's SeaWatch—an enterprise command, control, and navigation system—and other naval systems. This prior work was extremely helpful in explaining how to create a radar processing and tracking system that meets commercial and tactical needs. Open-source information from this project will assist in development efforts.

Another discovery was ThayerMahan's 'SeaPicket' system, an energy-harvesting, autonomous surveillance platform that integrates acoustic, radar/EW, video, and AIS sensors. SeaPicket is designed for long-term deployment and offers persistent maritime domain awareness by collecting and processing data on vessel movements. This system uses artificial intelligence and machine learning to analyze sensor data and provide real-time insights to port security organizations and field commanders. Overall, this project illustrates the integration of multiple sensors in a modular design with autonomous operation, which has been beneficial in understanding the goal of developing a plug-and-play MDA system. Similar energy-harvesting techniques and data analytics methodologies will be incorporated into the design to enhance system autonomy and efficiency.

Lastly, Kelvin Hughes' SharpEye S-Band Radar was examined due to its relevant characteristics. This commercially available solid-state radar system is designed for MDA and navigation. It is used on a variety of naval, Coast Guard, and commercial vehicles due to its low power consumption, high reliability, and advanced tracking capabilities. SharpEye uses Doppler processing, which detects and classifies targets based on their movement patterns, helping differentiate between stationary, slow, and high-speed vessels. As a result, clear radar imaging can be achieved even in heavy rain or rough seas, making it ideal for persistent MDA applications. The system also eliminates the need for high-voltage components, significantly reducing maintenance requirements. Studying this work provided valuable insights into how radars process data, optimize power efficiency, and operate in challenging conditions. Additionally, it highlighted the potential for Doppler-based tracking to enhance real-time detection of non-AIS vessels. These techniques establish a strong baseline for design choices in the development of a radar-based MDA system.

## 2.3 Goals and Objectives

The self-contained radar system is designed to enhance maritime domain awareness by addressing critical challenges such as detecting non-AIS vessels, operating independently in harsh marine environments, and maintaining reliable long-range communication. By prioritizing portability, self-sustainability, and affordability, the system will enable continuous monitoring and real-time data transmission.

Through a combination of hardware and software innovations, the MDAS aims to create a durable and efficient solution for vessel detection and tracking in remote maritime regions. The following goals and objectives outline the key functionalities required to bring this system to completion.

### 2.3.1 Basic Goals:

- Develop a self-sufficient radar system that does not rely on the ship's power supply.
- The system must detect vessels transmitting AIS, and vessels without AIS transmission.
- Establish a reliable method for transmitting data from the radar system to the base station.
- Design the system to operate autonomously for long periods with minimal maintenance.
- Make the system lightweight and easy to install on various maritime setups.
- Provide on/off power control for the radar via a physical switch and remotely through Starlink from a remote device.
- Develop a user-friendly interface that integrates radar overlays with AIS Marine Tracker.

### Advanced Goals:

- Enable continuous data transmission from radar ensuring live updates without delay.
- Reduce power consumption by turning off the radar when ported.
- Allow the radar to operate intermittently rather than continuous operation.

**Stretch Goals:**

- Ensure expandability by allowing multiple modules to connect, improving load balancing and synchronized data processing.
- Obtain processable images in addition to the visible light camera for operation in moonlight conditions.

**Hardware Objectives:**

1. Construct a self-sustaining power source with integration capabilities for wind energy.
2. Utilize a microcontroller to analyze radar data and process it for transmission back to base station via Starlink protocol.
3. Integrate a GPS module with the microcontroller to accurately slew the camera towards targets.
4. Configure the radar to enter a low-power standby mode when not actively in use.
5. Ensure the use of sturdy, waterproof, and corrosion-resistant materials to protect the radar module and connecting wires.
6. Include a physical power switch that allows the module to be turned on or off by the operator.

**Software Objectives:**

1. Develop an algorithm to process radar data and subtract AIS transponder information, isolating non-AIS targets.
2. Create a user-friendly interface for monitoring and control, integrating AIS Marine Tracker with radar overlays.
3. Develop a server accessible via Starlink to send commands that remotely power the radar module on and off.
4. Enable the server to remotely send commands to the mounted camera for capturing images on demand.
5. Enable automatic radar shutdown when the vessel is docked and restart upon departure.

**Stretch Goal Objectives:**

- Sustain a scalable module database with intra-connected communications allowing for radar proximity efficiency.
- Integrate an infrared camera capable of operating with low light for target identification.

**Optics Goals and Objectives:**

<u>Goals:</u>

- Basic:
  - Attach an enhancing optical system to a CCD camera to increase performance
  - Use a camera system to take long-distance pictures of potential threats
- Advanced:
  - Improve the optical system for better performance
- Stretch:
  - Implement an additional camera system for self-surveillance
  - Obtain processable images from an infrared camera in addition to the visible light camera for operation in moonlight conditions

<u>Objectives:</u>

- Basic:
  - Attach a Keplerian beam expander system to increase camera zoom capability
  - Attach a  Keplerian beam expander system to increase camera performance
- Advanced:
  - Alter existing Keplerian beam expander system to further improve zoom and performance
- Stretch:
  - Integrate an infrared camera capable of operating with low light for target identification.
  - Integrate variable zoom

### 2.3.2 Required Specifications

The specifications for the MDAS are divided into subsections each detailing specific aspects of the system's requirements and implementation.

***Table 1.1*** *Engineering Specifications*

| **Portability** | |
|---|---|
| Total Weight | ≤ 25kg |
| Enclosure Volume | 6.5” by 6.5” by 5” |
| **Radar** | |

| | |
|---|---|
| Detection Range | 50 to 60 nautical miles (57.5 to 69 miles) |
| Data Transmission Rate | 2 to 12 times per minute |
| Maximum Targets Tracked | 40 to 60 Vessels |
| **Full System** | |
| Total Wind Energy Production | 400 to 500 Watts |
| Power Consumption | ≤ 275 Watts |
| Maximum Voltage | 48 V |
| Cold Start Time | ≤ 120 seconds |
| Operating Temperature | 5°C to 50°C |
| Response Time (Radar Module to Base Station PC) | ≤ 3 minutes |
| Maintenance Interval | ~6 months |
| Total Cost | ≤ $15,000 |
| **Software/ Communication** | |
| AIS Filtering Algo Accuracy | ≥ 99% accurate |
| Remote Shutdown Latency | ≤ 1 second |
| **Optical System** | |
| Zoom | 5x |
| Number of Lens Additions | 2-3 |
| Pitching Angle of Gimbal | -90° to 0° |

## 2.4 Project Features and Functionalities

### 2.4.1 Hardware

The hardware components of the self-contained radar unit are carefully selected to meet the project's requirements of compactness, low power consumption, and minimal maintenance. Each component plays a crucial role in ensuring the system's functionality, self-sufficiency, and long-term reliability in a marine environment.

At the core of the system is the marine radar, which provides the primary sensing capability, detecting objects and mapping the surrounding environment. Complementing this is a camera mounted on a gimbal, which captures visual data of either the radar unit itself or nearby objects of interest using its gimbal. Together, these components allow for a comprehensive understanding of the surroundings, with the radar providing detection and the camera offering visual verification.

To power the system sustainably, a wind turbine is employed to generate renewable energy. This energy is regulated by a charge controller, which ensures that the current fed into the battery remains within safe limits, protecting the battery from overcharging or damage. The battery serves as the central energy storage unit, supplying power to all system components when renewable sources are insufficient or unavailable.

To meet the diverse voltage requirements of the system, DC-DC regulators are used to step up or step down the battery's output to provide stable power to each component. This includes powering the microcontroller, which serves as the system's brain, and managing data from the radar, camera, and other peripherals. The microcontroller is also responsible for facilitating communication between the radar data and external devices via cellular connectivity, ensuring that the data is transmitted to both servers and mobile devices for remote monitoring and analysis.

Additionally, the system includes a mobile device paired with the radar apparatus, acting as a local on-off switch for the entire system. This allows for on-site control and rapid deployment adjustments. To enhance adaptability, a versatile mounting system has been designed to house all components in a relatively compact manner while ensuring compatibility with various ships, allowing for flexible installation across different marine vessels.

Each of these components interacts seamlessly to create an efficient system. The wind turbine and charge controller feed renewable energy into the battery, which acts as a central hub of power distribution. The DC-DC regulators ensure that each component receives the appropriate voltage for operation. The microcontroller acts as the central coordinator, handling data processing and communication while the radar and camera perform their respective sensing tasks. This carefully designed interaction between components ensures that the radar unit remains operational over extended periods, even in remote locations, while maintaining its self-contained nature.

### 2.4.2 Software

The software for the self-contained radar unit is designed to enable remote monitoring, control, and data processing while ensuring seamless operation with minimal user intervention.

At its core, the system continuously transmits the GPS location of the radar node to a central server, allowing users to track its position in real time. When needed, users can send commands from the server to turn the radar on or off, enabling remote control of power usage and system operation. The system is integrated with a bay station database that plays a crucial role in managing radar operations and data storage.

The bay station database is responsible for issuing instructions to radar units to turn on or off as required for data collection, allowing for efficient control over the system. Once activated, the radar collects raw radar data and transmits it to the server via a Starlink connection, ensuring low-latency and reliable data delivery, even in remote maritime locations. The software then employs an AIS subtraction algorithm to filter out all vessels that are broadcasting AIS signals, ensuring that only non-AIS vessels remain in the collected data set. This improves detection accuracy and operational efficiency while reducing false positives.

The processed radar data is then securely stored in the database for further analysis, long-term tracking, and potential integration with other maritime monitoring systems. Users can remotely trigger the system to capture a camera image for additional verification. The image can be used to visually inspect either the radar unit itself—confirming operational status—or the area where an unidentified vessel was detected, providing potential visual confirmation of the target.

The software integrates these functions into a streamlined workflow, ensuring efficient communication between the radar node and the bay station database while enabling users to monitor and control the system remotely with minimal latency.

### 2.4.3 Software Block Diagram

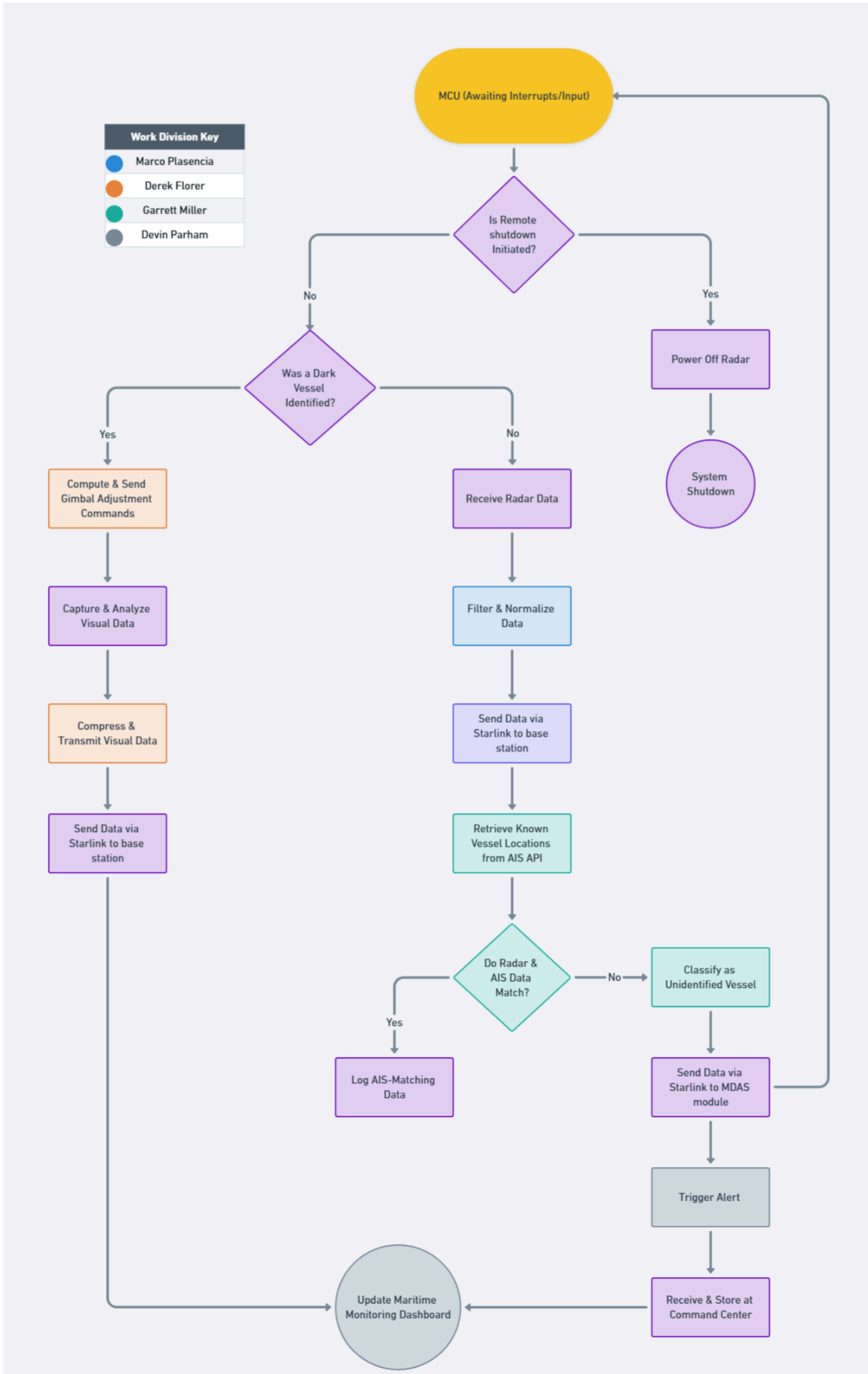



***Figure 2.1*** *Software block diagram*

### 2.4.4 Hardware Block Diagram

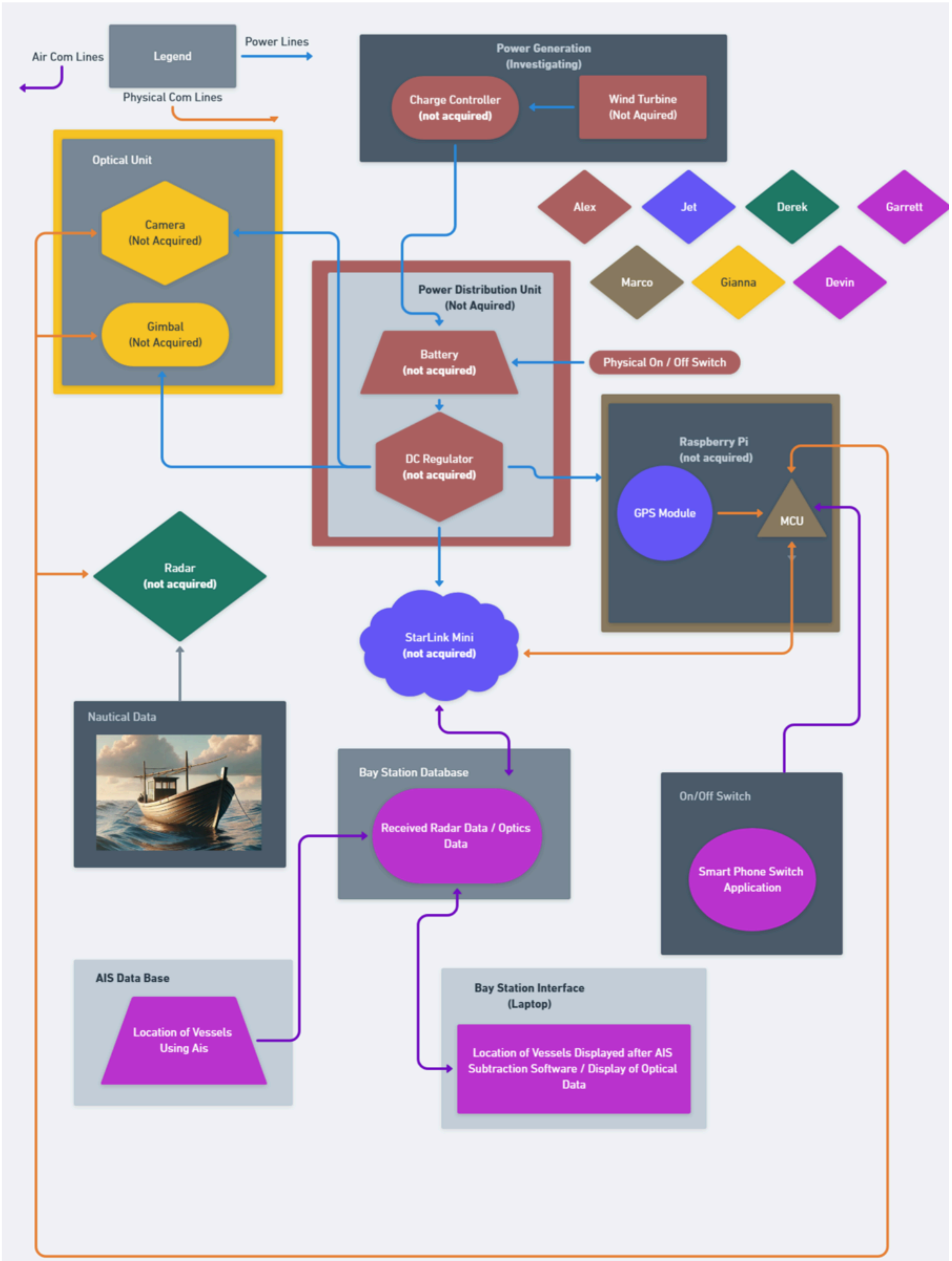



***Figure 2.2*** *Hardware block diagram [6]*

### 2.4.5 Optical System

In addition to the included radar system, we are also integrating an optics system. We are implementing a long-distance camera system that can help with the identification of neighboring ships that may be encountered on the open ocean. The camera will be a commercially available CCD camera, mounted on a gimbal for an increased field of view. An optical system will be attached to the front of the camera to increase performance. This system will consist of multiple lenses to create a stationary beam expander, with AR coatings. This beam expander will help increase the performance at longer distances. The type of expander will be a Keplerian beam expander, utilizing three lenses.

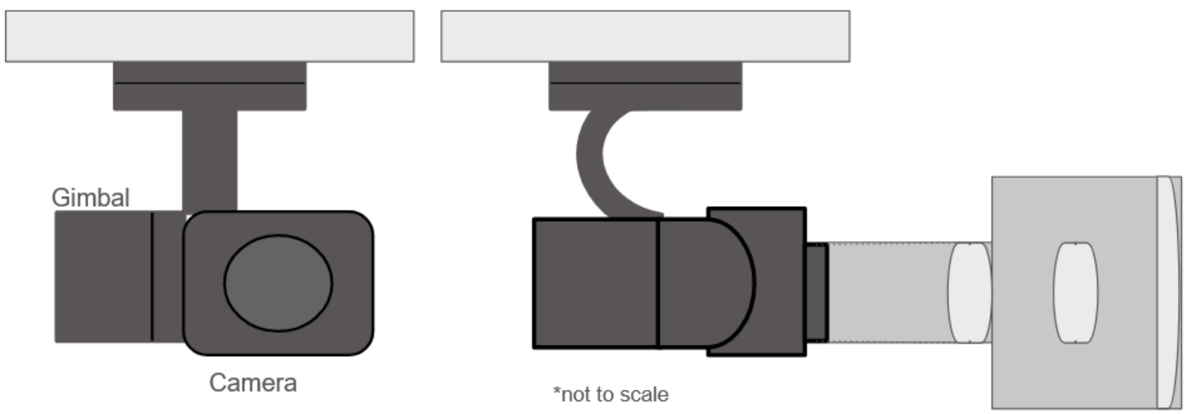



***Figure 2.3*** *Optical Sensor Concept Diagram*

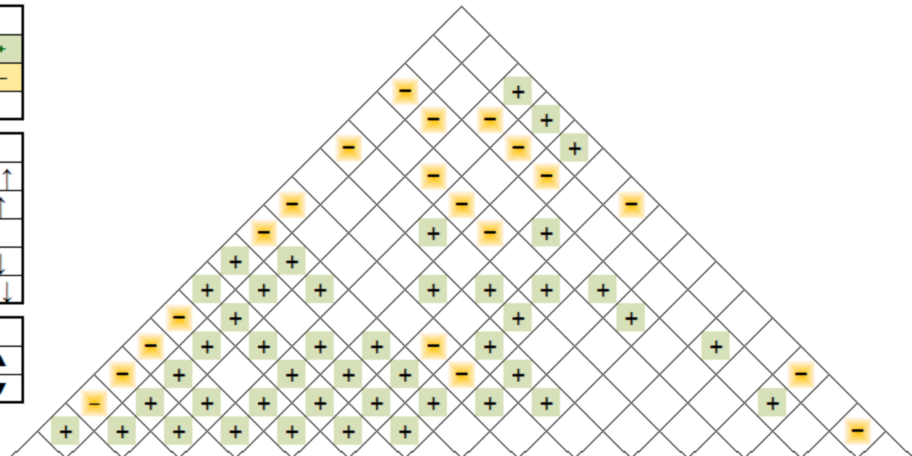
## 2.5 House of Quality

***Table 3.1*** *House of Quality*

| Correlations | |
|---|---|
| Positive | + |
| Negative | – |
| No Correlation | |

| Relationships | |
|---|---|
| Strongly Positive | ↑↑ |
| Positive | ↑ |
| Moderate | |
| Negative | ↓ |
| Strongly Negative | ↓↓ |

| Direction of Improvement | |
|---|---|
| Maximize | ▲ |
| Minimize | ▼ |



| Column # | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Engineering Requirements / Marketing Requirements | Direction of Improvement | Weight | Size | Detection Range | Data Transmission Rate | Concurrent Targets Detected | Total Energy | Power Consumption | Maximum Voltage | Cost | Cold Start Time | ISO Range | Operating Temperatue | Response Time | Maintenance Interval | Algorithm Accuracy | Latency |
| Direction of Improvement | | ▼ | ▼ | ▲ | | ▲ | | ▼ | | ▼ | ▼ | ▲ | | ▼ | ▲ | ▲ | ▼ |
| Portability | ▲ | ↑↑ | ↑↑ | | | | ↓ | | ↓ | ↑ | | | | | ↓ | | |
| Ease of Use | ▲ | | | | | ↑ | | | | | ↑ | ↑ | | ↑↑ | | ↑ | ↑↑ |
| Affordability | ▼ | ↓↓ | ↓ | ↓↓ | | | ↓↓ | ↓↓ | | ↓↓ | ↑ | ↓↓ | ↓ | ↓ | | | |
| Reliability | ▲ | | | ↑ | | ↑↑ | ↑ | | | ↑ | ↓ | ↑↑ | ↑↑ | ↓↓ | ↑ | ↑↑ | ↓ |
| Energy Efficiency | ▲ | | | | ↑ | | ↑↑ | ↓↓ | | ↑ | | | | | | | |
| Weather Resistance | ▲ | | | | | | | | | ↑ | | ↓ | | | ↑ | | |
| Safety | ▲ | ↓↓ | ↓↓ | | | | | | ↓ | | | | ↓ | | ↑ | | |
| Target Values | | ≤ 25kg | 6.5" by 6.5" by 5" | 50 to 60 nautical miles | 4 to 10 times per second | 40 to 60 Vessels | 400 to 500 Watts | ≤ 275 Watts | 48 V | ≤ 15,000 | ≤ 120 seconds | 100 to 3200 | 5°C to 50°C | ≤ 3 minutes | ~6 months | ≥ 99% accuracy | ≤ 1 second |

# Chapter 10: Administrative Content

## 10.1 Budget

The tentative budget for the radar system is $15,000. This is subject to change as budget restrictions can be negotiated depending on approval from SOUTHCOM.

The majority of the budget has been allocated to the core components, those being the radar unit and the Starlink module. The remaining budget has been primarily allocated to the creation of the power system to run the core components using renewable resources.

## 10.2 Bill of Materials

***Table 4.1*** *Bill of Materials*

| **Bill of Materials (BOM)** | | | | |
|---|---|---|---|---|
| **Component** | **Model / Description** | **Power Requirements** | **Additional Notes** | **Approximate Price** |
| Raspberry Pi | Raspberry Pi 4 Model B (8GB RAM) | 5V DC, 3A | Requires waterproof, vibration-resistant enclosure and passive cooling (heat sinks, thermal pads) | $80 |
| Starlink | Starlink Maritime Kit | 48V DC, 50-100W | Needs unobstructed mounting for optimal signal reception, a weather-resistant design | $250/month |
| Cyclone Radar | Raymarine Cyclone 6-Foot Model with Development Kit | 28V DC, 100-120W | Requires corrosion-resistant housing and must be mounted to minimize interference | $8,250 |
| Wind Turbine | Pikasola 400W Wind Turbine Generator | 12V DC | Compact and lightweight, suitable for moderate wind conditions | $269.99 |

| | | | | |
|---|---|---|---|---|
| Battery | Ampere Time 12V 200Ah LiFePO4 | 12V DC | Long lifespan, maintenance-free, reliable for continuous operation | $539.99 |
| Charge Controller | Victron SmartSolar MPPT 100/30 | 12V/24V DC | Maximizes solar energy harvesting, Bluetooth-enabled for monitoring | $245 |
| Power Distribution Unit (PDU) | Mean Well RSD-300 Series | Multi-output: 5V, 28V, 48V DC | Industrial-grade, high-efficiency, overcurrent, and thermal protection | $135.85 |
| DC-DC Converter | DROK 48V to 5V Step-Down Converter | 5V DC Output | Powers Raspberry Pi efficiently from Starlink power source | $19.99 |
| Mounting Hardware | Stainless Steel Brackets and Fasteners | N/A | Corrosion-resistant, ensures secure attachment of components | Varies |
| Enclosure | IP67 Waterproof Electronics Box | N/A | Protects components from water and environmental damage | $18.88 |
| Camera | CMOS/CCD camera | 12V DC | Protection from environmental damage, waterproof | Varies (Goal <$100) |
| Gimbal | Swellpro GC1-S Waterproof 1 Axis 4K Camera Gimbal | 12V DC | Non-corrosive material, waterproof/protected mechanical materials | $459 |
| **Total:** | | | | **$10,369** |

### 10.3 Distribution of Workload

***Table 5.1*** *Workload distribution*

| Member Name | Discipline | Responsibilities |
|---|---|---|
| Alexander Drew | Electrical Engineering | Development of the power system that will power the main components of the device. |
| | | Power Distribution |
| | | Aid with MCU programming |
| Derek Florer | Computer Engineering | Project Lead |
| | | Responsible for radar selection and integration |
| | | Starlink antenna functionality |
| Jet Chen | Computer Engineering | GPS implementation using Starlink |
| | | Design weatherproof enclosure and mounting hardware |
| | | Help optimize Power Distribution |
| Marco Plasencia | Computer Engineering | AIS Algorithm Development |
| | | Software Integration & System Communication |
| | | Documentation |
| Gianna Montevago | Photonics | Camera system |
| | | Camera enhancement details |
| | | Gimbal for cameras |

### 10.4 Project Milestones

***Table 5.2** Project milestone plan*

| Senior Design I Project Milestones: Spring 2025 | | | |
|---|---|---|---|
| **Task** | **Time Period** | **Due Dates** | **Who's Responsible?** |
| Develop Project Idea | Weeks 1-3 | 1/10 | Everyone |
| Team Formation | Weeks 1-2 | 1/14 | Everyone |
| Bootcamp | Week 3 | 1/21 (assignment due 1/24 @ 12 pm) | Everyone |
| Divide and Conquer Document | Weeks 2-3 | 1/24 @ 12 pm | Everyone |
| Kickoff Meeting (with sponsor and other teams) | Weeks 2-3 | N/A | Everyone |
| Divide and Conquer Meeting | Week 4 | 1/28 @ 1:30 pm | Everyone |
| Committee Formation | Weeks 1-3 | 1/24 @ 12 pm | Everyone |
| Optics Midterm Demo | Week 8 | 2/25 @ 9:30 - 11:00 am | Gianna |
| Midterm Report | Week 10 | 3/24 @ 12 pm | Everyone |
| Midterm Group Meeting | Week 11 | Date TBA | Everyone |
| 30-Page Paper Milestone | Weeks 4-7 | N/A | Everyone |
| 60-Page Paper Milestone | Weeks 8-12 | N/A | Everyone |
| Final Paper Draft | Week 14 | 4/22 @ 12 pm | Everyone |
| Optics Final Demo | Week 15 | 4/15 @ 9:00 - 11:30 am | Gianna |
| ABET Quizzes | Weeks 8-12 | 3/7 @ 11:59 pm | Marco, Jet, Derek, and Alex |

# Appendices

## Appendix A

[1] National Plan to Achieve Maritime Domain Awareness,

https://www.dhs.gov/sites/default/files/publications/HSPD_MDAPlan_0.pdf

[2]Shipboard Surveillance Systems - Surface Search Radar | SSR,

https://ssreng.com/shipboard-surveillance-system/

[3] System: SeaPicket - ThayerMahan,

https://www.thayermahan.com/systems/seapicket

[4] Commercial S Band Radar | HENSOLDT,

https://www.hensoldt.net/products/92/commercial-s-band-radar-kelvin-hughes-sharpeye-radar

[5] United States Southern Command Website

https://www.southcom.mil/

[6] Boat Image Generated Using Chat GPT