Development of Boat Homing Device using Automatic Identification System (AIS) Technology

by

John Carlo G. Cadiente
ECE-5

Jonas J. Jabonillo
ECE-5

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Chapter 1

INTRODUCTION

The Philippines is an archipelagic country. Most parts of the country are surrounded by water which makes fishing a common livelihood. The Philippines was among the top 20 countries in marine capture production according to the Food and Agriculture Organization of the United Nations (FAO) last 2020 [1]. The Philippine fisheries production is categorized into three: commercial fisheries, municipal fisheries, and aquaculture. This study will focus on municipal fisheries which refer to fishing done in inland or coastal areas. Municipal fishing can be done with or without the use of a fishing vessel of up to three gross tons [2]. These fishing vessels are commonly called locally as "*bangka*". These vessels usually lack the modern technology we have today which provides safety and identification out at sea. One of those is the AIS which stands for Automatic Identification System. This system is a requirement for all vessels over 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and passenger ships irrespective of size to be fitted with an automatic identification system (AIS), and all passenger ships to transmit, on VHF, information in digital form to describe what kind of vessel they are using, their location, identity, course, speed, and heading [3]. Additionally, local fishermen also express concerns about drifting. When they arrive at their designated fishing spots, they have to turn off the boat engine in order to proceed with fishing. This is where drifting occurs because of the waves which move them away slowly from their fishing spots. An AIS fitted with a homing feature will be of great help during these situations, especially when they are met with unexpected bad weather when out at sea. Regulations state that municipal fishing vessels are not required to have an AIS, but providing small-scale, inexpensive AIS can be of great help to our local fishermen in terms of their safety when venturing out at sea and coming across larger vessels. This will allow the smaller vessel to detect nearby larger vessels and avoid potential collisions.

Various studies about the AIS have been previously conducted. A low-cost AIS receiver embedded with intercommunication using microcomputer and software defined radio [4]. An implementation of an AIS transmitter that broadcasts position reports with varying GPS longitude and latitude data [5]. This study is one of the continuing efforts related to the development of low-cost AIS for small municipal fishing vessels.

According to the report published by the Maritime Industry Authority (MARINA) in 2016, the number of incidents of maritime vessels in the Philippines amounted to an estimated 587 incidents, the most common being caused by drifting or engine failure of the vessels. The types of vessels included in these incidents were motor vessels, fishing vessels, barges, motor tankers, and others [6]. Several fishermen have expressed concerns regarding them getting lost due to drifting while fishing. Previous studies were not able to include results of vessel collision avoidance and homing features. Small municipal fishing vessels may still experience collisions and still get lost at sea. This study will focus on implementing these two features on a small-scale AIS using a microcontroller.

This study aims to develop a homing device for fishing boats using Automatic Identification System (AIS) technology. The specific objectives are (1) to implement the functions of an AIS in an embedded system, (2) to develop a collision warning notification in an AIS device, and (3) to enhance the AIS operation by incorporating a homing feature.

The study would mainly benefit municipal fishermen and potentially small vessel owners. By providing them with collision avoidance, preservation of life, and property can be achieved. As for the homing feature, aside from providing them with navigational aid, it could also save them fuel because of the optimal route plotted by the homing feature which allows them to arrive quickly to their destination which would also allow them to deliver fresh produce not left too long out in the sea.

This study only covers the development of an AIS device with the integrated homing feature. The homing feature of the device is limited to coastal areas. Initially, the researchers will conduct laboratory testing for initial function tests and calibration. Additionally, a comparison between the developed device and a commercially available AIS will be conducted in the laboratory to validate the accuracy of the device. For the final testing, the researchers will conduct an outdoor testing in an actual water environment.

Chapter 2

REVIEW OF RELATED LITERATURE

This chapter introduces the different related studies conducted by other researchers and challenges which are related to this research.

2.1 Automatic Identification System (AIS)

The Automatic Identification System (AIS) is an electronic tracking system that is used by ships to communicate with each other using transceivers, transmitting positional data to each other over dedicated VHF frequencies. There are two dedicated channels for AIS transmission called AIS1 (or channel 87B) and AIS2 (or channel 88B), which operate at 161.975 MHz and 162.025 MHz, respectively. AIS1 is mainly used for ship-to-ship communication while AIS2 is for ship-to-shore communication. Additionally, it supports the transmission of large quantities of data, it is receptive even against obstacles and weather, and it possesses networking capabilities between ship-to-ship communications [5][7][8][9][10].

2.2 AIS Message

The data transmitted along the radio frequency channels, AIS1 and AIS2, are called AIS messages. These messages contain information that would provide the location, position timestamp, course, speed, and other essential maritime information. This is the dynamic information part of the message, the first piece of the AIS message which contains three main pieces. The second is the static information which is fixed data provided by the user. When a ship undergoes renovation, it is the responsibility of the user to update the static information which would reflect the said renovations. The information manually entered by a ship's operator is voyage-related information that can be shared optionally through AIS. The last piece is a combination of static and voyage-related information [5][7][8][9][10].

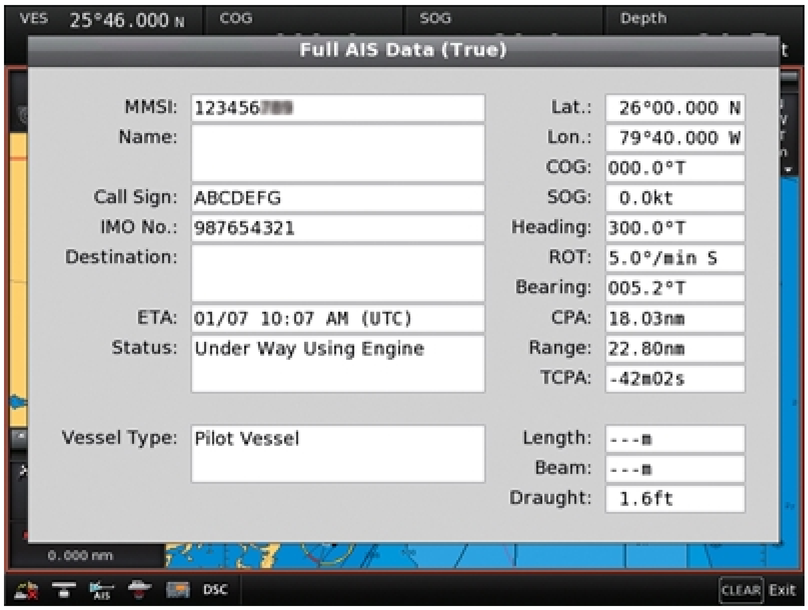

Figure 2.1 AIS Data

2.3 AIVDM Sentence

AIVDM is one of the two primary sentences for AIS data. The information being exchanged between AIS-equipped vessels and the Vessel Traffic System (VTS) follows the National Marine Electronics Association (NMEA) standard called NMEA 0183 which dictates two different sentence formats, AIVDM for received data and AIVDO for your own vessel's information. In this study, AIVDM is the focus since the device is only an AIS receiver. Table 1 is an example of an AIVDM sentence, coded according to the NMEA standard. The AIVDM sentence in the example below contains a vessel's dynamic information [5].

!AIVDM,1,1,,B,38;>Jo5P008aeA`8FrVVjwv@0000,0*51		
Field no.	Field	Description
Field 1	!AIVDM	Address field
Field 2	1	Total number of sentences needed to transfer the message, (1 to 5)
Field 3	1	Sentence number, (1 to 9)
Field 4	Empty in this sample	The sequential message identifier ,(0 to 9)
Field 5	B	AIS Channel
Field 6	38;>Jo5P008aeA`8Fr VVjwv@0000	The data payload.
Field 7	0	The number of fill bits required to complete the data payload to a 6-bit boundary, (0 to 5)
Field 8	*51	The NMEA 0183 data-integrity checksum for the sentence, preceded by "*."

Table 2.1: AIVDM Sentence Structure

2.4 OpenPlotter

OpenPlotter is an open-source application that houses many different software which aim to provide navigational aid for small to medium vessels. It is also a complete onboard home automation system. OpenPlotter is a low-consumption application that works on ARM computers like the Raspberry Pi or any computer running a Linux Debian derivative. Small to medium vessel owners can use OpenPlotter as an inexpensive alternative to high-end equipment used in larger vessels. It can also be used to transmit and receive various vessel-related information such as position, course over ground, and bearing to aid in the safety and security of the maritime industry [5].

2.5 OpenCPN

OpenCPN (Open Chart Plotter Navigator) is a free software project that aims to simulate how a dedicated chartplotter and navigation software functions, for use underway or as a planning tool. OpenCPN is developed by a team of active sailors using real world conditions for program testing and refinement. OpenCPN supports different chart formats, data transfer, and GPS tracking [11][12]. OpenCPN uses GPS to determine the ship's own position and uses data from an AIS receiver to plot the positions of nearby vessels [13]. The range covered by the AIS receiver depends on the VHF antenna used.

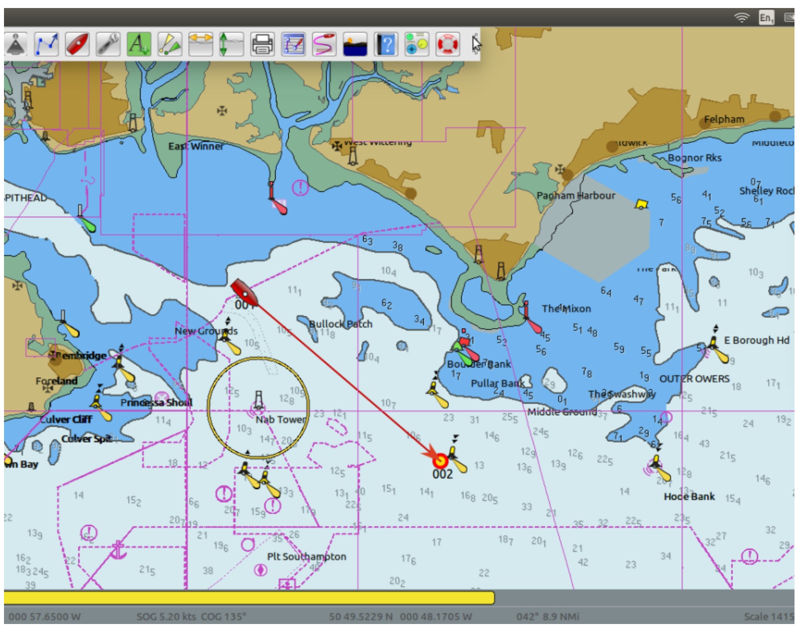

Figure 2.2: OpenCPN

2.6 Software Defined Radio (SDR)

An SDR is a radio that performs signal processing using software techniques. The radio still incorporates analog components like antennas, wideband band pass filters (BPF), low noise amplifiers, and mixers for down converting the higher radio frequencies to a lower intermediate frequency (IF) in the heterodyne receivers or to baseband in the direct conversion receivers. An SDR is characterized by digital signal processing accomplished in flexible and reconfigurable functional blocks [14]. SDR aims to be able to transmit and receive signals of any frequency, power level, bandwidth, and modulation scheme.

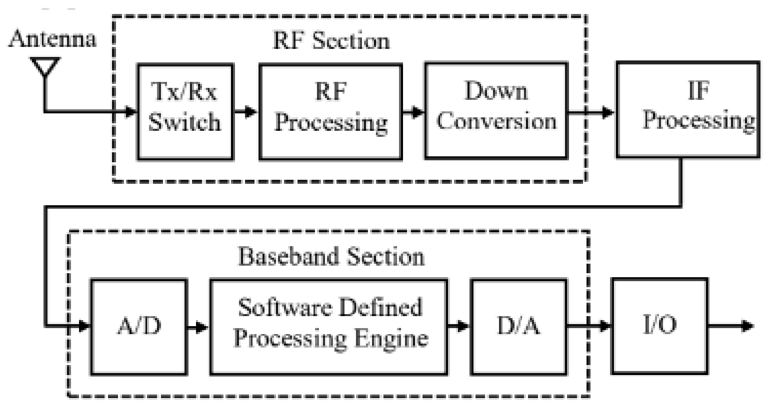

Figure 2.3: Functional Diagram of a Software Defined Radio

2.7 RTL-SDR

RTL-SDR (RealTek) is a low-cost USB device that can be used as a computer-based radio for receiving live radio signals. Depending on the RTL-SDR it could receive frequencies from 500 kHz up to 1.75 GHz. The RTL-SDR software will provide the following functions of a traditional receiver: Selection of the desired frequency and bandwidth, Demodulation of the received signal, and Interference suppression [15].

Figure 2.4: RTL-SDR

2.8 GPS

The Global Positioning System (GPS) is a navigation system using satellites, a receiver, and algorithms to synchronize location, velocity, and time data for air, sea, and land travel. The satellite system consists of a constellation of 24 satellites in six Earth-centered orbital planes, each with four satellites, orbiting at 13,000 miles (20,000 km) above Earth and traveling at a speed of 8,700 mph (14,000 km/h) [16]. GPS will provide insight to vessel captains on navigating to the sea. It will also gather data from the users to provide an accurate map.

2.9 GPS receiver

A GPS receiver's job is to locate four or more of these satellites, figure out the distance to each and use this information to deduce its own location [17]. When turning on your receiver, it may take some time in locating these satellite signals, then download data from the satellite before positioning can commence.

Fundamentally, two things are needed for the receiver to work. First, the GPS receiver measures the distance from itself to a satellite by measuring the time a signal takes to travel that distance at the speed of light. Second, when the satellite’s position is known, the GPS receiver knows it must lie on a sphere that has the radius of this measured distance with the satellite at its center [18]. This operation is based on a simple mathematical principle called trilateration.

Trilateration is used to calculate location, velocity, and elevation, trilateration collects signals from satellites to output location information. To determine the vessel's location, we need to determine the distance from at least 3 satellites. Using multiple satellites will make the GPS data more accurate. To compute the distance from the GPS Receiver to satellite, Eq 2.1 is applied where rate is equal to the speed of light and time is how long the signal travels through space.

$$Distance = rate\ x\ time$$

Eq. 2.1

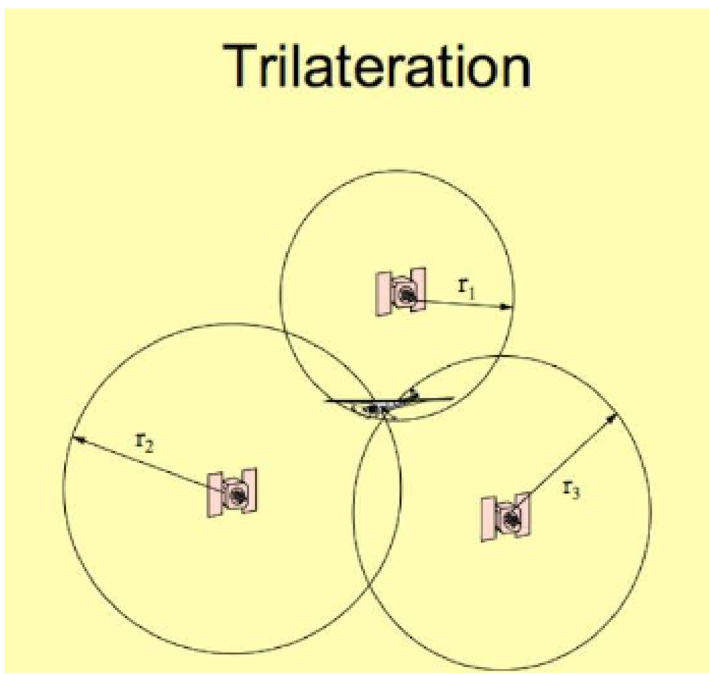

Figure 2.5: Trilateration

2.10 VHF Antenna

A VHF antenna is also known as aerial stands for a very high-frequency antenna that transmits signals through its device for communicable devices such as radios, televisions, cell phones, and other cordless phones, etc. The waves of frequency range from as low as 3 MHz to as extremely high as 30 MHz. Some CB radios and shortwaves use very high frequency, but it is commonly used for FM radio. VHF cannot exceed the local radio horizon of 100 miles. Atmosphere noise, any electrical equipment causing trouble, and any other interferences are less probable to cause any disturbances in VHF frequencies [19].

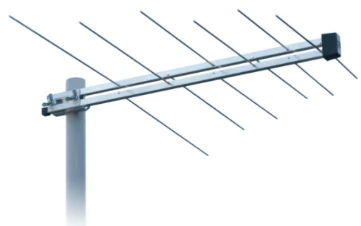

Figure 2.6: VHF Antenna

2.11 Raspberry Pi

In the proposed topic, to implement AIS operation, the researchers are going to use a microcontroller board. One of the most widely used microcontrollers is Raspberry Pi. The Raspberry Pi is a low-cost, small, and portable sized computer board. It is used to develop interacting objects and can communicate with the software running on our computers/laptops. Raspberry Pi has built-in software which enables users to program using Python language. Python is the core language in the Raspbian operating system [20]. Raspberry Pi is easy to use and is compatible with many operating systems such as Windows, Linux, and Mac OS. Raspberry Pi is one of the most common microchip controllers that introduce people into this field since it is a fun way to learn.

Figure 2.7: Raspberry Pi

Chapter 3

METHODOLOGY

3.1 Conceptual Framework

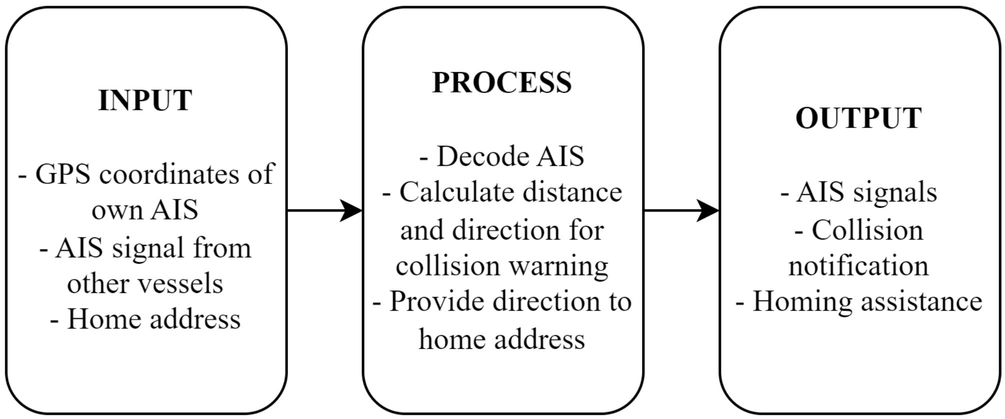

Figure 3.1: Conceptual Framework

A VHF antenna connected to an RTL-SDR dongle and GPS receiver is used to receive AIS signals and GPS signals, respectively. An SDR will then be used as a decoder for the received AIS messages. Additionally, the user must set a home address for the homing feature. Once configured, both the AIS and GPS signals are then used in OpenCPN to display the data on a map. The GPS data of the user and other vessels will be used to calculate collision warning.

3.2 List of Materials

Hardware:

1. Power source
    - A laptop will be used as a power source. It can serve as both a power source and a display for the microcontroller which makes it easy when

testing the device. The power source can be replaced with a power bank later on for portability.

2. Microcontroller
    - The microcontroller that will be used is the Raspberry Pi. It will be easier to work on the RPi because of its compatibility with the software that will be used.
3. RTL-SDR receiver
    - Used as a radio scanner to receive AIS signals.
4. VHF antenna
    - The antenna will be connected to the RTL-SDR receiver to receive AIS radio signals.
5. GPS receiver
    - This will provide positional data for the user's vessel.

Software:

1. OpenPlotter
    - This software will calibrate the SDR device.
2. OpenCPN
    - OpenCPN will use the gathered AIS and GPS data to map out the user's positional data and the location of other nearby vessels.

3.3 Conceptual Prototype

Shown in Figure 3.2 is how the prototype is imagined. The main part of the device is the Raspberry Pi which will run all the necessary applications. The RPi can be powered by a laptop or a power bank, in this case, a laptop will be used so it can serve as both the power source and the display for the RPi. A VHF antenna is connected to an RTL-SDR receiver which is connected to the RPi. Additionally, a USB GPS receiver is also connected. The RPi will be loaded with OpenPlotter which will process the AIS and GPS signals received.

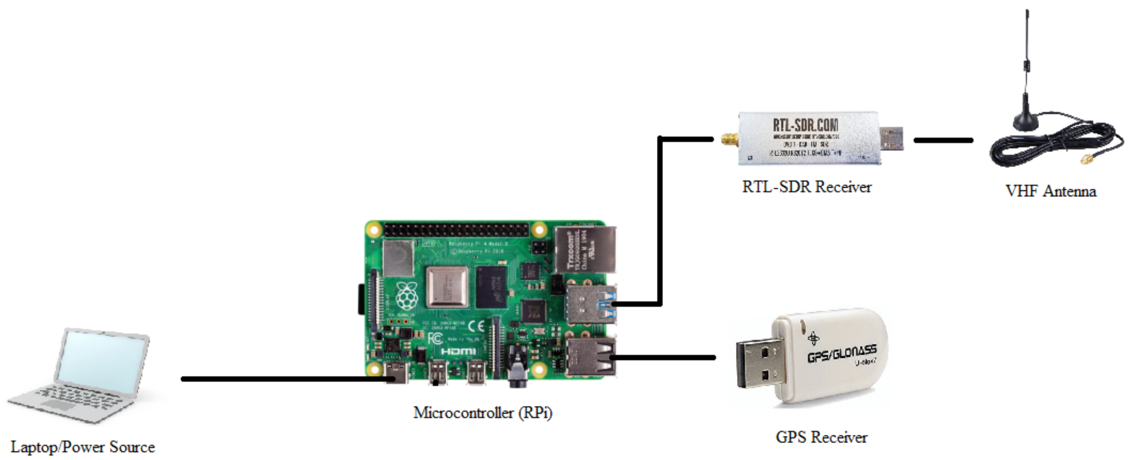

Figure 3.2: Conceptual Prototype

3.4 Block Diagram

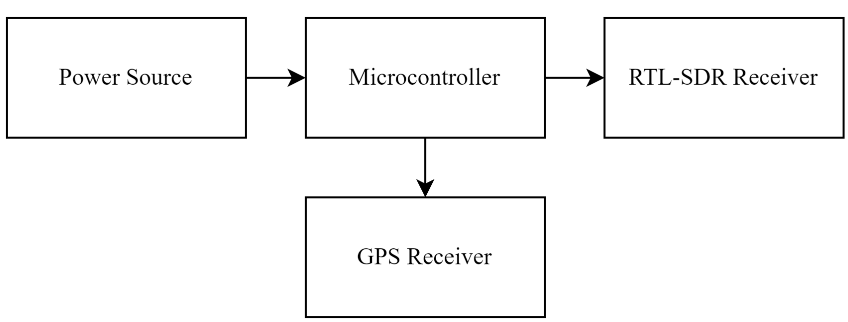

Figure 3.3: Block Diagram for Signal Receiving

The power source will power up the microcontroller which in turn powers up both the RTL-SDR and GPS receivers. The received VHF AIS radio signals by the RTL-SDR receiver and the GPS signals received will be sent to the microcontroller which has the program OpenPlotter installed. OpenPlotter is responsible for decoding the AIS messages to NMEA 0183 standard. These messages are then sent to OpenCPN to display the received vessel-related information along with positional data received from the GPS receiver.

3.5 Software Development

A. Setup

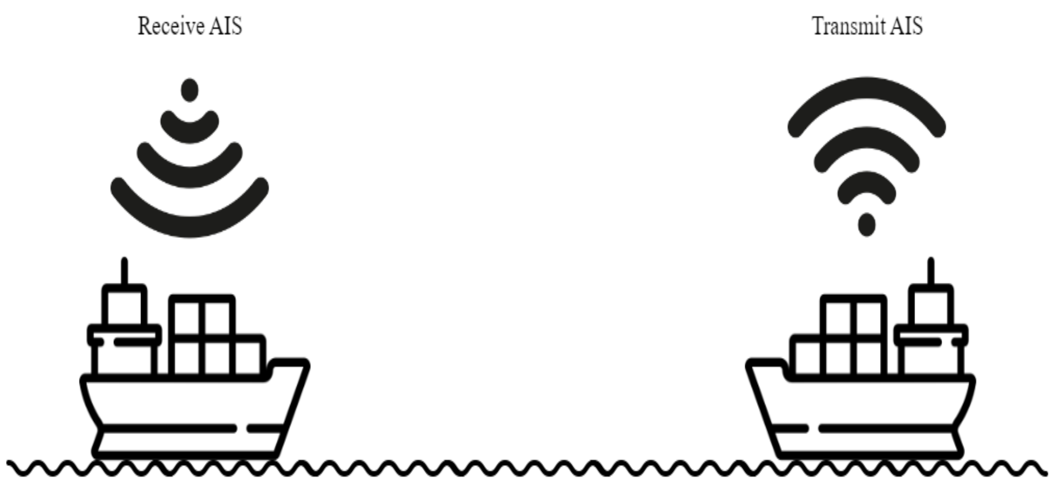

Figure 3.4: Setup used for testing

Shown in Figure 3.4 is the setup for the device. The device is loaded onto the user's vessel shown on the left which will receive transmitted AIS signals from other nearby vessels.

B. Conceptual Graphical User Interface

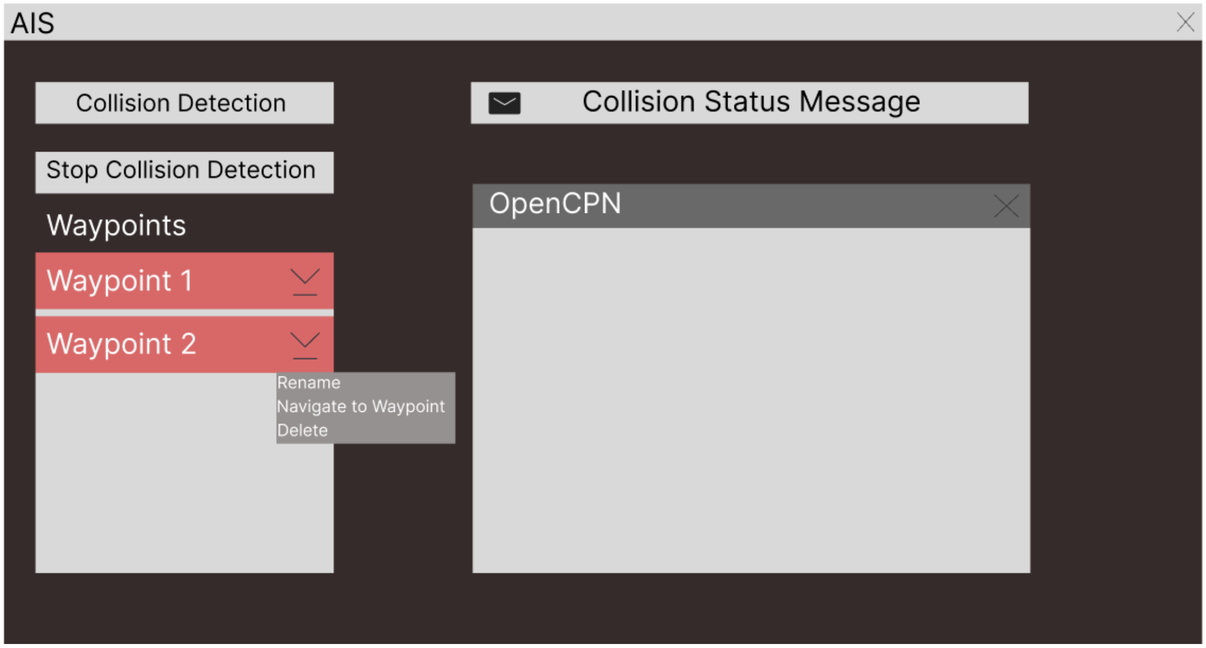

Figure 3.5: Software GUI

Shown in Figure 3.5 is the user interface of the software for the device. On the upper left side of the GUI, the user has the option to turn on Collision Detection and also has the option to stop it. To the right of this, a collision status message will appear after the user turns on Collision Detection. A message will appear notifying the user when the device detects a vessel or multiple vessels near enough to cause a potential collision. In the lower half of the screen will be the homing feature. The left side displays the user's saved waypoints. A dropdown menu is available which allows the user to rename the waypoint, navigate to the waypoint, or delete the waypoint. To the right of this is OpenCPN, a software that allows the user to see both his and other vessels' location on a map. The user will also create new waypoints using OpenCPN.

The idea behind how the collision detection and homing feature will be implemented is shown below:

1. *Collision Detection*
    - A program will be developed that will calculate the distances between the user's vessel to the vessels within the coverage area of the AIS receiver. The distance will be calculated using the Haversine formula, which uses the collected latitude and longitude data received from both the GPS and AIS receivers as input. If the calculated distance is 5000m or less, a notification will show up on the application which will warn the user if there is a nearby vessel or vessels which can cause a possible collision.
2. *Homing Feature*
    - The user first makes a waypoint using OpenCPN. The saved waypoint will show up on the left hand side of the GUI in which the user will have three options hidden in a dropdown menu: Rename, Navigate to Waypoint, or Delete. Choosing "Navigate to Waypoint" sets a course to the waypoint.

C. System Flowchart

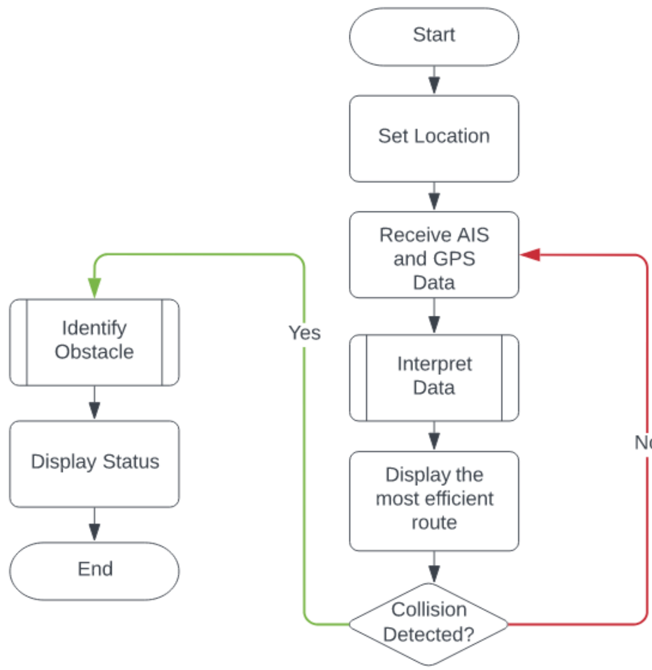

Figure 3.6: System Flowchart

Figure 3.6 shows the overall process of this study. It first starts when user set their location on where they plan to head. The device then received radio signals to identify the nearby vessels. The system starts to interpret the data that it received and it displays on the program the most efficient route to take in order to get to the destination safely. The program then scans the vicinity periodically to detect if there would be a collision. If it detects a possible collision, the program will display a status and the LED would blink to give a warning to the user. If there is no collision detected, the program will loop back to receiving radio signals to continuously analyze the surroundings until it reached its destination.

3.6 Testing

A. *AIS Data Verification*

MMSI	*AIS Receiver (Prototype)*		*AIS Receiver (Commercial)*		*Distance*
	Latitude	*Longitude*	*Latitude*	*Longitude*	

Table 3.1: AIS Data Comparison

Shown in Table 3.1 is the comparison of the AIS data received between the prototype and a commercially available AIS receiver. First, the Maritime Mobile Service Identity (MMSI), which is the unique ID of a vessel, will be collected to verify that the AIS data being collected is retrieved from the same vessel. Then the distance will be calculated between the coordinates retrieved from the prototype and the commercial AIS using the Haversine formula.

Haversine formula

$$D = 3440.1 * \arccos[(\sin(\text{lat } A) * \sin(\text{lat } B)) + \cos(\text{lat } A) * \cos(\text{lat } B) * \cos(\text{long } A - \text{long } B)]$$

The Haversine formula simply takes the longitude and latitude information in radian of both the user and the target sample vessel to calculate the distance between them. The value 3440.1 is the radius of the earth in Nautical Miles (NM).

B. Coverage Testing

Fixed Location of Device:	
MMSI	*Distance (Meters)*

Table 3.2: Distance from Receiver

First, the researchers will use a commercial AIS to check the area for AIS-equipped vessels and use this as a reference for the coverage of the prototype. The MMSI of the detected AIS-equipped vessels by the prototype will then be collected. The prototype will be placed in a fixed location. The distances between the vessels and the receiver will then be calculated. The highest distance calculated will be deemed the furthest coverage the prototype can reach.

C. Collision Detection Testing

User's Location	*Vessel Location*	*Distance*	*Notified?*

Table 3.3: Collision Detection Testing

The MMSI of the vessel being tested for possible collision will be collected to verify which vessel is being tested. Both the user's and sample vessel's latitude and longitude location will be collected to be used as the input for the Haversine formula to compute the distance between the two. A distance of 5000 meters or less will be set to trigger the collision notification.

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