Marine Highway Traffic Monitoring System with Trajectory Prediction from Automatic Identification System (AIS) Sensor Data using Artificial Neural Networks

by

Briones, Simon Felix A.

Casople, Gian Marco M.

Dimatulac, Feline Shawnae V.

A Research Report Submitted to the School of Electrical, Electronics, and Computer Engineering

in Partial Fulfillment of the Requirements for the Degree

Bachelor of Science in Electronics Engineering Program

Mapúa University

November 2018

Chapter 1:

INTRODUCTION

Over the past few years, the continuous urbanization and economic growth of the country because of the natural increase in population, has been observed and experienced by many. A very good example of a problem caused by the increase in population is its direct proportionality to the increase in sea vessel population, this is in attempt to not only connect isolated parts of the Philippines but also to ease the problem regarding heavy car traffic congestion. Having a car nowadays can only take you so far whilst consuming so much time, this brings us to the next easiest and cheapest alternative to travelling by land which is traveling by water. As a result of the Philippines being an archipelago, which is defined as an expanse of water with many scattered islands, the mode of transportation and deliveries through seafaring is inevitably one of the most popular choices due to the fact that its cheaper than flying and significantly reduces travel time. The popularity of travelling and deliveries via boats and ferries however have not changed the effective albeit outdated and improvable monitoring and managing of sea travel of the Philippines which is the Philippine Nautical Highway System. The nautical highway system was effective in connecting isolated parts of the country and reducing transportation cost but it also limits and hinders the maximization of the vast expanse of the Philippine waterways. This system also lack proper tracking and monitoring of not only cargo and people, but also the nautical routes of each vessel which is crucial in preventing sea vessel collisions and accidents. The way of sea vessel monitoring is effective but fails to maximize the potential of AIS in contributing to not only the safety and security of sea travels but also its capability of providing information that can aid in the travel proper of seafarers.

In a recent studies, an advanced deep learning framework structure was proposed by the authors to deal with key issues considering massive amount of AIS data streams [1]. The authors stated problems considering AIS data streams: irregular time sampling and noisy data. The authors addresses these issues and explores about the implementation of Recurrent Neural Networks (RNNs) to develop an automatic system which extract and detect important information in AIS data streams. Thus, the development of automated and AI-based system is a critical challenge. Another study presents an algorithm for prediction of ship movement trajectory [2]. It is important for marine navigators to know future position of himself and nearby target ship in specific time span to prevent collision. The authors proposed an algorithm that increases the reliability and accuracy of prediction. Both are very common problems in AIS including deep learning system ones poorly adapted.

With the quick progress of economy, static traffic difficulties are getting more attention, leaving nautical travel behind. Being that the Philippines is an archipelago, it would make more sense to give just as much urgency and attention to seafaring as given to land commute and air travel. The lack of monitoring of sea vessels in the Philippines have proven to be disadvantageous in more ways than one, an example of which is the security risk that follows the loosely monitored commute and cargo shipping. Another disadvantage is the inability to explain and substantiate the reason of sea vessel accidents and collision, the inevitable congestion of the limited nautical highways, lack of thought and maximization of the Philippine waterways and the inconvenience of following a fixed route when there might be a much safer and easier route to be taken. The tropical climate can also contribute to the disadvantaged of the Philippine Nautical Route System, without proper tracking and monitoring or even the provision of alternate routes, storms and typhoons are able to render the Philippine water transport system helpless and at a standstill. A way to not only monitor and track sea vessels but also provide alternate routes to seafarers is substantially more convenient and logically sustinent than just providing a general route.

The main objective of the study is to monitor maritime traffic through AIS data streams and provide trajectory prediction and detect whether or not vessels are out of its suggested route using an artificial neural network. Specifically, the study aims to : (1) develop a transmitter and receiver of AIS data; (2) develop a system that will be able to process the received AIS data streams; (3) develop a neural network that will be able to detect vessels that is out of its suggested route and predict their trajectory based on its past and instantaneous AIS data stream.

Maritime traffic monitoring is one of the most important feature for vessels and ports to have to ensure the safety of the vessels travelling in the same area and prevent or lessen the accidents in the maritime sector. AIS from every vessel in the same area transmits their data streams to one another and to ports with AIS receivers, and form a "map" of the position of every vessel, with AIS data transmitted, in the area. The researchers proposed a system that will monitor maritime traffic through AIS data streams, and provide trajectory prediction and detect vessels that are out of their suggested route using an artificial neural network. This system installed in a port will provide the operator of the port a second opinion on how the maritime traffic is to be managed. This system installed in a vessel or ship will provide the operator of the vessel an optimal path to take in order to prevent accidents or obstacles along the way.

This system will only monitor single point to point destination and it will only provide simulation testing. The ship is only limited to an acceptable margin of error if the ship is out of its expected path. The AIS transmitter will transmit ship's ID and location (longitude and latitude). For its dynamic information includes ship's position with accuracy indication, course over ground, speed over ground, heading and navigational status. The system would give out notice or message to ships or vessels, within the range of the receiver, about their predicted trajectory and if they are out of the required nautical highway. The GUI will provide selected marine highway for specific port.

Chapter 2

Review of Related Literature

Automatic Identification System (AIS)

AIS is used primarily to avoid ship to ship collision, marine traffic management, and ship information gathering. This is accomplished to simultaneous transmission of position, identification, heading, speed and other related information. In AIS network, only ships with AIS transceiver can be seen. Hence, not all the ships in the area is visible especially smaller vessels. The IMO and SOLAS only mandated passenger ships, cargo ships and other ships that has around 300-500 gross tonnage to have AIS [3].

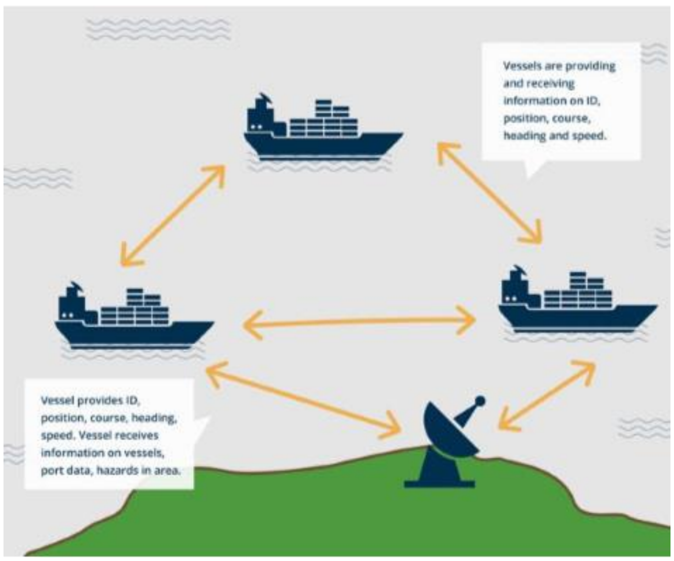

Figure 1. *Illustration of how AIS works from [3]*

At the moment, there is no perfect vessel tracking system but AIS is making waves being one of the most used vessel tracking system and is also becoming increasingly effective as accuracy and refresh rates get even better in time. It has the capability to interact with other detection sources, that’s what makes it an important element of integrated navigation and warning systems. With the addition of supplementary environmental and situational data makes it more versatile for the use in the maritime sector [3].

There are two classes of AIS transponders: class A and class B. Class A has the higher specification of the two and is mandated for commercial vessels, while class B, has the lower specification, is intended for smaller vessels [3]. The table below shows the difference in specifications between the two classes.

Specifications	Class A	Class B
Type of ship	all international voyaging ships with a gross tonnage of 300 tonnes or more, and on all passenger ships regardless of size.	Smaller, mostly leisure, vessels
Transmission	Continuous	Every 30 seconds
Power	12.5 W	2 W
Horizontal Range	40 nautical miles	line-of-sight
Communication Technology Used	SOTDMA (Self-Organized TDMA) technology	CSTDMA (Carrier Sense TDMA) technology
Information Provided	Static, Dynamic and Voyage-related information about the ship	Only Static information about the ship

Table 1. *Difference between Class A and Class B AIS Transponders*

There are 3 different types of information being provided by AIS, specifically Class A AIS transponders: Static information, Dynamic information and Voyage-related information. Static information or the “Fixed” information about the ship. It is entered into AIS on installation and it is “Fixed” because it can only be changed if the ship had undergone a major renovation or change. Dynamic information is the navigational status of the ship which is automatically updated from the ship sensors connected to AIS. This information includes the ship’s: position, position timestamp in UTC, course over ground (COG), speed over ground (SOG), heading, navigational status, and rate of turn (ROT). Voyage-related information is the type of information that might need to be manually entered and updated by the ship’s operator or captain. But this type of information is optional to share through AIS. This type of information includes the following: Ship’s draught, hazardous cargo type, Destination and ETA, and route plan (waypoints) [3].

AIS Transmitter and Receiver

Different studies have been conducted about the implementation of AIS. An implementation of Software-Defined Radio on Maritime AIS has been studied, where the data being transmitted by AIS is converted to RF signal [4]. Software-Defined Radio (SDR) AIS receivers has been conducted but the application is for Satellite AIS Receiver [5].

An SDR, is a defined radio in which traditionally implemented hardware are implemented by means of software on a computer. Also, all the physical layer function will be software defined. SDR is used differently between receiver and transmitter. For SDR based AIS transmitter, uses a general purpose processor for signal processing, interpolation filter, digital mixer, Digital to Analog Converter, RF converter and a power amplifier. Figure 2 shows the diagram for SDR transmitter [4]. While SDR based AIS receiver uses different block such as RF section, IF processing and Baseband section this is implementer with GNU radio. Figure 3 shows the diagram for SDR receiver.

[6] In this study a single channel AIS receiver is designed and implemented with the use of a SDR. The propagated data from AIS transmitter based SDR is extracted with the use of GNU Radio. It is a software use for implementation of an SDR. It also has included graphical user interface where users can define how SDR would function. Decoding of AIS data begins with the extraction of raw RF signal, demodulate its waveform then obtain the AIS packet data in binary form. Through the comparison between the commercial grade AIS receiver and SDR based AIS receiver, the transmitted location has only small difference because of the timeframe of the transmitted data. The time difference between the tests could have resulted to different position of the ship. However, the difference is minimal that indicates that SDR based receiver is viable to implement.

In recent studies the implementation of AIS transmitter on SDR has been conducted. SDR is a radio communication system in which components that have been implemented hardware are instead implemented by means of software. Changing the system of an SDR means changing only its specific parameters in code rather than remaking the hardware. This is useful in converting the received data into RF signal that to be transmitted to the AIS receiver. The AIS transmits a total of 27 different messages that contains different information. Messages 1, 2, and 3 contains position report for Class A AIS, it reports navigational information such as longitude and latitude, time, heading, speed, and ships navigation status. Message 4 contains base station report, it is used as an indication of the ships presence through static reference of ships position and time. These AIS messages is encapsulated at the link layer and transforming into valid transmission packet.

The AIS transmits a total of 27 different messages that contains different information. Messages 1, 2, and 3 contains position report for Class A AIS, it reports navigational information such as longitude and latitude, time, heading, speed, and ships navigation status. Message 5 contains information on a ship and its trip it includes static data of ship's intended position. These AIS messages is encapsulated at the link layer and transforming into valid transmission packet. Table 2 describes how longitude and latitude should be encoded in Message 1 and Table 3 describes how ship's destination should be encoded in Message 5.

Parameter	Bits	Description
Longitude	28	Longitude in 1/10 000 min (+/-180 deg, East = positive (as per 2's complement), West = negative (as per 2's complement). 181= (6791AC0h) = not available = default)

Latitude	27	Latitude in 1/10 000 min (+/-90 deg, North = positive (as per 2's complement), South = negative (as per 2's complement). 91deg (3412140h) = not available = default)

Table 2. *AIS Message 1*

Parameter	Bits	Description
Destination	120	Maximum 20 characters using 6-bit ASCII; @@@@@@@@@@@@@@@@@@@@ = not available For SAR aircraft, the use of this field may be decided by the responsible administration

Table 3. *AIS Message 5*

For the implementation of SDR based AIS transmitter a GPS module, antenna, microcomputer, and SDR with an antenna is used. The GPS module output GPS related NMEA sentences. Then it will be received by the microcomputer for further processing and relayed it to the SDR. SDR transmit it as a RF signal. The NMEA sentences that has been transmitted by the GPS contains position data on a message 1 AIS report mainly the direction of longitude and latitude value. This information is modified to a standard 168-bit AIS data packet. This packet is now modified through GNU radio program to perform other link layer functions such as incorporating NRZI encoding on the whole packet. The digital data that has been modified is converted into a frequency modulated signal ready for transmission.

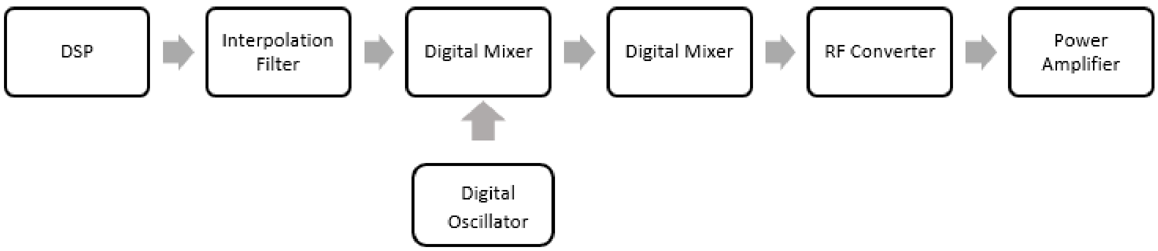

Figure 2. *SDR transmitter*

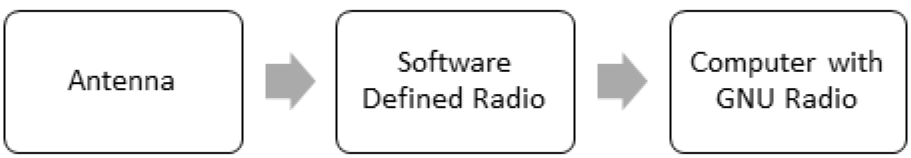

Figure 3. *SDR Receiver*

GNU Radio is used to implement the function of an SDR. It is a free and open source software that provides signal processing blocks to implement software defined radios. Also, it can be used without hardware in a simulation like environment. It is also can be used with available low cost RF hardware to create SDR. A GUI is also included in the software where users can defined how SDR would function [5].

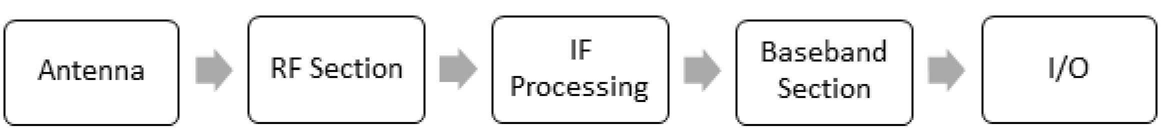

Figure 4. *Functional Diagram of SDR*

Through comparison between the SDR based AIS and handheld GPS the transmitted location via longitude and latitude direction has only small amount of difference and it is due to the decimal places between the two systems. The SDR based AIS uses four decimal places but the handheld GPS only produces three decimal places. This study shows that the SDR based AIS allows for quick and flexible development compared to its hardware counterparts [7]. It is faster by changing only the code instead of modifying the hardware.

GPS Position data based on NMEA Standard

The control in data specification for communication between marine electronics devices has been defined by the National Marine Electronics Association. It permits the exchange of information between marine electronic equipment to computers. There are a standard for each device category. GPS receiver is defined with NMEA standard specification. The most important NMEA sentences include the GGA which contains current position fix data. An example of GGA is given in Table 4.

EXAMPLE	DESCRIPTION
GGA	Global Positioning System Fix Data
123519	Fix taken at 12:35:19 UTC
4807.038,N	Latitude 48 deg 07.038' N
01131.000,E	Longitude 11 deg 31.000' E

1	Fix quality: 0 = invalid, 1 = GPS fix (SPS), 2 = DGPS fix, 3 = PPS fix,4 = Real Time Kinematic, 5 = Float RTK, 6 = estimated (dead reckoning) (2.3 feature) 7 = Manual input mode, 8 = Simulation mode
08	Number of satellites being tracked
0.9	Horizontal dilution of position
545.4,M	Altitude, Meters, above mean sea level
46.9,M	Height of geoid (mean sea level) above WGS84 ellipsoid
Blank	time in seconds since last DGPS update
Blank	DGPS station ID number
*47	the checksum data, always begins with *

$GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47

Table 4. *Example of GGA Sentence*

Processing AIS data and collecting of data from the Philippine Marine Nautical Highway

The Philippine Marine Nautical Highway serves as a nationally followed marine route for sea vessels travelling within the country via waterways, although a bit outdated this system proves to be quite effective at the very least. This method of monitoring marine traffic, however, lacks security in more ways than one. By implementing AIS, sea vessels can automatically exchange navigation information, including unique identification, position, course, and speed, with nearby ships and terrestrial AIS receivers to facilitate the tracking and monitoring of ships' location and movement [8].

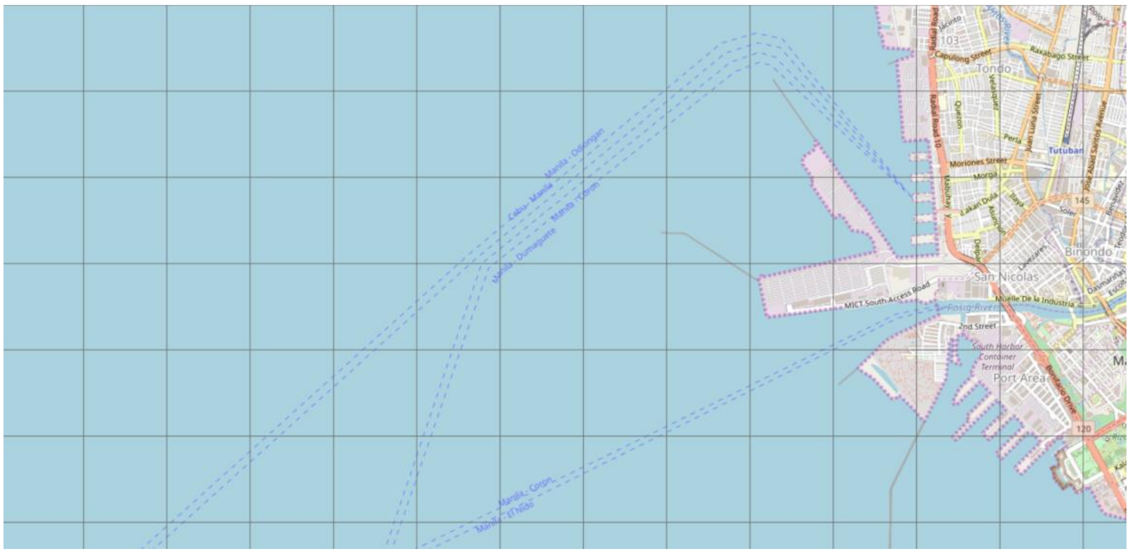

Figure 5. *Sample nationally followed marine route for vessels coming from Manila [9]*

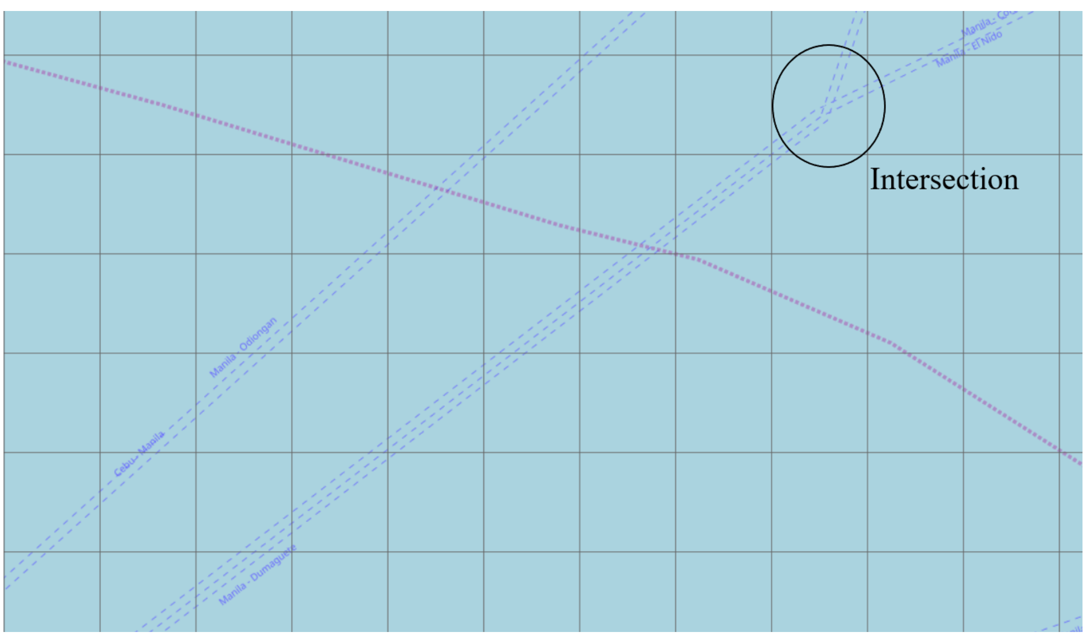

Figure 6. *Intersection between marine routes*

In addition to being able to monitor these specifics, by also implementing the data from the Philippine Marine Nautical Highway, ships can receive various data regarding the national waterways and will be able to receive valuable information that can be of use to their travels not only about the terrain but also about the trajectories of other vessels that they may encounter.

In the illustration shown in figure 5, from [9], sample of nationally followed marine route for vessels coming from Manila. This illustration shows that for every source-destination, there is a unique and suggested route for vessels to follow. In figure 6, it shows that some marine routes intersect from one another. In this study, the system proposed aim make use of AIS data stream and marine nautical highway to make the reliability of AIS for collision avoidance.

The data collected through AIS will in turn be processed in a way that it will serve the purpose and will be beneficial to the travelling vessels. AIS automatically exchange navigation information to affect collision avoidance and safety control [10]. With this purpose in mind, AIS maritime traffic monitoring on a local and national level using the Philippine Marine Nautical Highway will enable the real time monitoring and multiple way guiding and data updating, collecting and processing of vessels through the marine routes of the Philippine waters.

Artificial Neural Network on out-of-route vessel detection and trajectory prediction

Artificial Neural Network (ANN) is a type of computational model based on the structure and functions of biological neural networks or brain. Any information that flows through it affects its structure because, just like a brain, a neural network learns, in a sense, based on the input and output. In figure 7, it shows that a neural network has three layers, namely: input layer, hidden layer and output layer. As shown in figure 7, a neural network does not follow a linear path. Rather, information from the input layer is being processed collectively, or in parallel with one another, throughout a network of nodes or in the hidden layer. Nodes in a neural network are also called neurons and they are the individual elements of the network. Its operation is simple, they read an input, process it and generate an output. But once neurons are interconnected to one another to form a network of neurons, it can exhibit incredibly rich and brilliant behaviors.

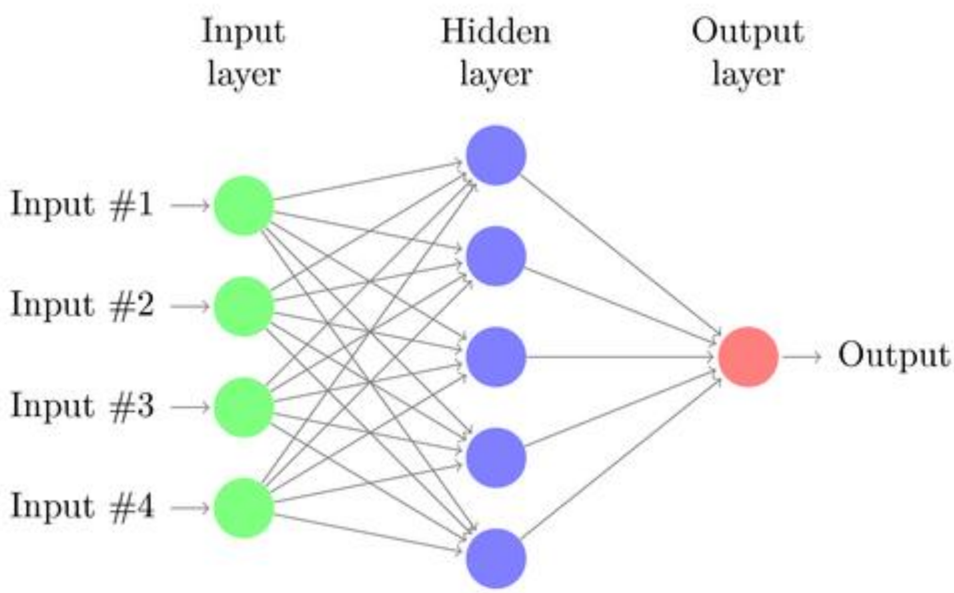

Figure 7. *Sample Neural Network*

[8] In this study, ANN was used to predict the position and course of a vessel by utilizing GPS/radar data. The ANN was trained by the data (namely: latitude and longitude, course, speed, and time) collected from the GPS of four vessels in 1-minute sampling period [11]. The trained ANN was used for the prediction of 1, 2 and 3-minute ahead position and course of the vessel.

Trajectory prediction is a way of ensuring efficient and conflict free voyages for vessels. It is essential to know the future trajectory of a vessel to avoid collisions along the way. [2] In this approach of real time trajectory prediction for moving objects with the use ANN, the trajectory history served as the input to its neural network. The predicted position, velocity, and acceleration of the object as the output (predicted trajectory). This kind of approach can also be used in maritime application since its input is trajectory history, which can be obtained through AIS. The maritime application for trajectory prediction which is discussed in [12][13], resort to mathematical models. [12] In this paper, it is stated that the state estimation and navigation trajectory prediction of a target can be divided into three sections[12][13]: 1) development of the target motion model (TMM); 2) measurement model and the associated techniques (MAT); and 3) trajectory tracking and estimation (TTE).

Chapter 3

Methodology

This chapter offers the essential elements to complete this proposal. These elements are the following; the conceptual framework of the study, in-depth discussion of how to execute each objective of this study, and data gathering.

Conceptual Framework

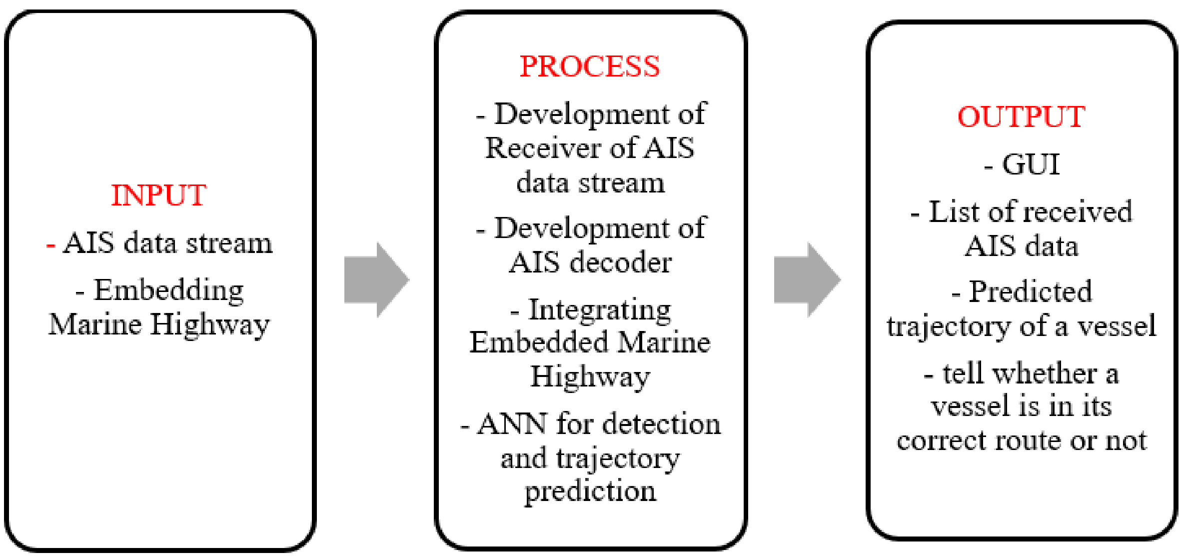

Figure 8. *Conceptual Framework*

Based on the conceptual framework shown in Figure 8, the input of the proposed system is the AIS data stream that will be received from vessels within the range of the system's receiver. The receiver will then send the message to the system itself. The system will extract the essential information from the message then send it to the ANN for analysis. The system will also display the list of AIS data received through the GUI created for the users. The ANN will be able to tell whether a vessel is within the route required by the PNRH or not and predict the trajectory of a vessel.

SDR based AIS Transmitter

The transmitter setup for SDR based AIS transmitter consists of an antenna, GPS module, Microcomputer and an SDR with antenna. The GPS module will be responsible for the output of various modified NMEA sentences. The received sentences is processed further by the microcomputer and then sent to SDR. The SDR will be responsible for constructing the data into a radio frequency signal.

Figure 9. *System diagram for SDR based AIS Transmitter*

An SDR implements the conventional RF hardware output in the software domain. In application-specific processes, a corresponding hardware is needed to implement the signal modification. Figure 9 shows SDR based AIS transmitter that uses a general-purpose processor for signal processing, interpolation filter, digital mixer, Digital to Analog Converter, RF converter and a power amplifier.

Acquisition and Parsing of Data from AIS

There is a multitude of data stored in a GGA NMEA sentence, but for the purposes of encoding GPS position data on a Message 1 AIS position report, only four fields of the data are relevant to use, namely, the latitude value, the direction of latitude (North or South), the longitude value, and the direction of the longitude (East or West). These four pieces of information are modified by following the format for the longitude and latitude data of the standard 168-bit AIS data packet, as seen in Table 2.

Integrating Position Data to AIS Message Type 1

The longitude and latitude data, formatted as 28-bit and 27-bit data respectively, is now appended to the AIS data packet. For the longitude data, it occupies the bits from bit 62 to bit 89 of the 168-bit AIS packet. For the latitude data, it occupies the bits from bit 90 to bit 116. Other data in the 168-bit field include the message type, MMSI, repeat indicator, etc. The other data fields' specific content is irrelevant to the purpose of this paper, which is to be able to repetitively transmit AIS packets with a changing longitude and latitude field for every transmission, dependent on the location of the device at the time of transmission.

Encapsulating the Message to Standard Packet Structure

The 168-bit AIS packet has now been defined with the longitude and latitude field values obtained from the GPS module. This AIS packet is now passed to a GNU Radio program, modified with an out-of-tree module named AISTX. The AISTX module is responsible for other link layer functions, including bit stuffing, appending the checksum, appending the start and stop bits as well as the training sequence, and incorporating an NRZI encoding on the whole AIS packet.

Transmitting using the SDR

Following the AISTX module on the GNU Radio program is the GMSK Mod block. The GMSK is the modulation used by the AIS standard for data transmission. The GMSK Mod block converts the digital data from the AISTX module into a frequency modulated signal ready for transmission. The GMSK specific parameters used for the transmitter in this paper are stated in the ITU-R M.1371-5 standard [10]. The final output of the GMSK Mod block is the quadrature signal of the GMSK modulated signal, to be utilized by the SDR Hardware. Finally, the SDR hardware used in this study is interfaced through the GNU radio sink block, which is the final block of the GNU Radio program for transmission. The SDR converts the quadrature signal from the GMSK block into RF signals, which is transmitted through the antenna connected on the SDR

AIS Transmitter		GPS Receiver	
Longitude	Latitude	Longitude	Latitude

Table 5. *Data from AIS transmitter and from GPS receiver*

The data received from AIS transmitter and GPS receiver are tabulated in Table 3. The AIS receiver does not accept invalid AIS messages. Since the AIS receiver was able to interpret the transmitted AIS message, it is implied that the message transmitted complies with the standard message structure.

SDR based AIS Receiver

The setup for SDR based AIS Receiver consists of an antenna, software defined radio and computer with GNU radio. The antenna will receive the data transmitted from the SDR based AIS transmitter, the received digitization is performed at some stage downstream from antenna, typically after certain processes. Then, the transmitted radio frequency signal will be relayed to computer with GNU Radio to undergo different layer of data extraction.

GNU radio handles the signal processing of the digital data. A convenient graphical user interface is included in the software where users can define how exactly the SDR would function. GNU Radio has filters, channel codes, synchronization elements, equalizers, demodulators, vocoders, decoders, and many other elements as shown in figure 4. These elements can be easily connected to manage how the data flows in the SDR.

The Transport Layer is responsible for converting data into transmission packets of correct size, sequencing of data packets and interfacing to upper layers. Network layer is used for establishing and maintaining channel connections, management of priority messages, distribution of transmission packets between channels and data link congestion resolution. The Link layer specifies how data is packaged to apply error detection and correction to the data transfer. The Physical Layer is responsible for the transfer of a bit-stream from an originator, out to the data link.

Vessel	Details	SDR-based receiver
Ship 1	MMSI	
	Longitude	
	Latitude	
Ship 2	MMSI	
	Longitude	
	Latitude	
Ship 3	MMSI	
	Longitude	
	Latitude	

Table 6. *Sample table for SDR-based receiver*

Table 6 compares the data received from the SDR-based AIS receiver and the data from the commercially available AIS. The Mobile Maritime Service Identity (MMSI), Longitude and Latitude are compared since this study focused on AIS Messages position reports.

System Architecture Design

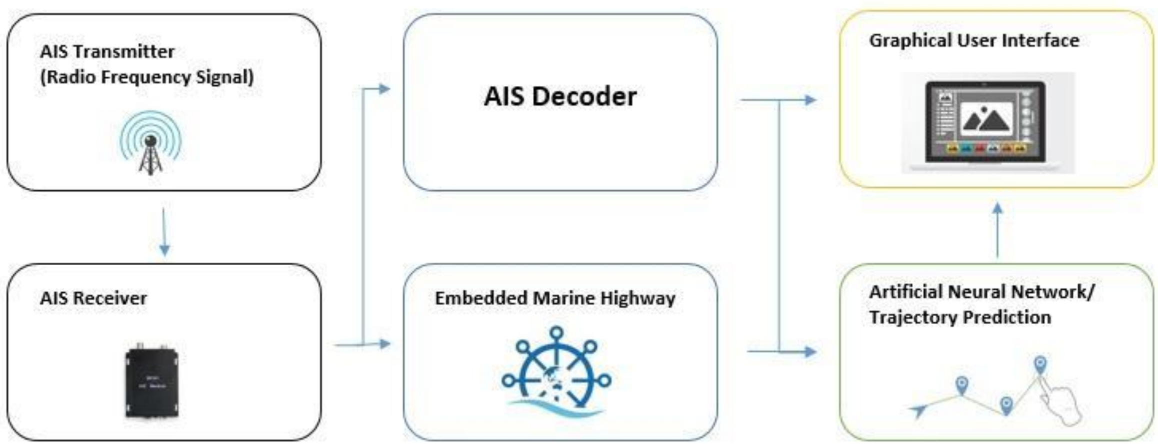

Figure 10. *System Architecture*

The radio frequency signal from the AIS transmitter will be sent to the receiver consistently every 10 seconds assuming that the theoretical vessel is in motion. Once received, the data, which consists of the static and dynamic information provided usually provided by the AIS in real time, will be decoded into a type of data that can be understood by the system. The GUI will have an option where in the user can embed the marine nautical highway within the range for data analysis. The data extracted from the receiver will then be processed to the Artificial Neural Network for trajectory prediction and as well as in determining whether or not the sea vessel remains on the correct route in order to reach its destination. The decoded AIS message along with the predicted future location of the ship and whether or not it remains on course, will be reflected in the GUI, the system will add trajectory predictions every five minutes in accordance to the current course of the ship while the unused data received from the AIS transmitter will be fed to the system and will aid in improving the accuracy of the predictions.

AIS Decoder

Physical Layer AIS Data Extraction

To begin decoding AIS data, the study first obtains the means for capturing the raw RF signal, recording the waveform, and demodulating the waveform through Gaussian Minimum Shift Keying (GMSK). The result of the demodulated waveform is a stream of binary data. These steps are performed by the physical layer of the OSI model, to which the AIS data flow is heavily based upon. The binary data is then processed by the link layer of the OSI model.

Link Layer of Data Extraction

The python script first reads the text file containing the received raw AIS digital data and loads the long bit stream. After this, NRZI decoding is performed on the bit stream. This decoding is performed by recording the change in two consecutive bits in an NRZI encoded bit stream. When a bit changes in the NRZI encoded message between two consecutive bits is observed, a ‘0’ is appended to the decoded AIS message, and a ‘1’ if otherwise. The next step is finding for the training sequence, as well as the start and stop flag. All AIS packet transmissions begin with a 24-bit training sequence, which is an alternating bit stream of 1's and 0's. Between the start and stop flag is the AIS data. The goal of this step is to remove the training sequence, start, and stop flag. The result is the AIS data.

Parameters	Transmitted AIS data	Decoded Message
Ship's position with accuracy indication and integrity status		
Position Timestamp in UTC		
Course over ground (COG)		
Speed over ground (SOG)		
Heading		
Navigational status (e.g. underway by engines, at anchor, engaged in fishing etc)		
Rate of turn (ROT)		

Table 7. *Verification of the decoded AIS message*

Artificial Neural Network (ANN)

The main objective in this section is the development of artificial neural network for the prediction of navigation trajectories of ocean vessels and detection whether an ocean vessel is out of its suggested route or not. Therefore, this section is divided into three subsections: Trajectory Prediction, Detection and the training of ANN.

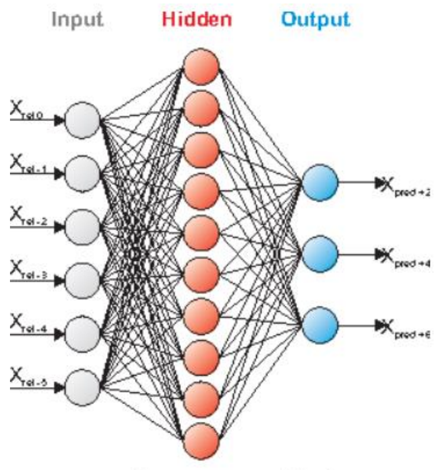

Figure 11. *Artificial Neural Network for Trajectory Prediction*

The ANN makes associations between varieties of the information in the input layer. The ANN is more of an intuitive reasoning rather than the logical reasoning normally executed by machine. One of the main advantage of using ANN in this study, is the incorporation of uncertainty in its process. Moreover, the ANN has the capability to learn with any complex structure of data. With that, the ANN is capable to implement a learning algorithm and make decision support ability of ocean vessel navigation prediction.

Trajectory Prediction

In this study, a three-layer neural network model (figure 8) is proposed to predict the path trajectory of ocean vessels. The ANN inputs proposed are: longitude, latitude, speed over ground (SOG), course over ground (COG), MMSI number, heading and the suggested route info from the embedded marine highway. The ANN outputs proposed are the predicted trajectory of an ocean vessel for the next five minutes, specifically the latitude, longitude, speed, course and heading predicted for the next five minutes. The ANN is to be fully connected and every neuron connected to second layer neuron.

The output of each neuron is proposed to be calculated by an activation function (sigmoid function) [14]. After the artificial neural network receives the inputs, it will propagate them from the input layer through the hidden layers to the output layer, where the responses are obtained. The inputs are proposed to be obtained from the AIS decoder and embedded marine highway.

Time	Latitude	Longitude	Speed	Course	Heading
Current					
1 min					
2 min					
3 min					
4 min					
5 min					

Table 6. *Proposed Output table for Trajectory Prediction*

Detection

For the detection whether the sea vessel remains on its suggested course or not, also a three-layer neural network model is proposed. The ANN inputs proposed are: longitude, latitude, suggested route info from the embedded marine highway, and other routes surrounding the suggested route. For the ANN to tell whether a vessel is out of its suggested route or not, other routes surrounding the suggested route is to be considered.

Same neural network approach as the one to proposed in trajectory prediction is also proposed in this section. The same algorithm in [15] is to be utilized in the two neural networks proposed. The inputs are proposed to be obtained from the AIS decoder and embedded marine highway.

MMSI number	Out of route or not?
ship 1	
ship 2	
ship 3	

Table 7. *Proposed Output table for Detection*

Training of ANN

For the training of ANN for trajectory prediction, past AIS data is proposed to be fed to the neural network. Since the transmission of AIS data from AIS transponders are continuous for Class A AIS transponders that transmit dynamic information about the ship, the proposed system for ANN will use the AIS data transmitted by a single vessel for the past minute for trajectory prediction and for the ANN for detection will use the instantaneous AIS data received from a ship. The unused data will be used for training also for further improving the reliability of the prediction. The neural network is trained using the backpropagation algorithm and a quasi-newton least squares method. The activity diagram of the quasi-Newton training process is shown in figure 12.

Improvement of the parameters is performed by first obtaining the quasi-Newton training direction and then finding a satisfactory training rate.

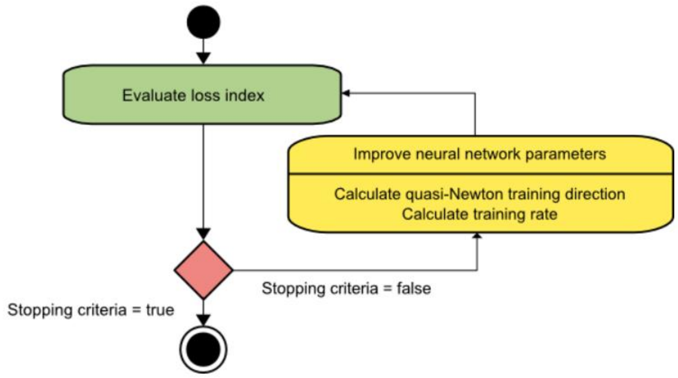

Figure 12. *Quasi-Newton training process*

For the training of ANN for the detection whether the vessel is out of its suggested route, past AIS data, suggested route to be used and other route surrounding the suggested route for a specific point to point course. In this study, Manila to Cebu route is to be used as the training dataset. The mathematical model proposed to be used in training this neural network is the backpropagation algorithm and the quasi-Newton least squares method.

References:

[1] D. Nguyen, R. Vadaine and R. Fablet, “A Multi-task Deep Learning Architecture for Maritime Surveillance using AIS Data Streams” The 5th IEEE International Conference on Data Science and Advanced Analytics, Oct. 2018.

[2] Perera, L.P.; Oliveira, P.; Soares, C.G. “Maritime traffic monitoring based on vessel detection, tracking, state estimation, and trajectory prediction.” *IEEE Trans. Intell. Transp. Syst.* 2012, 13, 1188–1200.

[3] BigOceanData, “The Definitive AIS Handbook”, January, 2017.

[4] K. F. Mathapo. “A Software-Defined Radio Implementation of Maritime AIS”, December 2007.

[5] G. Sahay, P. Meghana, V. V. Sravani, T. P. Venkatesh and V. Karna, "SDR based single channel S-AIS receiver for satellites using system generator," *2016 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)*, Bangalore, 2016, pp. 1-6

[6] F.R.G. Cruz, R.C.M. Gania, B.W.C. Garcia, J.C.R. Nob, “Software Defined Radio Implementation of a Single Channel Automatic Identification System Receiver*,” IEEE Region 10 Conference, TENCON*, Jeju, Korea, 28 - 31 Oct 2018, pp. 2447 - 2450.

[7] F.R.G. Cruz, R.C.M. Gania, B.W.C. Garcia, J.C.R. Nob, “Implementing Automatic Identification System Transmitter on Software Defined Radio,”

[8] P. Lei, T. Tsai, Y. Wen and W. Peng, "A framework for discovering maritime traffic conflict from AIS network," *2017 19th Asia-Pacific Network Operations and Management Symposium (APNOMS)*, Seoul, 2017, pp. 1-6

[9] O. Hannemann, “Open Nautical Chart”, available: http://opennauticalchart.org/

[10] ITU-R M.1371-5 Technical Characteristics of an Automatic Identification System (AIS) using Time Division Multiple Access in the VHF Maritime Mobile Frequency Band.

[11] U. Simsir and S. Ertugrul, "Prediction of Position and Course of a Vessel Using Artificial Neural Networks by Utilizing GPS/Radar Data," *2007 3rd International Conference on Recent Advances in Space Technologies*, Istanbul, 2007, pp. 579-584.

[12] P. Payeur, Hoang Le-Huy and C. M. Gosselin, "Trajectory prediction for moving objects using artificial neural networks," in *IEEE Transactions on Industrial Electronics*, vol. 42, no. 2, pp. 147-158, April 1995.

[13] X. Rong Li and V. P. Jilkov, "Survey of maneuvering target tracking. Part I. Dynamic models," in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 39, no. 4, pp. 1333-1364, Oct. 2003.

[14] A. Daranda "A Neural Network approach to Predict Marine Traffic" VU Institute of Mathematics and Informatics, Akademijos str. 4, Vilnius LT-08663, Lithuania, October, 2016.

[15] E. Jones, T. Oliphant, P. Peterson et al., SciPy: Open source scientific tools for Python, 2001, software available at http://www.scipy.org/.