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Satellite-Based AIS for Improved Navigation and Maritime Safety - STUDSAT-2

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Abstract: Automatic Identification System is designed to prevent water automobiles like ships and corvettes from colliding, by allowing them to know the exact location of ships at sea which has a danger of Collision over the track of vessel. AIS is the discrete method used by all Sailors for exchanging their co-ordinates using SOTDMA for collision avoidance over the track. This paper discusses AIS message transmission and Reception and how it can be used for realizing traffic control in Maritime. In this paper, we show how GMSK Modulation and NRZI encoding techniques can be used for transmission of a signal from AIS Transmitter in Satellite to the receiver in the ground station. The ground station thus will have an extensive database of such received AIS Messages which are decoded at ground station end system level.

Keywords: SOTDMA, ADCS, CSTDMA, NASTRAC.

1. Introduction

Project STUDSAT-2 (STUDent SATellite-2), India's first twin Nano-satellite mission which aims to demonstrate Inter-Satellite Communication between two Nano-satellites STUDSAT-2A/2B is an inter-disciplinary Nano-satellite project being designed and developed by undergraduate students from seven engineering colleges across the state of Karnataka, India. Mission objectives of the project are to demonstrate In-orbit Satellite Separation, and demonstrate Inter-Satellite Communication (ISL) between STUDSAT-2A and STUDSAT -2B, implementation of drag sail technology in slave satellite (STUDSAT -2B) for de-orbiting and transmitting the AIS messages received from Type-A Ships (i.e. Corvettes and Frigates or Bulk Carriers) which are generally above 300 Tons, as a Primary payload system—and also allowing HAM communities to communicate via AX25 protocol during disasters.

AIS is a system to communicate which is solely based on Radio Frequency (RF), a remote correspondence that utilizes the transmission and Reception (Sending and Receiving) of Electromagnetic Waves. These waves work like the principle of cell phones. A vessel's faculty use AIS to guarantee the security of the ships on maritime and to monitor the course of ships to make the beeline.

Satellite AIS (S-AIS) is a payload of a satellite system which acts as a transponder on-board that receives the message from the AIS transmitting ships and sends it back the ground station while at AOS(Acquisition of Sight) is acquired, w.r.t STUDSAT-2, the transmitting of messages to the ground station, starts once the Satellite STUDSAT-2A comes at AOS of the ground station and remains to send the message up to fifteen minutes by the mode of ISL to the ground station and the system stays active till the Loss Of Acquisition(LOA) of STUDSAT-2B.

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S-AIS is mostly used for maritime domain awareness, search and rescue intelligence systems. Thus Satellite AIS is an effective way to track the current location of vessels and its track in the most remote areas of the world, especially beyond the reach of terrestrial only AIS systems and over Open Ocean.

SOTDMA over TDMA:

AIS communications rely basically on Time Division Multiple Access systems (TDMA), which allows multiple devices to communicate each is given "*time slot*", unlike telephones which use TDMA and are always have communication with the cell tower; Ships are limited when it comes to a range of a tower, so each ship should own its time slot to broadcast within. If not, the other ships within that close range would constantly compete for the same time-slot while sending its current position, and sometimes messages might be lost due to interference resulted.

For orderly communication, in AIS communication system, Self-organizing TDMA (or SOTDMA) is used. SOTDMA is the much of a complex TDMA access scheme defined for AIS and thus provides the autonomous operation of the network offshore as a backbone.

SOTDMA provides dynamic and autonomous management of limit in busy maritime traffic zones. In the critical circumstance, 'slot re-use' rules are applied where all TDMA slots are occupied. This permits the slots occupied by the stations most distant to a particular mobile station to be re-used for its own transmissions. This optimizes the size of an AIS 'cell' and ensures the position reports from the nearest vessels are not affected.

The basic hardware prerequisites to support SOTDMA are:

- VHF transmitter equipped for operating on any AIS channel in the marine VHF band
- Two VHF receivers equipped for operating on any AIS channel in the marine VHF band
- Full-time decoding of all received information messages in order to populate an internal slot map.
- Sufficient memory (RAM) to store a slot map for at least five minutes of TDMA slot allocations (the allocation status for 22500 TDMA slots).
- For TDMA timing, GPS receiver is used to provide a time reference.

Designed for Class A devices, SOTDMA transmits data as follows:

- AIS device searches for an available slot in the AIS slot map
- Reserves available slot
- Transmits information into the reserved slot and is notified to other AIS hardware of its intention to utilize this slot for the following transmission.

To make this fair, the slot selection is random, and each selection has a random timeout (the length of time the AIS transmitter will be permitted to continue to use the time slot). In this way, every device that receives the "preannouncement" As vessels move, they may need to change their time slot assignments. So when an AIS device changes its time slot, it preannounces both the new time and the timeout for that location.

The constrained scope of these AIS signals over the sea creates a cell or a cluster of ships with AIS transmitters inside communications range (such that all ships can hear and be heard by traffic).

Such organized prior-ranged time slots and timeouts create an AIS communications cell within such a cell. Fig. 1 illustrates time slots forming a communication cell. Based on the ship's direction, speed and where it is going, the protocol (SOTDMA) will adjust the number of reporting time slots required, scheduling time slots from as meagre as two seconds for fast moving ships to as long as three minutes when at anchor.

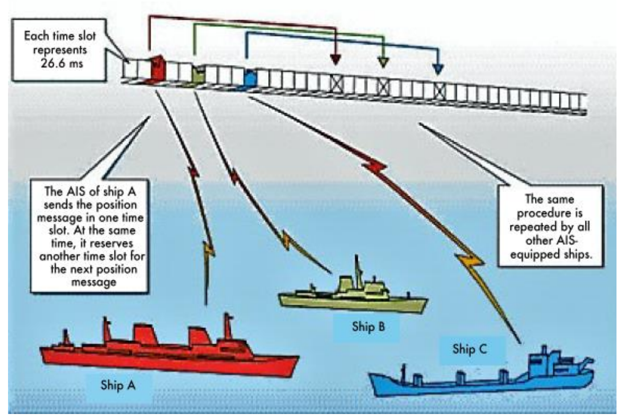


Fig 1: AIS messages transmission by Ship Transponders and slot assignment

Just like a busy highway, with many ships passing in and out of coverage of AIS comm^{on} cells, slot collision's possibility does exist.

It doesn't mean vessels collide if slots collide, the ship i.e. closest will do have a stronger signal making sure that the more closer ship conveys the most important AIS message and will be received correctly.

Understanding the AIS Protocol

An AIS message in wholesome contains much information about the vessel, and also includes the details regarding Course, Position, Rate of Turn, Speed, some more details like Destination and ETA, Ships name and Type of Vessel(depending on MSMI).

There are several types of such devices exists which all cooperate utilizing AIS protocols and International performance Standards. Thus such protocols are essential to make all devices are harmonically communicating in the same "LANGUAGE".

The different class of AIS device is allowed to be carried by a particular vessel on the mandate such ships come under. i.e, The vessels which fall under International Maritime Organization's mandate must carry Class A and ships that voluntarily carry AIS can carry any class of device but the prefer Class B most often. Class A devices are found onboard vessels and are transceivers that operate using SOTDMA. and they work with ship's radar and display systems with integrated display and transmit at 12.5 watts. Class B SO devices are too located on-board and are transceivers using SOTDMA but transmit at 5 watts. Class B CS(*carrier-sense*) CSTDMA that is confined to a single schedule slot for transmissions. Class B CS doesn't require to have Integrated display and are capable to work with 2 watts and by default transmits at a rate of every 30 sec and has GPS (integrated) and be able to receive all typical AIS messages.

AIS Base Stations:

AIS base stations are fixed stations that Mari-time authorities monitor to control vessel traffic. These base stations do control AIS devices and have functional capabilities to turn AIS devices on or off and Reserve time slots for Special tx's and control time slots and power level of Mobile AIS devices. Within its vicinity, the base station can further impose more efficient SOTDMA organization ensuring communication in busy harbour areas.

AIS too has limits, being widely used technology. Still, there is the part about round Earth that presents limitations for the system. AIS has limited signal transmission and is limited to up to 50 Nm. Hence the horizon is the limit for ships. This range limitation can prevent maritime authorities from compiling a complete picture of marine traffic outside its borders on big scale hence where S-AIS comes into picture where The AIS Signals travels in a straight line. At the same time, ships follow the curvature of the Earth, so the ships drop out of view.

2. Background

Working With Satellite AIS

However, AIS is an essential system for maritime safety. As AIS cannot reach beyond 50 nM, here we find out using satellites with existing AIS technology which ultimately gives a picture of vessel activity, even in high traffic and specially on remote areas.

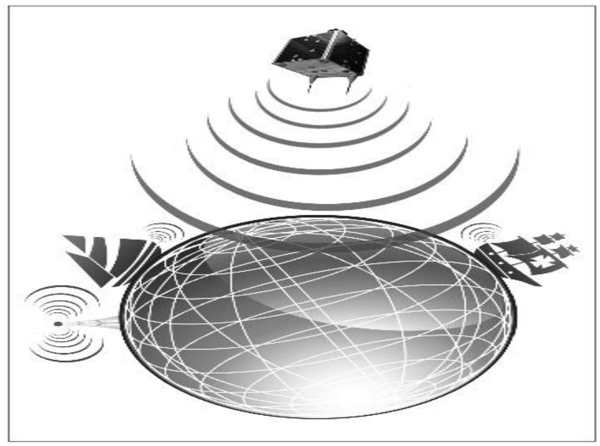


Fig 2.1 Extended range of S-AIS signals

Thus S-AIS provides Improved potentiality to identify threats and monitoring of vessel traffic at more cost-effective assets. The bonus to getting the bigger picture is such that S-AIS can be implemented without new outfit or additional hardware upgrades.

Seeing the two types of S-AIS

S-AIS signals can be detected using two ways, **On-Board Processing (OBP)** and **Spectrum Decollision Processing (SDP).**

Whereas **OBP** uses (on-satellite receiver board) specialized receivers on satellites(on-Sat) that does work alike to Standard AIS receivers, but on-Sat receivers are more sensitive. OBP much does not need any special processing and it does work well in very low-density areas i.e. the Pacific Ocean where there are low traffic and less traffic collision. Nevertheless, OBP is not as effective as in detecting signals in the horizon that contains merely higher than 1,000 vessels, as slot collisions due to high density. Thus OBP may not detect all AIS messages during its very first pass, or orbit, or over any area, and as well might need to go over an area multiple times before it makes a complete picture. If an area has a substantial volume of vessels making traffic - more significant than 2,500 vessels — OBP will have an even harder time giving a full, accurate picture. As with so many signals, slot collision occurrence, the OBP fails to resolve colliding messages.

As the satellite is seeing at multiple communication cells makes way for slot collisions. Within a communications cell, an AIS device's slot selection is randomized and tagged with a random timeout. As receivers have two channels for backup, as the closer vessel is always heard first, the Collision doesn't affect the primary purpose of collision avoidance. However, sometimes the slot collision might affect the receive station.

SDP: In this technique, the satellite listens to all available AIS signals and captures such signals across the AIS radio frequency spectrum. Then just forwards all the information received to station on Earth without even trying to make any sense out of it. Once the messages are received powerful computing is used to sort out all such AIS messages excluding noise of the cells. Using advanced algorithms, the received information is all processed and decollated simultaneously, by this method almost ships are to be detected making a new tradition. SDP is mostly useful in heavy maritime traffic, and S-AIS is effectively enough to detect messages and work effectively. So we get an accurate picture of what's going on down on the water, even at the high-density area more quickly

3. Objectives

Versatility of S-AIS

Surely S-AIS technology is many things, but it also has one track- one signal in methodology. Sure it can track vessels and keep them safe, but it's just a tip of the mountain. S-AIS can be used for the huge number of purposes, and this part explores the applications and many possibilities of applying this technology. We can classify the uses as follows in general.

A. Monitoring vessels and water they navigate

B. Enhancing Search and Rescue (SAR) operation

C. Ensure security of people, business interests and borders

4. Proposed Work

Implementation AIS

AIS Message needs to be Encoded and Modulated before transmitting and Decoded and Demodulated before receiving it. We aim at implementing AIS using NRZI encoding and GMSK Modulation. Encoding is done to convert the data from one format to another format to make transmission more robust and reliable. There are several methods to map digital data to digital signals.

NRZI Encoding: If the present bit value of the incoming signal is 1, then there occurs a transition at the beginning of the bit interval. Suppose the present bit value at the incoming signal is 0. In that case, there is no transition at the beginning of the bit interval.

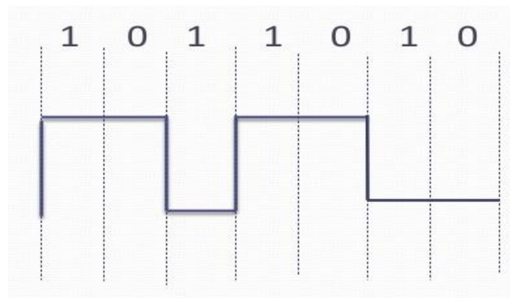


Fig 5.1 NRZI Encoding

Implementation of NRZI Encoding and Decoding using MATLAB and SIMULINK

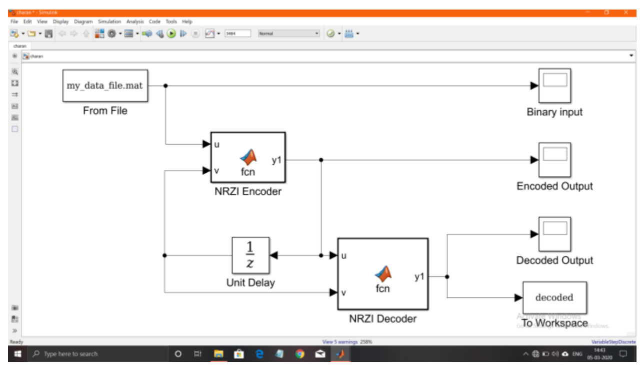


Fig 5.2 Simulation of encoder and decoder

From File: This block gets the ASCII values of the text message as input from the metafile. The output of the block is binary.

Encoder: Encoder performs the function of NRZI Encoding of the given binary data. An X-Or gate is used in the encoder block. The inputs to this Xor gate are the present value of data and the previous value of encoded.

Unit Delay: The Unit delay block gives the previous value of the encoded data to both encoder and decoder.

Decoder: Decoder performs the NRZI decoding of the encoded data.AnXor gate is used in this block. The inputs to this Xor gate are the present value of the encoded data and previous value of the encoded data.

Decoded data is saved in the workspace as a variable and later converted to text. Scopes are used to checking and verifying the correctness of blocks and functions.

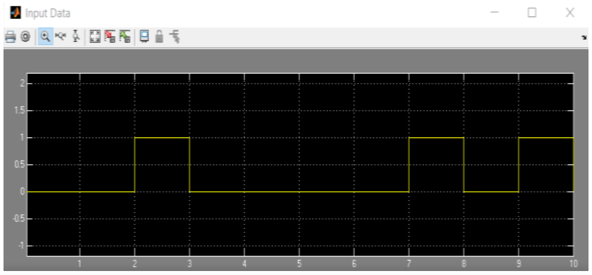


Fig 5.3 Waveform of input data.

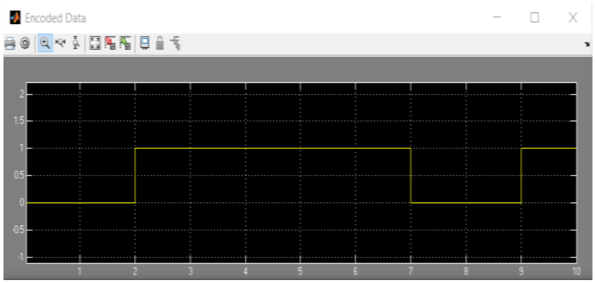


Fig 5.4 Waveform of encoded data.

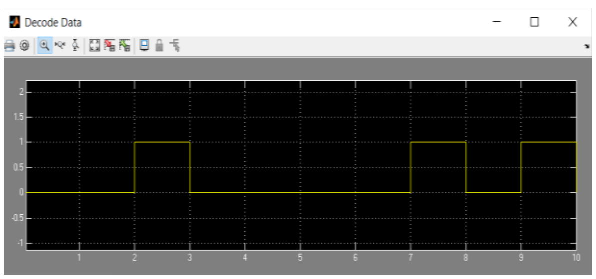


Fig 5.5 Waveform of decoded data.

GMSK Modulation

Gaussian Minimum Shift Keying, GMSK is a form of modulation based on frequency shift keying that has no phase discontinuities and provides efficient use of spectrum as well as enabling high-efficiency radio power amplifiers.GMSK is probably most widely associated with the 2G GSM mobile communications system where it proved to be an effective form of modulation. It was one of the reasons that GSM cellphones had a long battery life because of the high efficiency that could be obtained from the RF power amplifiers.

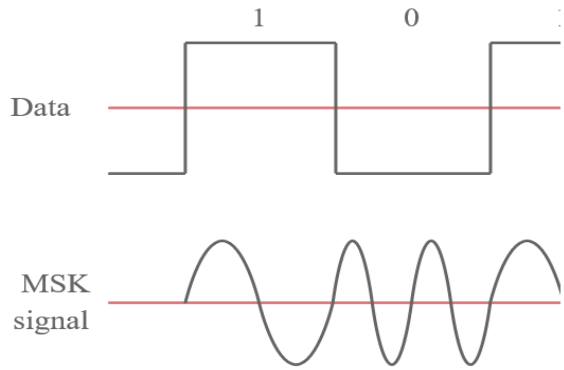


Fig 5.6 GMSK modulation

GMSK Modulation using SIMULINK

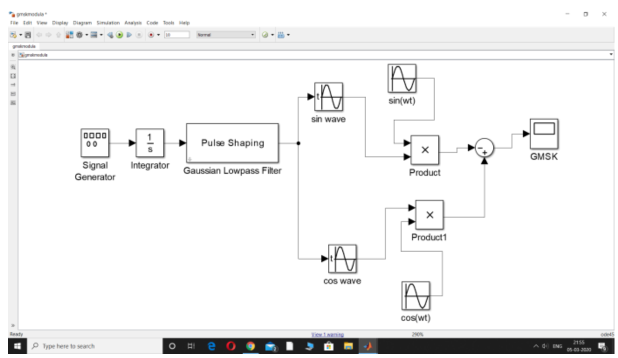


Fig 5.7: Simulation of GMSK Modulation.

Sine Wave: This block generates the sine wave of the frequency higher than the input data frequency.

Pulse Generator: This block generates binary data.

Gaussian Function: Gaussian function block filter the data by removing the high-frequency component of the signal. It smoothens the edges of the binary transitions.

Switch: This block switches the output signal between two frequencies based on the input value given. If the input is 1, the signal of frequency f1 is passed. If the input is zero, the signal of frequency f2 is passed.

Scopes are used to checking and verifying the correctness of blocks and functions

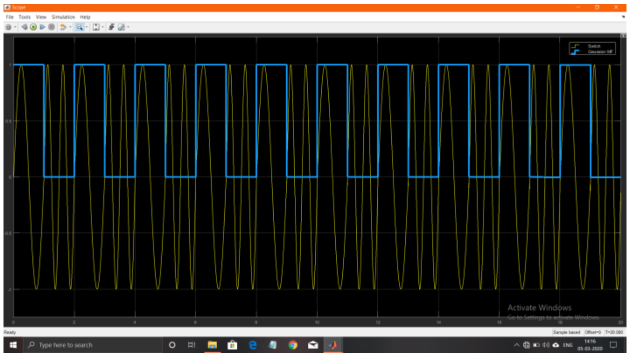
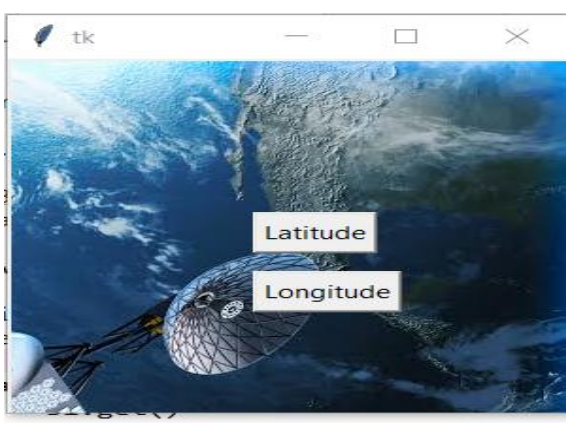


Fig 5.8 Output of GMSK Modulation

5. Results and Evaluation

After decoding the AIS message, the message gets stored in the ground station. In this, the decoded AIS message is stored in the ground station. The AIS message is obtained in such a way that the message gets stores only when the satellite comes towards the ship. We will get the connection for only 10 to 15 minutes, and the almost large amount of message is obtained. To decode this obtained message we will use python an interpreter language because it goes through an interpreter, which turns code you write into the language understood by your computer's processor. The interpreter reads the source code line by line and executes it along the way. GUIs were introduced in reaction to the perceived steep learning curve of command-line interfaces (CLIs), which require commands to be typed on a computer keyboard. Python is used as a basis for creating a flexible, usable and reliable desktop application. By using the python language in spyder, for designing the GUI we created the buttons, framework etc.



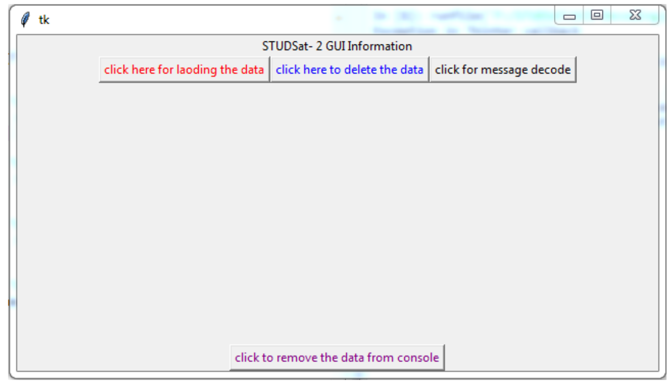


Fig 6.1: GUI to AIS messages loading, Decoding and Mapping

Once the GUI is designed, now we have to decode the AIS message, and it is done in spyder here we will use the concept of AIS parser and AIS server. What did these two things mean? The AIS Parser modules approach to parsing AIS messages is 'on demand'. A message is merely stored, and the parse function does some necessary checks. When data is requested only as much of the message is parsed as is needed to decode the requested data. For instance, when the AISType is read-only, one byte of the message is translated and parsed. So it makes sense only to read the values that are needed. Although some typical values are cached in the result object once they have been requested, most values are not - meaning that they are parsed every time they are requested.

The result object obtained from the parse function has variable supported values which return an object containing the field names that can be retrieved from the result object associated with their type of unit. The contents of the interpreted decoded message may look something like this:

```
In [6]: ais_format
Out[6]:
{'type': 18,
 'repeat': 0,
 'mmsi': 0,
 'speed': '0 knots',
 'accuracy': '1',
 'lon': '5°21\'52.3"E',
 'lat': '43°17\'41.6"N',
 'course': '356.6°',
 'heading': 'N/A',
 'second': 1,
 'regional': 0,
 'cs': 'Class B CS',
 'display': 'N/A',
 'dsc': 'VHF voice radio with DSC capability',
 'band': 'Can use any frequency of the marine channel',
 'msg22': 'Accepts channel assignment via Type 22 Message',
 'assigned': 'Autonomous mode',
 'raim': '1',
 'radio': 917510}
```



```
In [9]: ais_format
Out[9]:
{'type': 1,
 'repeat': 0,
 'mmsi': 316001245,
 'status': 'Under way using engine',
 'turn': 'N/A',
 'speed': '19.6 knots',
 'accuracy': '1',
 'lon': '123°52\'39.9"W',
 'lat': '49°12\'1.01"N',
 'course': '235.0°',
 'heading': '235.0°',
 'second': 7,
 'maneuver': 0,
 'raim': '0',
 'radio': 24724}
```

Fig 6.2: Decoded AIS Message obtained from the database

sample messages decoded above:
'!AIVDO,1,1,,,B00000000868rA6<H7KNswPUoP06,0*6A'
'!AIVDM,1,1,,A,14eG;o@034o8sd<L9i:a;WF>062D,0*7D'

The AIS Server provides a JSON over REST interface (HTTP). This light-weight interface enables AIS clients to interact with Enterprise One applications and forms. Any client or software language that uses JSON over REST can interface with the AIS Server. This type of server is perfect for clients or software languages that use JSON over REST.

After doing the GUI concept, AIS parser and AIS server in spyder using python interpreter language, now we have to locate the points in the map of the uploaded ship number. The entire framework is done using node.js. From using python to make GUI, we conventionally shift to Java language for creating maps to locate the latitude and longitude of the ships. First, for creating maps, we will use node.js, once creating maps using the node.js, we will create a box for entering the shipping number. Once we enter the shipping number, we automatically get the movement of ship that is we get the location from the starting point to endpoint. One such executed ship track is shown below.

Fig 6.3: Ship course obtained from the decoded AIS message.

6. Conclusion

AIS developed to be highly intense and tracking network for the short-range identity of ships. However, time-to-time it was anticipated to be detectable from space. The TDMA scheme used by the AIS system makes a significant technical and highly reliable Reception of AIS messages from all types of Transceivers:Class A, Class B Identifier, AtoN, SART and many more. The satellite-based global coverage of AIS enables the better performance of the terrestrial-based network. The growing body of research on methods of exploring data (AIS) for minimalization of seafaring and safety on priority, rational analysis of maritime traffic, rote extraction, collision/anomaly detection, weather routing, path planning and many more.

7. Acknowledgement

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