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Visualization, Vulnerability and Manipulation in Internal Communications Systems on the Navigation Bridges

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ABSTRACT: This paper is the continuation of a project previously presented for the training of students in both the Bachelor's and Master's degrees in Radio Engineering. The proposal makes it possible to visualise and understand how navigation equipment shares information on board a ship, using low-cost devices. Through an SDR receiver, free software (SDA, ShipPlotter, OpenCPN) and minimal investment, students can receive AIS transmissions, decode them, get their NMEA frames to view over electronic letters. This practice recreates an ECDIS environment in a PC, promoting self-learning, technical curiosity and innovation. In addition, it explores the possibility of generating false NMEA frames to demonstrate the vulnerability of the system, reinforcing the importance of information integrity in navigation. The project demonstrates how, without costly equipment, it is possible to assimilate complex concepts into communication and navigation systems, reinforcing the motivation and active learning of students.

1 INTRODUCTION

El Maritime transport depends inter alia on navigation systems and communications equipment for safe navigation. However, due to the technological advances that are coming to ships in these sectors [13], students in the grades or masters of this maritime sector must have good training.

In all areas of the maritime sector, port management, maritime transport... require a qualified staff[3].Therefore, the training must offer a number of qualities and skills to obtain great professionals in the sector. All this with the existence of a solid foundation in the formation.

Therefore, when theoretical classes are a bit complicated to understand, we must put forward different proposals to solve the problem.

Consequently, students do not understand complex concepts as the process of moving from working with independent teams to doing it together, this project was proposed. Where the exchange of information on a navigation bridge is carried out in a continuous manner.

This proposal, which follows the previous study [14], presents some practices on theory, through the use of low-cost devices available on the market. With only a small investment of the order of 20 or 30 € and the use of a PC, which in this case can be the student's own personal computer.

In order to carry out the practice we need a receiver capable of tuning the AIS frequencies, the PC, and Shareware or Freeware software.

2 DESCRIPTION

This project focuses particularly on understanding how navigation equipment (GPS, AIS, ECDIS, ETC) share information. This requires knowledge of the NMEA standard, as well as IEC 61162-1 [18] and IEC 61162-2 [19] standards, which define technical aspects such as wiring and data format.

An economical practice is proposed that uses a low-cost receiver capable of tuning marine VHF channels 87B and 88B, along with an appropriate PC and software, to receive real-time AIS information. The signal received, initially in audio format, will be digitally processed using free or test software to obtain NMEA frames with static, dynamic and navigation data from ships, coastal stations and digital aids.

This information can be viewed on electronic charts, offering a complete view of the maritime environment. However, it is noted that reliability depends on the veracity of the data issued, as there is no control over its origin.

Finally, students are sought to understand how to share these NMEA frames between on-board computers, either via USB converters to RS422/RS485 [16] or within a single PC, simulating a basic ECDIS system and encouraging practical learning of internal communications on a government bridge.

3 MATERIALS USED IN PRACTICE

3.1 *Receptor software o SDR*

For reception in the channels, 87B and 88B in VHF assigned to the AIS system we will use a low cost radio receiver capable of receiving the channels of maritime communications assigned to the maritime mobile service. The receiver to be used is a receiver initially designed as a dongle for receiving digital terrestrial television on a PC. Nowadays they are popularly known as RTL-SDR, and allow changing their performance only by installing a different driver to the one needed to demodulate transmissions of digital terrestrial television or TDT. In this simple way, they can be transformed into a Radio Device Designed by Software or SDR [9]. The installation of free radio software also offers the possibility of receiving transmissions ranging from the OM band to UHF, and all this thanks to the joint work of two integrated circuits well known by radio engineering students, the popular CI tuner R820T/2/R860 [11] among others together with the IC demodulator RTL2832U [12].

Both circuits in combination and constant communication constitute a radio receiver in full rule and completely break with the concept of the traditional hardware superheterodyne receiver where functionality depended on physical elements such as filters, amplifiers, demodulators etc.

On the contrary, the SDR receiver works basically and in a very small way converting the received RF signal to a lower frequency, called FI, which allows its sampling in a digital analog converter, ADC, with its own limitations imposed according to Nyquist sampling theorem. In this way the received signal passes from analog to digital once it has been quantified and encoded.

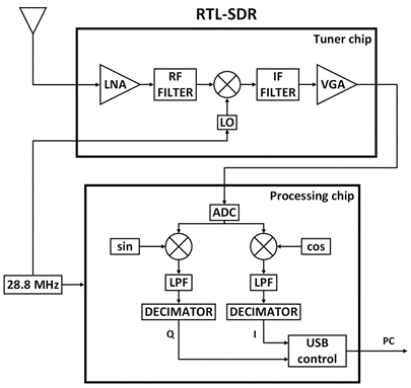


Figure 1. Block Diagram RTL-SDR

Part of this work is carried out in the first stage of the device, and more specifically in the tuner IC, where the received signal is amplified, filtered and mixed with the signal generated by the local oscillator in order to obtain the FI. Once the FI is amplified and the unwanted components are removed, it is driven to the demodulator circuit to be scanned.

The FI signal already in the demodulator is first sampled and quantified before passing through a square modulator [6] decomposing it into two new signals, known as phase I signal and Q-square signal. Later these two signals are decimated into a downstream digital converter [21], DDC, to move the digital signal of interest or FI to a lower frequency by sampling at a lower frequency than required according to Nyquist's theorem. In this way, the initial FI signal is broken down into two new baseband signals for further treatment.

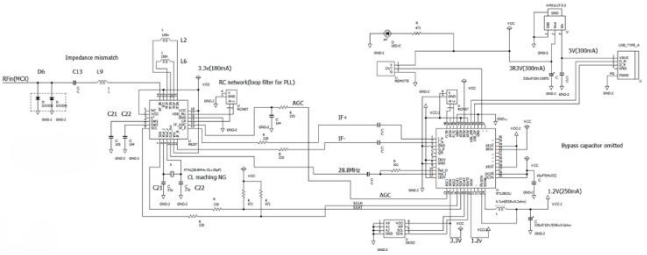


Figure 2. Circuit RTL-SDR

After obtaining I and Q signals, and how to expect, only the digital signal processor or DSP [5, 10] analysis remains. Processing this data using specific software allows reverse engineering operations by being able to emulate filters, demodulators, detectors etc. without the need for specific hardware.

Figure 3. Physical device SDR

As this type of device is initially designed to operate with digital terrestrial television and not beyond the frequencies used for this purpose, it is therefore completely necessary to change its initial performance. Thus converting them into radio frequency receivers, which is possible by switching the original driver to a free driver known as Zadig.

3.2 *Driver Zadig, software SDRConsole y audio VB-CABLE Virtual*

Installing this driver is relatively simple and simply connect the USB device, cancel the Windows installation itself, and manually install the driver Zadig[22].

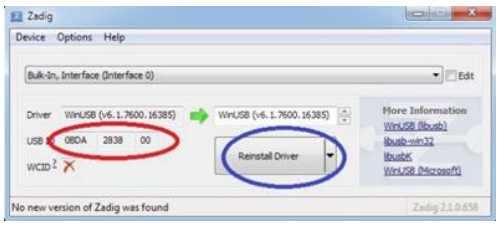


Figure 4. Software Zadig 1

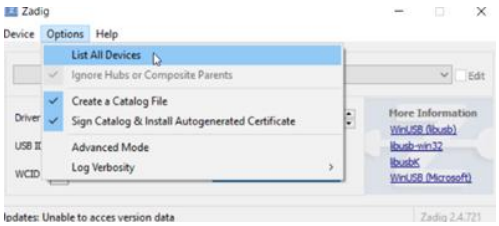


Figure 5. Software Zadig 2

After the installation of the Zadig driver, the USB device will function as a radio receiver capable of tuning stations from 500 kHz. up to 1.7 GHz. approximately. At this point, there is therefore a radio receiver capable of replacing a commercial AIS receiver, if the appropriate antenna is used at the frequency to be received.

The control of this physical device must be carried out by installing software capable of controlling on the one hand the receiving zone composed of the tuner R820T/2/R860, and on the other hand, the digital signal processor composed of the demodulator RTL2832U.

Although there is a wide variety of free software capable of managing the receiver proposed for this practice, we will decline by SDR Console (v3) [15] due to its pleasant and complete graphical interface that allows to visualize both the receiving stage and the signal processing simultaneously.

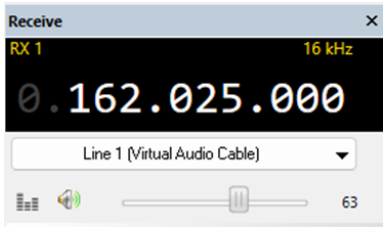


Figure 6. Receiver

Figure 7. Mode

Figure 8. Filter

Figure 9.Received Signal

At this point in practice, it is already possible to hear any audio broadcast that our receiver is able to tune, always limited by the antenna used. In the case of VHF band frequencies, we will use for practice a small telescopic antenna, although we could use one specifically calculated for the reception of the channels of our interest 87B and 88B, that is, the frequencies 161,975 MHz and 162,025 MHz respectively.

By tuning the frequencies mentioned above, it is already possible to receive transmissions from nearby ships from the AIS, which will be perceived as repetitive sound pulses impossible to understand by the human ear, although carriers of digital information.

To extract this information it is necessary to use a system capable of analyzing that sound signal and transforming its frequency variations into "0" and "1" logical.

This work will be carried out by internally injecting the audio obtained from the AIS channels into some software capable of carrying out this arduous work.

To inject the audio internally and avoid the annoyance of hearing it we will choose to install a virtual audio output. It will be done by installing the free VB-CABLE Virtual Audio Device utility [20],

which gives the SDA/Onsole receiver a new audio output from the existing ones on the PC, and allows it to be directed internally without the need for a physical connection.

3.3 *Software shareware ShipPlotter*

The extraction of the digital information of interest will be done by installing one of the many software available on the network.

We have opted for ShipPlotter [4] test software for this work. The function therefore is to analyze the audio signal that arrives, the detection of the frequency changes present in it, the transformation of these changes into binary states and the grouping of the "0" and "1" into frames that comply with the norm NMEA0183

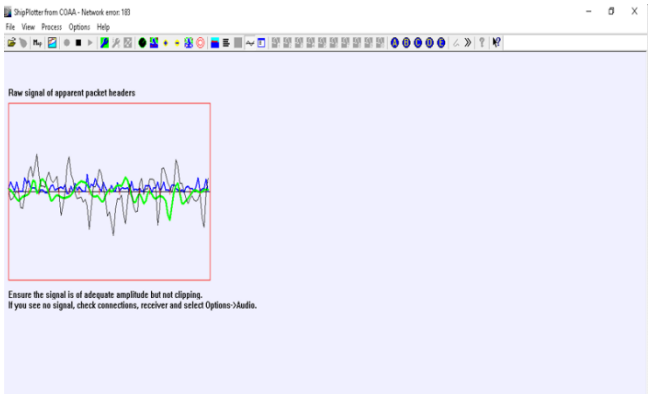


Figure 10. Software shareware Ship Plotter

In addition, the program also allows the dissemination of digitized information to other devices through different types of communication ports.

In our practice we will opt for a UDP port as an output port for the dissemination of the obtained NMEA information, as it is intended to reduce the entire practice to the use of a single PC.

For a better understanding of the information ShipPlotter sends to other devices, it is convenient and advisable to know how AIS information frames are structured, so it is recommended to read ITU-R M.1371 [7]

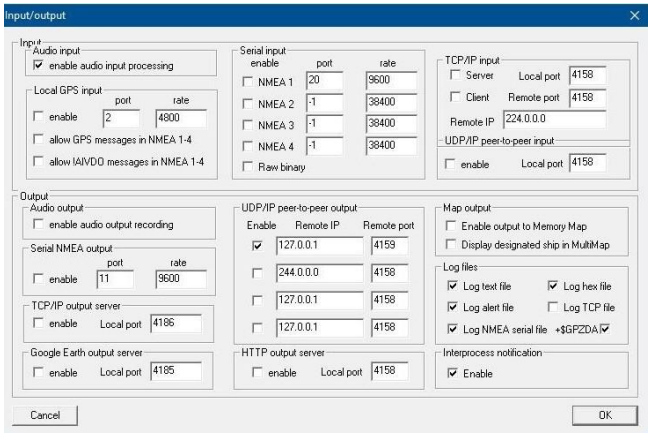


Figure 11. Input/output

3.4 *Software shareware OpenCPN*

ShipPlotter software, in addition to extracting NMEA statements through audio input, representing them on an electronic letter, is also able to act as a talker in an NMEA network, which is why the practice makes use of a second program that acts as a NMEA listener and represents the information received.

In order to visually represent the information received and decoded will be made use of OpenCPN free software [17], designed as a navigation planner capable of displaying nautical charts on which the information that said software reads through different input pathways overlaps, be it TCP network connections, UDP GPSD, SIGNAL K or serial type.

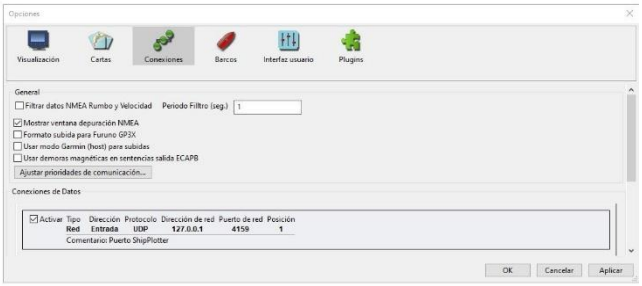


Figure 12. Connections

OpenCPN acts as a receiver or listener and allows monitoring the NMEA frames that reach you through the different ports and represent the information of them on an electronic nautical chart for interpretation by the pilot.

The NMEA frame debugging window allows the radio engineering student to observe some of the 26 different types of messages that are transmitted according to the ITU-R M.1371.

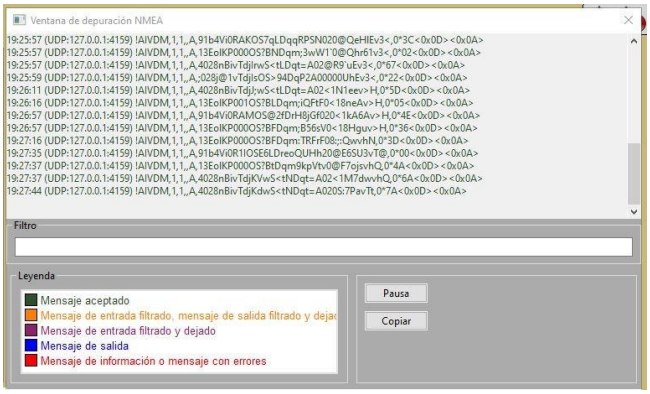


Figure 13. Sentences monitored by OpenCPN

As an example, an NMEA debug screen has been captured in the listener, OpenCPN, where information from the talker, ShipPlotter, is observed.

Although it is difficult to read and understand an AIS-type NMEA statement in plain view, the utility allows the student to copy one of them and extract their information on one of the many free websites that do so. Besides being able to employ specific software that marine equipment manufacturers provide, as is the case with Actisense NMEA Reader [1]. As an example, we have chosen to copy one of the many frames received and after decoding it we observe the different parameters that make it up and that fit the aforementioned ITU-R M.1371

By looking at it, we can know that the statement corresponds to a message of type AIS of an external station (AIVDM). It contains a total number of one single judgment (AIVDM, 1) transmitted to include the information, that the judgment in question is the first of a total of 1 (AIVDM, 1, 1) and finally that was received in the channel AIS A (AIVDM, 1, 1, A). The rest of the included data is much more complicated to read in plain sight, as unlike the usual NMEA frames that employ ASCII encoding [2], the ones used in the AIS system employ a 6-bit binary encoding because of the large data content they must include. This is why it is necessary and convenient to use the specific software mentioned above.

Figure 14. Sentence NMEA

This particular NMEA plot or judgment corresponds to a programmed position report from the Sailing Aid (AtoN) San Sebastián Castle with MMSI 992242123 and placed in the nautical chart at 36º 31.6999 'N and 6º 18.9700' W. etc

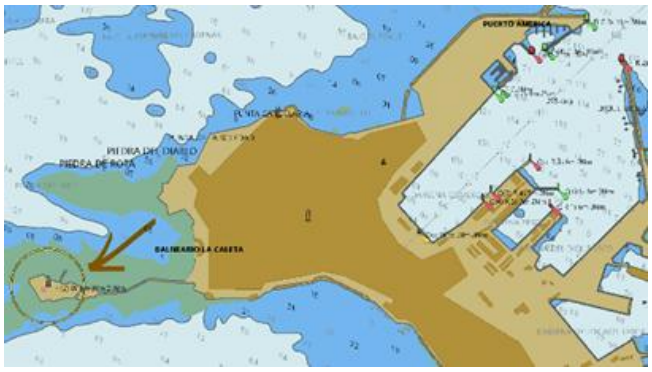


Figure 15. Castillo de San Sebastián

4 ASSEMBLING THE PRACTICE

It may seem that the main objective of the practice is the transformation of a personal computer into a complete ECDIS system, where we can see in real time the fleet that sails near our coast. However, the real goal is to motivate radio learners by innovation and self-learning as they can achieve the same result in a particular way and outside the laboratory with minimal investment.

Figure 16. Assembling the practice

First, in the laboratory we will use a personal computer that has previously installed the necessary software mentioned above, ShipPlotter and OpenCPN. In this way, we transform the computer into a complete ECDIS system capable of showing the information it receives through the VHF radio receiver associated with it.

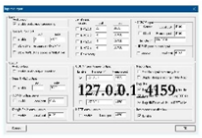
Our VHF radio receiver will be responsible for capturing signals transmitted from ships, base stations, radio stations etc. and providing them to ShipPlotter software in the form of audio, which in turn will extract the digital information they contain to be sent later to OpenCPN in the form of NMEA frames that will be presented on an electronic letter.

This way ShipPlotter will act as a talker while OpenCPN will act as a listener.

Finally, it remains to equip our practice with the radio receiver necessary to receive the channels 87B and 88B what we achieved by connecting our SDR device to one of the many USB ports available on the PC.

To share information the NMEA between different real equipment of a navigation bridge, it is necessary a wired connection, however, our practice will dispense with the connected one as the information will be shared via a UDP port common to both talker and listener since both are software type. In addition, UDP connections allow you to send data quickly even in multicast mode, supporting the delivery of data packets, even if they are not complete etc.

Table 1. Physical connections

Data Connection	
Talker **PC** **ShipPlotter**	**Listener** **PC** **OpenCPN/ECDIS**
UDP → UDP comunicación unidireccional	
	
CONEXIÓN RECEPTOR VHF	
SDR **R820T/2/R860 RTL2832U**	**ShipPlotter**
SALIDA audio virtual → ENTRADA audio virtual Conexión unidireccional	

At the point we only need to turn on the VHF, SDR, on any of the AIS channels (87B or 88B), which we will do by tuning 161,975 MHz and/or 162,025 MHz on the receiver software SDHonsole.

We will patiently wait a few seconds and, if near our receiver there are AIS transmissions, we will be able to observe how on the electronic letter shown by OpenCPN the information is appearing. As is the static, dynamic and crossing data of the ships around us, of the stations based on land and of course of the aids to navigation.

Here are some interesting screenshots showing the good results of the practice.

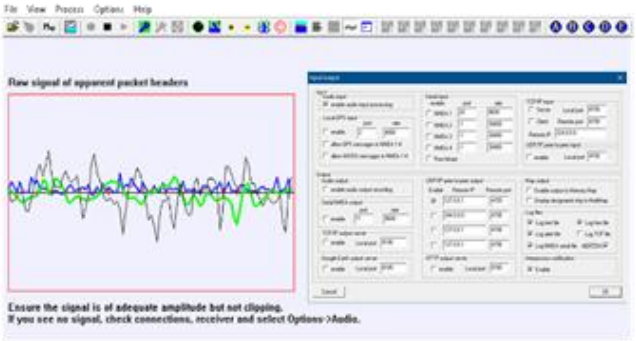


Figure 17. Audio, input output

We see how the audio signal injected into the talker is analyzed and decoded, transmitting it to the listener via UDP port, but no longer as audio but as NMEA frame. The listener monitors the talker´s UDP port and therefore the information received is interpreted as incoming information NMEA0183 and will be used according to the function programmed in the listener.

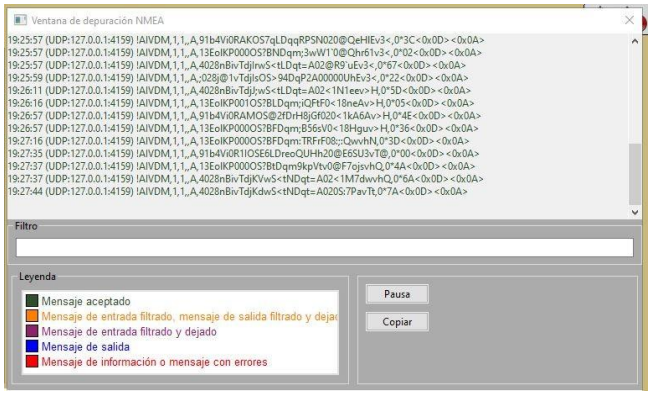


Figure 18. Debugging window

The NMEA information that the listener receives can be monitored in real time thanks to a debug window. This utility allows to extract certain sentences, or all of them, for further study and understanding and even to register in a file that may later be used for other purposes.

Information frames can be represented in different ways, one of them being a radar screen simulation, but always remembering that it is simulation and not a real radar, since the principle of operation of a real radar is completely different.

Figure 19. AIS Radar view

Especially the information received is represented on an electronic letter where data on, ship, base stations, etc. transmitting AIS information will be observed.

As these are repetitive transmissions, the representation on an electronic letter also allows showing the defeats maintained by the ships in route, as well as static data etc. that ultimately provides very useful visual information to the pilots and centers of marine traffic coastal.

Figure 20. Ship UCADIZ

We will show below several screenshots carried out in different days and hours, being able to observe the situation of maritime traffic in the bay of Cadiz in each of those moments.

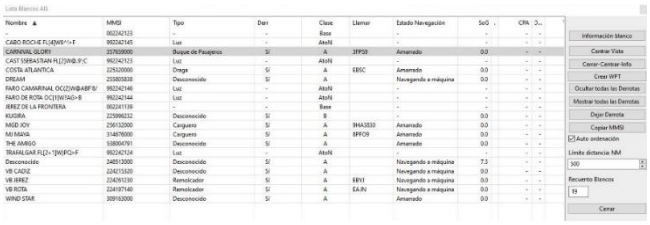


Figure 21. AIS target list

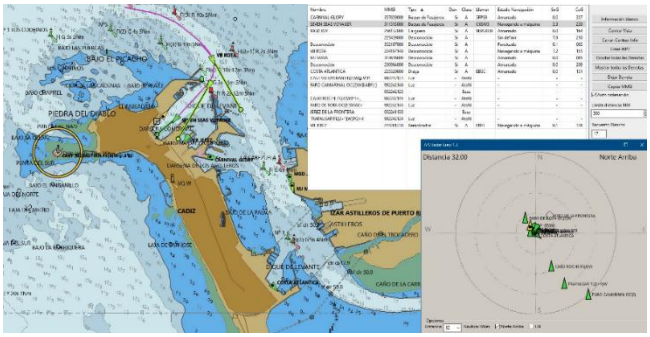


Figure 22. AIS target list, chart and radar simulation screen

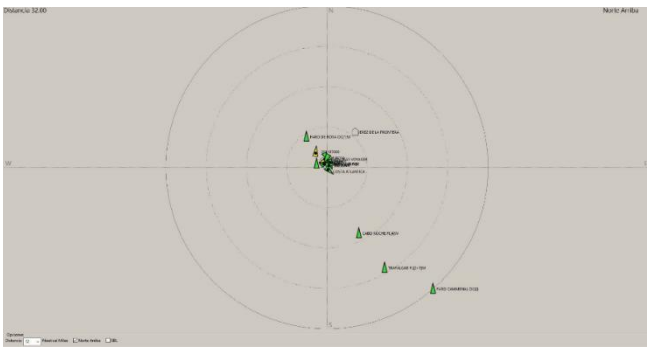


Figure 23. Radar simulation screen

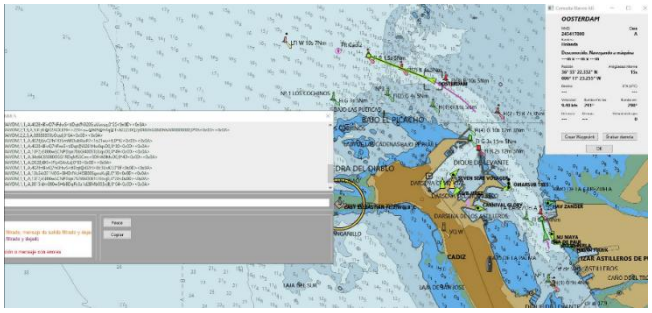


Figure 24. Chart and NMEA sentence

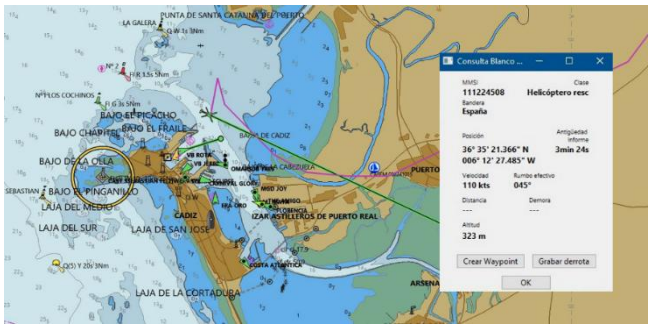


Figure 25. Chart and tracking

The work presented here reveals the feasibility of our practice to show the actual information decoded and presented on an electronic letter. But in addition, it allows to propose to the students challenges such as the creation of false NMEA frames that are mixed with real ones intentionally and that can carry out in personal way because it is not necessary a great economic investment.

To further encourage the interest of the students, we have generated a FALSE LIGHTHOUSE near the Rio San Pedro along with an AIRCRAFT in the same area, all while we can visualize real information about ships docked and en route.

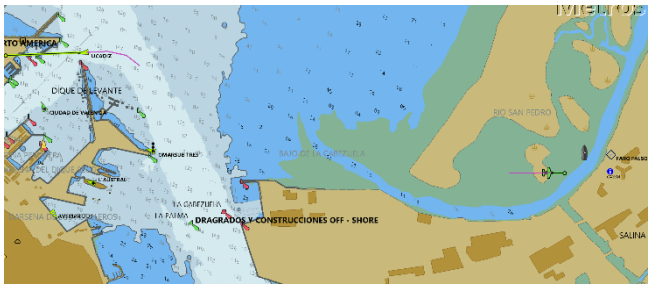


Figure 26. False Lighthouse

It should be noted that at no time has it been transmitted in the channels assigned to the AIS system, only the "false" NMEA plots have been elaborated to inject them into our network. Needless to say, any plot injected into any VHF transmission system capable of digitally modulating by Gaussian minimum displacement, GMSK [7], the channel 87B or 88B, would undoubtedly appear on those AIS receivers located in the transmitter coverage area, compromising the safety of navigation.

To make the falsity of the information presented more evident, another capture of AIS targets is shown in which two SAR aircraft are observed whose MMSI and assigned data are hugely striking. Specifically, the first MMSI 111111111 is reserved for aircraft group identity, and the second MMSI 000111111 does not comply with Rec at all. ITU-R M.585-9 [8] on Assignment and use of maritime mobile service identities, as 00 is reserved for coastal stations. The reader will also be able to observe the existence of a third SAR aircraft with MMSI 11125896 listed as "dedicated to fishing."

Everything seen in this last part of the practice aims to make it clear that it is possible to introduce false information into the real system, which is why we have used absurd information on whites.

In our case it has been experimented without transmitting in the AIS channels, but by injecting frames of false information about the NMEA data network

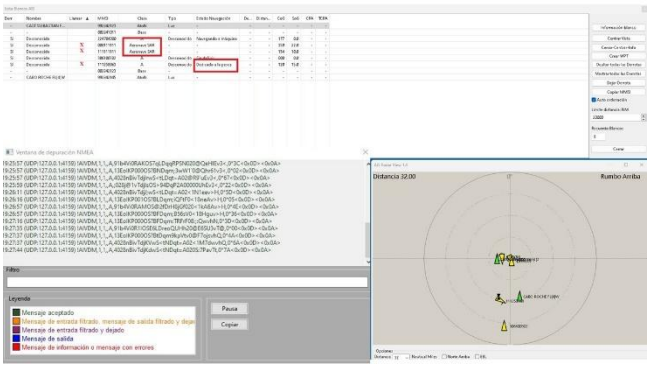


Figure 27. AIS targets

5 CONCLUSION

The study presented demonstrates the feasibility of integrating innovative and low-cost practices to facilitate the understanding of complex concepts in the field of electronic navigation. By using accessible technologies such as SDR receivers, free software, and simulation tools, students can experience in a practical way how AIS data is shared and visualized on a navigation bridge. This approach encourages self-learning, technical curiosity and the acquisition of real competencies in the use of NMEA and ECDIS systems. It also makes it possible to understand in a tangible way the importance of interoperability between equipment and the structure of the data frames used in the maritime environment.

The proposed assembly converts a conventional PC into an ECDIS system, capable of receiving, decoding and visualizing AIS frames in real time, thus facilitating training outside the laboratory and with minimal investment. In addition, the final exercise on the creation of false frames allows us to reflect on the reliability of navigation systems and cybersecurity in the maritime field. In short, an effective, innovative and economically viable pedagogical practice strengthens the technical capacities of future maritime professionals.

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