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Modern Navigation Challenges – Case Study Based on Students′ Practices on r/v Horyzont II in the Gulf of Gdańsk

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ABSTRACT: GPS signal jamming and spoofing have been known for decades, yet an increasing number of electronic devices rely heavily on GPS positioning. In recent years, this issue has been experienced firsthand in Poland and on Polish Territorial Waters, but in some other parts of the world, the problem has been known for much longer. Several alternative global range positioning systems have been developed, but none are as commonly used as GPS. Most ships navigating international waters are equipped only with GPS/DGPS receivers and do not carry receivers for other positioning systems. It is crucial to ensure that young navigators are appropriately trained in the navigation process using sources of position other than GPS, especially in crowded territorial waters and port approaches.

Each year, the research vessel "Horyzont II" takes groups of students from the Maritime University in Gdynia on board for a few weeks of practice in manoeuvring, navigation, and radar operation. Students have the opportunity to apply their theoretical knowledge gained over 2,5 years of study. Under the supervision of the ship's crew and teachers, they perform duties as officers, helmsmen, lookouts, radar and ECDIS operators. They also learn about daily vessel operations and participate in maintenance tasks. This article aims to present examples of GPS signal issues encountered during this year's training in the Gulf of Gdansk, their impact on equipment, the students' reactions, and their capacity to carry out efficient and safe navigation under these specific circumstances.

1 INTRODUCTION

According to ITU Radio Regulations (such as RR 5.328A and RR 5.329) there are four main bands dedicated to the Radio Navigation Satellite Service (RNSS), in which the GNSS constellations operate. These bands include:

1. 1559 – 1610 MHz used by the main navigation signals of GPS (L1), GLONASS (G1), Galileo (E1) and BeiDou (B1).
2. 1215 – 1254 MHz for second signals of GPS (L2) and GLONASS (G2) used for high-accuracy positioning.
3. The 1164 –1214 MHz band is used for safety-of-life signals, including GPS (L5), Galileo (E5), GLONASS (G3), and BeiDou (B2) frequencies.
4. 1260 – 1300 MHz used by Galileo (E6) and BeiDou (B3) for commercial uses and an increase in the accuracy of position.

The above-listed signals are base signal bands to accommodate essential navigational signals by all presently used GNSS constellations. There is several positioning systems with worldwide coverage available to determine the ship's geographical position, and they operate within these bands. Despite this most ships are carrying only GPS or dual-system receivers.

Multi-systems receivers are still relatively rare in the maritime domain.

GPS is a well-known, established by the United States system that has been operational since the 1980s. It operates with 31 satellites in Medium Earth Orbit (MEO). For civilian purposes, the L1 band is utilised at 1575.42 MHz; the L2 and L5 bands are reserved for military use and accessible only to authorised users.

GLONASS uses a 1602 MHz frequency in the L1 band for civilian use and a 1246 MHz frequency in the L2 band for military use. Due to its FDMA (Frequency-Division Multiple Access) structure, individual satellites transmit on slightly different frequencies within the same band. The L2C signal, transmitted in the L2 band, offers improved performance for civilian applications compared with standard L1 signals.

GALILEO operates in bands E1 (1575.42 MHz), E5a (1176.45 MHz), E5b (1207.14 MHz) and E6 (1278.75 MHz). Galileo satellites transmit signals simultaneously on multiple frequencies, allowing the receiver to select the best signal. Multi-frequency signal transmission enables improved ionospheric error mitigation and enhances position accuracy and integrity. Each band includes a civilian navigation signal, whereas E1 and E6 additionally support restricted-access or commercial services.

BeiDou Navigation Satellite System (BDS) developed by China; the third-generation satellites were launched into orbit by 2020. The system provides a global range by transmitting navigational and timing information to BeiDou receivers with an accuracy of approx.10m. It uses 3 main frequencies: B1 (1561,098 MHz), B2 (1207,14 MHz) and B3 (1268,52 MHz). Civilian signals are transmitted on multiple frequencies simultaneously, facilitating the mitigation of propagation-related errors. Military signals are mainly broadcast in the B1 band, while the B2 and B3 bands support high-accuracy navigation.

Figure 1. Research vessel "Horyzont II".

The training-research vessel "Horyzont II" was built in 2000. Every year, she makes two voyages to Spitzbergen with supplies and a science crew for the Polish research station. For the other 8 months, she sails with students from the Gdynia Maritime University and some of the maritime high schools in Poland. RV "Horyzont II" has a length of 56.34 meters, a breadth of 11.36 meters and a maximum draft of 5.33 meters. Her maximum speed is 12 knots. The vessel accommodates up to 40 passengers (students/scientists). Students of the Faculty of Navigation typically complete their onboard training during their third year of studies, from February to April. Given the time of year, weather conditions vary and may include light icing, fog, stormy with a lot of precipitation. Its specific construction, based on "Polarex" plans, gives the ship unique manoeuvring properties. In Figure 1, a general overview of the RV "Horyzont II" is shown. Visible are the features of the hull, such as a high freeboard and a navigational bridge located in the forward part of the vessel. The ship is equipped with a bow thruster and a pitch propeller improving manoeuvrability.

Figure 2. Navigational Bridge of the research vessel "Horyzont II".

The navigational bridge of "Horyzont II" has been adapted to support training activities. Besides all regulatory equipment demanded by SOLAS it is equipped with additional navigational equipment available to students. In Figure 2 the general arrangement of the bridge is visible, out of the picture are four students' navigational tables. Two of them are equipped with two Furuno X-band radar displays operating in a master-slave configuration. They use an antenna separate from the two main ships' radars. This allows students to use them freely without interrupting the safety of navigation or the general work of navigating officers. At these two stations, two independent GPS receivers are also available (JRC and Furuno). The third station is equipped with a repeater of the electronic chart (ECDIS) station NaviSailor 4000. Functions that cannot be accessed in there can be used by students on the master station under the supervision of the duty officer. It is worth mentioning that the "Horyzont II" ECDIS serves as an aid to navigation, and the ship is required to carry paper charts as the primary means of navigation. The fourth workstation is dedicated to paper charts navigation and performing all other required actions, such as making corrections to paper charts and completing the necessary logbooks.

2 PRACTICES AND THIS YEAR'S (2025) CHALLENGES

Due to the limited duration and specific nature of the training programme, navigation and practical exercises were conducted exclusively in the western part of the Gulf of Gdańsk. The vessel operated within the fairways of the Gulf of Gdansk VTS or in adjacent areas while performing tasks with students. During the two weeks of practice, the vessel enters the port, proceeds underway, anchors, and performs manoeuvring exercises based on the track prepared specially for that purpose in the ECDIS system. All these operations were executed by the students under the close supervision of duty officers and the master.

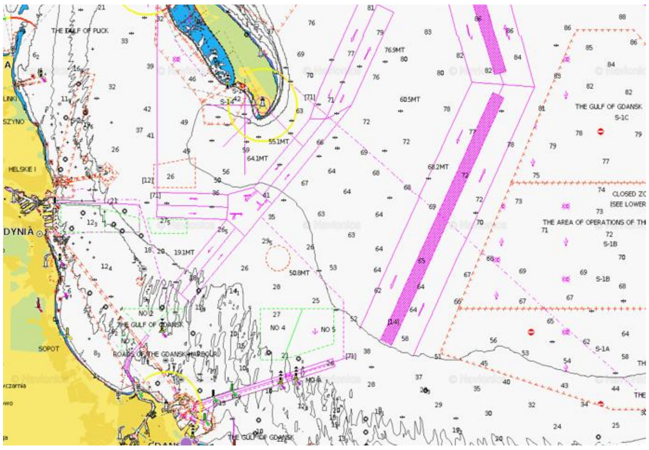

Figure 3. Fragment of navigational chart BHMW 73 with area of operating for R/V "Horyzont II".

In Figure 3, the area of operation for R/V "Horyzont II" is visible. The vessel, depending on weather conditions and the day's plan, sailed along fairways from Gdynia to the Hel Peninsula (visible in the upper part of the chart), then crossed to the traffic separation scheme of the port of Gdansk's approach and returned to the port of Gdynia or its anchorage. Most of the manoeuvring exercises, such as person overboard, were performed between the main fairways or south of Gdynia anchorage. During the two weeks of practice, increased activity of navy vessels in the area was observed. This required careful planning and execution of the exercises, as well as increased radio watch for possible communication. Over the two weeks of practice, training groups experienced GPS spoofing and jamming events, navigation in reduced visibility with and without access to GNSS-derived positions. When GPS signals were unavailable, students were instructed to rely on terrestrial navigation techniques and radar observations.

Total of 34 students were divided into three watch groups. Everyday group of 8-9 students maintained a four-hour navigational bridge watch taking shifts through the day and additional duties when they were off-duty. There were eight students on the bridge when the ship was underway, and two students when it was at anchor. Students not assigned to bridge duty could always come and observe, ask questions or learn in their off time.

The training program under my supervision, as an instructor on board the ship, was conducted from 3 to 16 March 2025. 34 third-year students from the Navigation Faculty of Gdynia Maritime University were mustered on r/v "Horyzont II". The vessel remained at sea almost every day, entering port every few days for an overnight stay. Nights spent outside port were conducted at anchor in the Gdynia anchorage area.

2.1 *GPS jamming event on 8th of March 2025 during navigation in reduced visibility*

On 8 March, the vessel departed the Gdynia anchorage at approximately 08:00, proceeding along the planned route within the Gulf of Gdańsk traffic lanes. The weather conditions on that day were fair, with light wind and visibility reduced to about 1,5 to 2,5 nautical miles at times. Traffic in the area was light, and the seas were calm. Nine assigned students, the Officer of the Watch (OOW), and the onboard instructor were present on the bridge.

Around 10.00 AM local time, the first anomalies in the GPS data were observed. At that moment, "Horyzont II" was passing "GD" (54◎32,1'N 018◎39,8'E) on port side buoy located at the junction of TSS. The attention of the instructor and OOW was drawn to a significant discrepancy between the vessel's water-referenced vector (log speed and heading) and the ground-referenced vector provided by GPS. These discrepancies were recorded and are presented in Figures 4a and 4b. As visible, the data received from the ship's log were significantly different from the data received from the GPS.

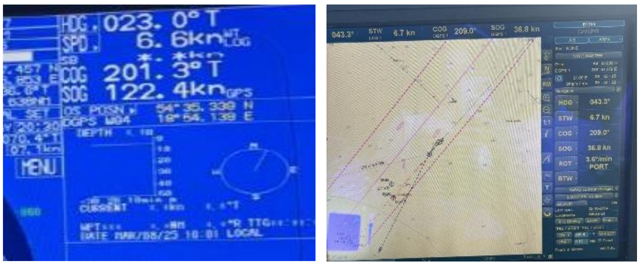

Figure 4a & b. Radar image (a) and ECDIS display (b) recorded on 8 of March 2025 during GPS signal disruption.

During this period, students were primarily focused on maintaining the planned route within the TSS using the ECDIS. They did not initially recognize the inconsistencies in the positional data until the instructor and OOW pointed them out. After informing the students that GPS receivers would be disabled temporarily, noticeable confusion emerged, accompanied by questions regarding how to proceed without GPS-derived positions.

Following several minutes of clarification and brief instructions, the situation on the bridge stabilized. Students were reminded that GPS and ECDIS are not the only navigational tools available and that alternative methods—such as visual coastal references, navigation marks, and radar observations—remain fully effective when GNSS positioning is unavailable. Once these methods were implemented, the remainder of the watch proceeded correctly, despite the GPS signal not returning to nominal values.

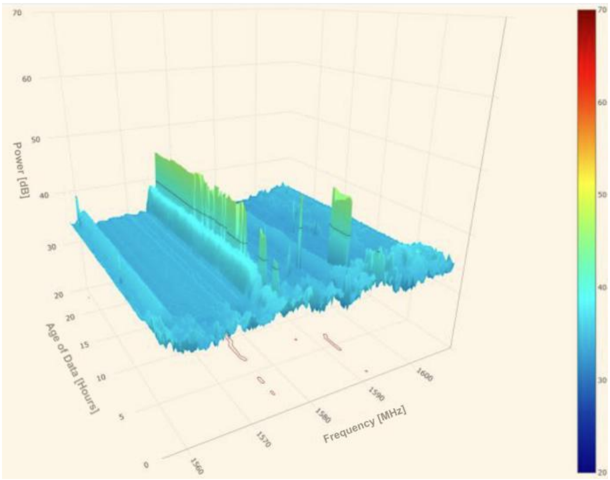

Figure 5. L1-band signal spectrum recorded on 8 March 2025. Receiver: GDYNIA (Trimble BD992), Antenna: Zephyr Geodetic 3

Figure 5 shows the L1-band signal spectrum recorded on the day of the event. The Z-axis represents signal strength, while the X and Y axes represent signal age and frequency. Standard received GPS signal levels typically range from 30 to 40 dB. The observed values significantly exceeded this range, clearly indicating the presence of intentional interference (jamming).

2.2 *GPS signal interference on 15th of March 2025*

A similar phenomenon to that observed on 8 March occurred one week later, on 15 March. Figure 6 presents the signal-to-noise ratio (SNR) for the different GNSS constellations. The colours represent the following systems: blue – GPS, black – GLONASS, red – Galileo, and green – BeiDou. Typical SNR values range between 40 and 50 dBHz. When the SNR drops below 40 dBHz, receivers begin to experience difficulties in computing a position and may eventually lose the ability to provide a fix. As shown in the figure, the interference caused a significant reduction in SNR across all satellite systems, clearly indicating broadband jamming within the L1 band rather than interference affecting a single frequency.

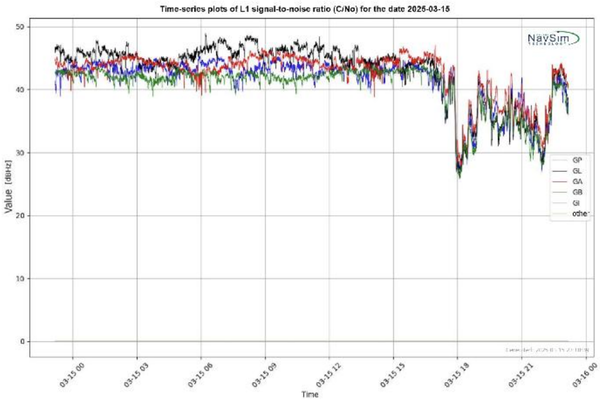

Figure 6. Signal-to-noise ratio for selected GNSS constellations on 15 March 2025. Receiver: GDYNIA (Trimble BD992), Antenna: Zephyr Geodetic 3.

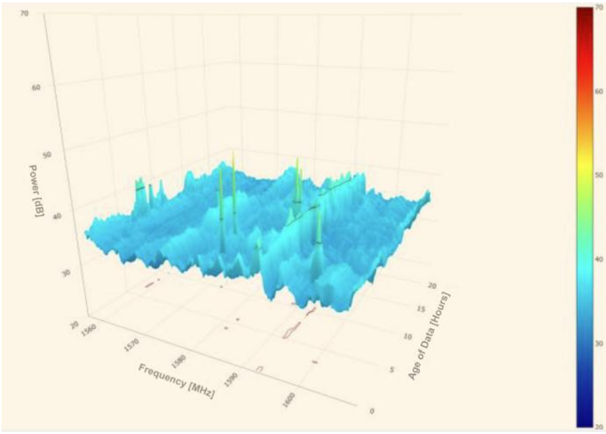

Figure 7. L1-band frequency spectrum of GNSS signals on 15 March 2025. Receiver: GDYNIA (Trimble BD992), Antenna: Zephyr Geodetic 3.

Figure 7 shows the L1-band signal spectrum recorded on the day of the event. The Z-axis represents signal strength, while the X and Y axes represent signal age and frequency. It shows very variable strength of the signal recorded on that day.

Because a different group of students was on bridge duty that day, a pattern similar to the 8 March event was observed. The students initially displayed uncertainty in interpreting the situation and determining the appropriate course of action. With guidance from the OOW and the instructor, they resumed effective navigation using radar and visual observations of navigational marks and coastal features — techniques fully independent of GPS availability.

2.3 *Position monitoring while at anchor*

The situation presented occurred on one of the mornings when the GPS receivers and the ECDIS system were properly functioning and providing stable position information.

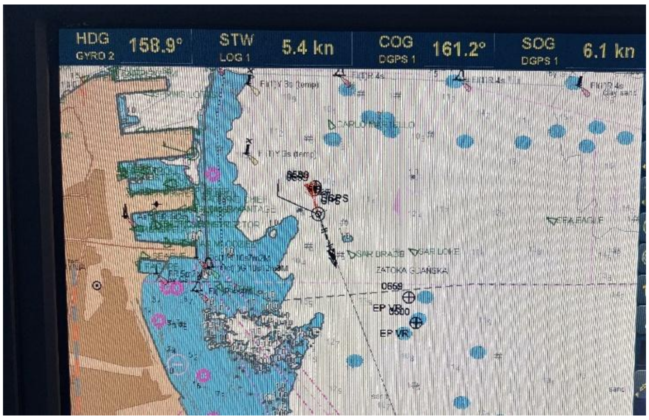

Figure 8. Positions marked by students in ECDIS while at anchor with a properly working GPS.

Figure 8 presents a comparison between positions obtained from the GPS system (upper section of the display) and those plotted by students based on radar measurements (lower section). The discrepancy between these two sets of positions was significant and exceeded the expected measurement uncertainty associated with radar fixes and manual plotting.

A post-watch analysis revealed that the students responsible for determining the radar-derived positions committed procedural errors. These errors concerned two principal aspects:

1. Incorrect transfer of radar data into the ECDIS system — in several cases, distances and bearings to radar targets were entered with rounding errors or incorrect values, resulting in a shifted plotted position.
2. Improper use of ECDIS plotting tools — instances were identified in which students incor-rectly determined the intersection point of lines of position or failed to apply the standard procedure for verifying consistency with the previous fix.

As a result, the radar-based positions deviated from the true vessel position in a systematic rather than random manner, indicating a methodological error rather than any technical limitation of the radar.

From a navigational safety perspective, such a discrepancy is significant. It may lead to incorrect assessment of the vessel's movement while at anchor — an especially critical issue in restricted visibility, where radar constitutes one of the primary sources of situational awareness.

The incident also highlighted an important training aspect. Students demonstrated a high level of reliance on ECDIS and GNSS-derived positions, whereas accurate and systematic radar plotting required greater attention and procedural discipline. This observation is consistent with trends noted in previous years, suggesting a gradual decline in proficiency in terrestrial navigation and manual position fixing within an increasingly sensor-dependent navigational environment.

In summary, the event demonstrates that even when GPS signals are fully available and ECDIS is operating correctly, procedural errors may result in substantial discrepancies in position determination. This underscores the need for continued development of manual navigational skills and a critical approach to sensor data among future watchkeeping officers.

3 CONCLUSIONS

Although electronic positioning systems have served as reliable navigational tools for many years, observations from the training cruise demonstrate that they remain vulnerable to electromagnetic interference as well as human error. The absence of a continuous and accurate position source increases the risk of navigational incidents, particularly in areas with dense traffic or during precision manoeuvring. Importantly, GNSS disruptions often occur in waters where effective radar and visual observations are fully feasible and where the ship's position can be determined accurately using terrestrial methods. Nevertheless, modern electronic systems tend to overshadow the importance of these fundamental navigational principles.

From an educational perspective, a clear tendency can be observed among students to rely primarily on electronic chart systems as their main source of situational awareness, while alternative sources—visual observation, radar, and terrestrial navigation—are frequently disregarded. Students also rely heavily on AIS for information regarding the movement of other vessels and their own motion, without cross-checking these data against sources independent of GNSS. Consequently, when their primary positioning system fails, students and future watchkeeping officers often exhibit confusion, hesitation, and delays in taking appropriate action. Limited proficiency in radar operation, paper-chart navigation, and the use of dead-reckoning modes in ECDIS further exacerbates this problem, as additional time is required to regain situational awareness. Such delays may be critical when attempting to avoid collision or grounding.

This highlights a significant challenge for educational and regulatory institutions: to train students not only in the efficient use of electronic navigational tools but also in the critical understanding of their limitations. As noted in several international studies and guidelines (e.g., IMO e-Navigation Strategy Implementation Plan, IALA VTS Manual, IHO S-66, UKHO reports on GNSS vulnerability, ICAO PBN guidance, RTCM papers on interference), contemporary navigators must maintain competence in traditional navigation techniques and be able to operate safely in environments where GNSS information is degraded or unavailable. The increasing ease of access to electronic data fosters overreliance on sensors and automation, often without adequate verification or cross-checking. Developing manual navigation skills and strengthening critical assessment of sensor-derived data should therefore remain essential components of training for future watchkeeping officers.

ACKNOWLEDGEMENTS

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