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Motion-based consistency audit of onboard Global Navigation Satellite System reference as reported by static Automatic Identification System data

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Abstract

The Automatic Identification System (AIS) is widely used for reporting vessel movements and broadcasting additional information related to the current voyage or constant parameters like the IMO number or the overall dimension of the hull. Since dynamic AIS data is shared mostly without human interaction, and is not flawless, the static AIS content edited manually is vulnerable to human error. This work introduces a simple vessel motion pattern approach that determines the probable foredeck/afterdeck location of the GNSS reference used by the AIS transponder, and compares it to the hull parameters obtained from the static AIS data, to find observable errors in the static AIS configuration of the mount point of the GNSS reference antenna.

Introduction

Current research projects of the DLR's Department of Nautical Systems, motivated by the e-navigation strategy of the International Maritime Organisation (IMO, 2008), have focused on the development of algorithms and techniques designed to provide accurate information on the usability of sensors, services and data used in maritime traffic systems. This work includes various analyses of the usability of data acquired by an Automatic Identification Systems (AIS).

Since its introduction in 2004, AIS has been considered a substantial improvement on maritime watchkeeping duties. The main purpose of the system is to assess the traffic situation in the proximity of the vessel in which the unit is mounted, or to track vessel traffic in areas for which vessel traffic services (VTS) is responsible. On-board AIS equipment helps watch officers evaluate the general intentions of other seaborne objects, and to unambiguously identify traffic objects by their names and call signs, thus avoiding confusion in conflicting situations and improving bridge-to-bridge communication.

There are two principal types of data messages broadcast by on-board AIS transponders that are relevant to assessing vessel traffic. The first is dynamic AIS data, which consists of a group of parameters obtained autonomously from devices on the bridge, including such vessel variables as latitude, longitude, speed over ground, course over ground, and true heading. Dynamic AIS messages allow vessels to share data describing their current positions and movements. The second is static AIS data, which consists of voyage-related information like destination harbour, estimated time of arrival, and maximum draught, as well as a set of internal configuration parameters which the crew cannot change. These unchangeable configuration parameters include the IMO number, the name of vessel, the vessel's call sign, and the overall dimensions of the hull.

The general quality of dynamic AIS data has been investigated in 2012 (Banyś, Noack &

Gewies, 2012; Heymann, Noack & Banyś, 2013). The results of this research showed that the parameters obtained from AIS transponders contained "unknown" values which might influence the usefulness of a dynamic AIS message in assessing vessel traffic (Banyś, Noack & Gewies, 2012). The "rate of turn" and "true heading" parameters appeared amongst the "unknown" values most frequently, followed by "course over ground," "speed over ground" and, to a lesser extent, "latitude and longitude." The results also demonstrated that having AIS data known to reflect errors was less risky than being unaware of the flaws in such data.

Another study, which analysed the reliability of navigation-relevant AIS parameters, showed that a specific AIS time series can be used to estimate the validity of traffic data shared among vessels over AIS communication channels (Heymann, Noack & Banyś, 2013). Except for manually processed "navigational status" data, dynamic AIS content is generated without human interaction and therefore is not error-free. Static AIS data, which is manually edited by watchkeeping personnel or set up by marine electronics suppliers, may also incorporate erroneous values because of unavoidable human mistakes (IEC, 2001).

Because of its inaccuracies, static AIS data describing the GNSS reference points for AIS-reported position and hull dimensions are analysed by being compared to photographs of vessels published on MarineTraffic.com. More specifically, this photographic comparison is used to determine the precise location of the superstructure and the most representative point for the on board antenna array. This basic information eliminates obvious navigational blunders based on static AIS data. In addition, a simplified vessel motion pattern, based on true heading, course over ground, and speed over ground, is used to discriminate between possible foredeck/afterdeck locations of the GNSS reference point, and to compare the estimated reference points with their AIS-generated counterparts.

Concept

The AIS data used in this analysis was acquired by the German Federal Waterway Authority (WSV) in August of 2014. It covers vessel traffic data within German territorial waters for the entire month of August. Raw AIS data, stored in NMEA-VDM (ITU-R, 2010) format including database reception timestamps, was subsequently converted into JSON format. For the purpose of this research, Class A transponders were taken into consideration. Only the dynamic AIS messages of type 1, 2 and 3, and the static type 5 AIS messages known to be free of "unknown" values, were used in the initial dataset. It is essential to be able to identify slow moving vessels making significant changes of course to describe a vessel's motion pattern. This task was facilitated by applying geospatial filters based on nautical vector charts (provided by the German Federal Hydrographic Authority, or BSH), to AIS data to extract vessel position reports within all turning areas in German harbours. A summary and overview of the turning areas used in this analysis is shown in Table 1.

Table 1. The coordinates of the turning area centroids (WGS-84)

Harbour	Centroid and radius of turning area	
Brunsbüttel	N53°54.41′ E009°10.08′	140 m
	N53°55.04′ E009°11.66′	200 m
Emden	N53°20.13′ E007°10.82′	110 m
	N53°20.63′ E007°11.29′	45 m
	N53°20.32′ E007°11.64′	150 m
	N53°20.98′ E007°11.83′	110 m
Hamburg	N53°31.31′ E009°53.48′	170 m
	N53°32.45′ E009°54.12′	240 m
	N53°32.20′ E009°54.34′	225 m
	N53°30.99′ E009°56.35′	240 m
	N53°29.96′ E009°56.58′	250 m
	N53°32.50′ E009°56.90′	160 m
	N53°32.17′ E009°57.20′	200 m
	N53°30.39′ E009°57.23′	150 m
	N53°29.03′ E009°57.66′	100 m
	N53°32.21′ E009°59.49′	175 m
	N53°32.23′ E010°00.03′	130 m
Lübeck	N53°53.99′ E010°42.05′	120 m
	N53°54.31′ E010°45.89′	100 m
Oldenburg	N53°08.59′ E008°15.11′	50 m
Rostock	N54°06.93′ E012°05.42′	130 m
	N54°09.55′ E012°06.26′	240 m
	N54°09.62′ E012°07.60′	175 m
Travemünde	N53°57.09′ E010°51.67′	170 m
Warnemünde	N54°10.38′ E012°05.76′	130 m
Wismar	N53°54.09′ E011°27.17′	140 m

Geospatial filtering produced a list of vessels inside any of the turning areas, as well as a collection of tracks containing the time series of AIS position reports for such vessels. During the final stage of the AIS data selection process, a great many photographs (queried from MarineTraffic.com by MMSI) depicting the selected vessels from different angles were subjected to careful visual examination. This examination allowed the identification of such basic features as the vessel type, length class, the relative location of the superstructure, and the location of the battery of on-board antennas. In this analysis, only cargo vessels and passenger vessels of a length of at least 50 meters were studied. This analysis was assisted by official hull data queried from the Lloyd's List Intelligence database (Lloyd's List Intelligence, (2015)). It was assumed that the GNSS reference antenna used by the AIS transponder was mounted together with other aerials above the bridge deck. It is important to emphasise that visual assessment could not with absolute confidence guarantee the location of GNSS reference points. Accordingly, it was used only as the best available approximation during the research. Clearly, the best possible information would be generated by actually surveying positions on board each vessel, but this degree of detail was not possible during this research and should be incorporated into future research.

In order to standardise the relative locations of the superstructure and the antennas, the classification scheme illustrated in Figure 1 was applied.

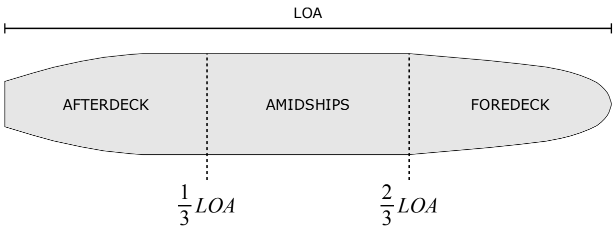


Figure 1. Scheme for locating relative positions of foredeck and afterdeck, relative to the overall length, that was used for analysis

In order to determine whether the mounting point of the GNSS reference antenna closer to the foredeck or the afterdeck, the movement characteristics of vessels manoeuvring within turning areas was analysed from the perspective of relationship between the lateral component of the velocity vector and the yaw direction (V_X in Figures 2 and 3). First, the angular yaw velocity was calculated from two consecutive dynamic AIS reports of true heading to determine whether the vessel was turning to port or to starboard. All vessel trackpoints with the same value for true heading were eliminated from the motion pattern. Vessels were also excluded from analysis whenever the aggregate of all true headings was less than 360 degrees. Preliminary analysis showed that vessels had to make at least one full turn in order to produce a score large enough to discriminate between a foredeck or afterdeck location for the GNSS reference point, and to make detected GNSS settings more distinguishable. Next, the velocity vector was projected onto the longitudinal axis and the lateral axis of the hull. This velocity vector was estimated from the "course over ground" and "speed over ground" variables, both computed from dynamic AIS data. This knowledge helped determine lateral velocity, and whether the vessel was proceeding ahead or astern, although the translation direction and its corresponding longitudinal velocity turned out to have no influence on the assessment of the motion pattern.

Despite the undeniable fact that the movement of a rigid body immersed in a fluid is a complex phenomenon that can only be simulated with the aid of sophisticated models and higher mathematics (cf. MARSIM, 1996), it was possible to define a simplified motion pattern composed of coarse data provided by dynamic AIS messages. Figure 2 shows the basic velocity vector configuration for a vessel moving ahead and steadily changing heading to port or starboard relative to the location of the GNSS reference point.

Figure 3 shows the alignment of velocity vectors for a vessel moving astern and steadily changing heading to port or starboard. In this case as well, it is necessary to know the relative on-board position of the GNSS reference.

Table 2 summarises the lateral vector magnitudes and the hull turns, as well as the way they were interpreted to determine vessel motion pattern.

Table 2. The properties of lateral velocity and changes of true heading used in the evaluation of the motion pattern

Lateral velocity	Steady turn	Probable location of the GNSS reference
positive negative	to port to starboard	afterdeck
negative positive	to port to starboard	foredeck

Every track point of a selected vessel was evaluated against the conditions listed in Table 2. Depending on the results of that comparison, a rating was generated favouring either a foredeck or afterdeck location for the GNSS reference. If the number of points in suggesting a foredeck location was at least twice as high the number of points in suggesting an afterdeck location, the GNSS reference was assumed to be located on the foredeck. The inverse of this procedure was used to assign the location of the GNSS reference antenna to the afterdeck. A pre-analysis of the entire AIS dataset indicated that requiring a rating ratio of two and a cumulative heading change of at least 360 degrees would be sufficient to properly distinguish between a foredeck and an afterdeck location for the GNSS reference. It is important to note that a clear distinction for an amidships location of the GNSS reference is not possible with the methods employed here.

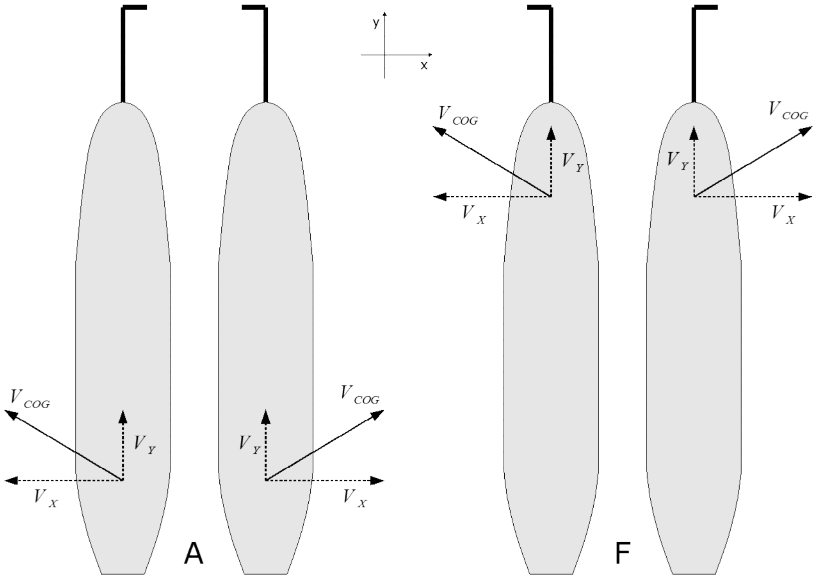


Figure 2. Longitudinal velocity V_Y and lateral velocity V_X during translation ahead and steady turn with GNSS reference on afterdeck (A) and foredeck (F)

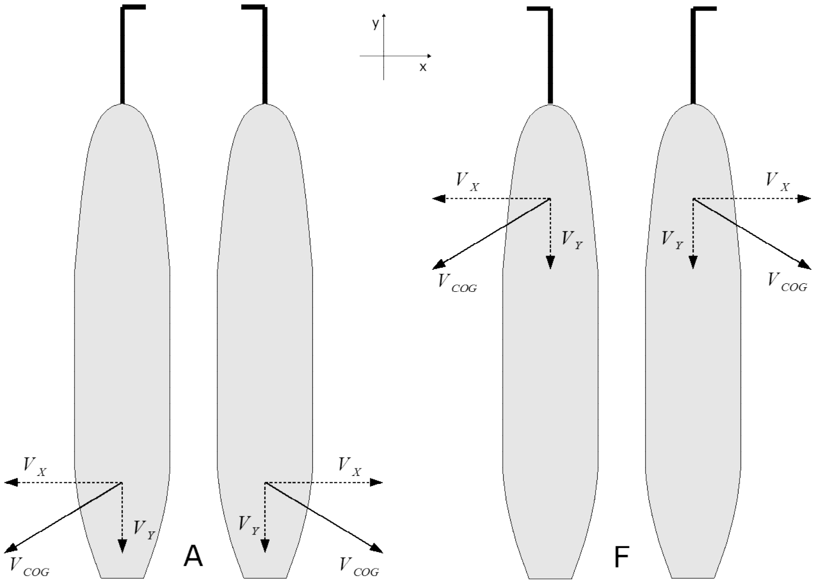


Figure 3. Longitudinal velocity V_Y and lateral velocity V_X during translation astern and steady turn with GNSS reference on afterdeck (A) and foredeck (F)

Visual analysis

Geospatial filtering of the dynamic AIS position reports of vessels manoeuvring within any of the 26 turning areas in August of 2014 resulted in the creation of a list of 1,616 maritime mobile service identities. Following visual examination of appropriate photographs and the Lloyd's database query, a final collection of 1,200 vessels was selected for further analysis. There were 1,036 vessels with the superstructure and the antennas located on the afterdeck, 69 vessels with an amidships location, and aboard 95 vessels for which the superstructure and radiocommunication structures were on the foredeck. The raw data for these summary numbers is shown in Figure 4.

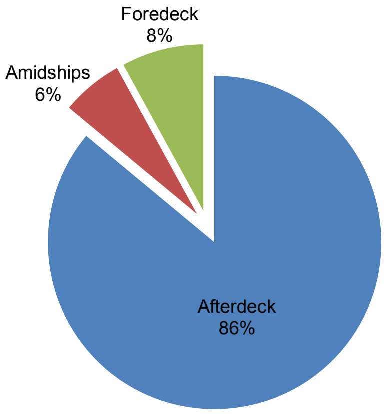


Figure 4. The percentage of probable onboard location of the GNSS reference antennae among the vessels selected for this study, based on visual assessment

Figure 5. Illustrative photographs of vessels used for visual assessment, with the superstructure and the antennas on foredeck (left), amidships (middle), and afterdeck (right) [source: MarineTraffic.com]

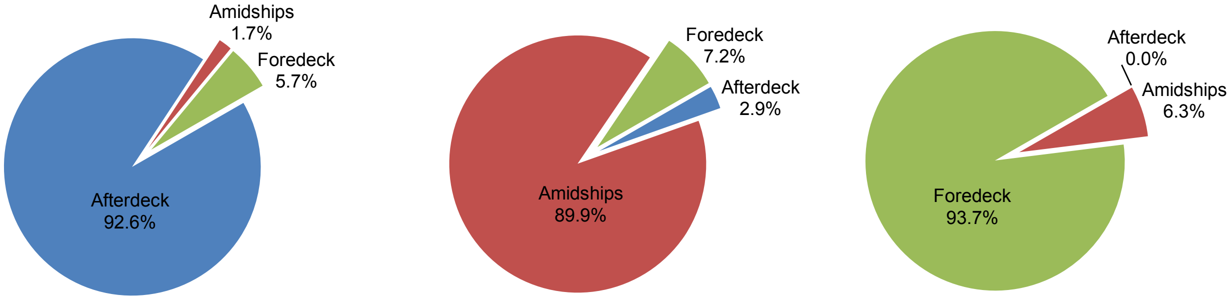


Figure 6. The percentage of the locations of the GNSS reference points as inferred from static AIS data on board vessels with their antennas installed on afterdeck (left), amidships (middle) and foredeck (right)

The overview of the AIS-reported locations of the GNSS reference on board vessels, which had their antennas mounted on afterdeck, amidships or foredeck, is shown in Figure 6.

A majority of vessels (92.6%) in the afterdeck category reported the location of their GNSS reference correctly. A total of 7.4% of vessels broadcast their static AIS data with an abnormal configuration of the GNSS reference. In 1.7% of such cases, location was reported as amidships, while 5.7% of such cases reported a foredeck location. For the amidships classification, most (89.9%) vessels reported the correct GNSS reference data over the AIS communication channel. Finally, for the foredeck group, most (93.7%) vessels reported the true location of their GNSS reference. There were no static AIS transmissions indicating an afterdeck location for the GNSS reference, while 6.3% of vessels described reported an amidships location.

Motion pattern analysis

A total of 131 vessels emerged from the analysis of the motion patterns of the preselected 1200 vessels. This means that 89% of the preselected vessels were not disqualified because rating ratio was less than 2 or because the cumulative heading change was less than 360°. One of the reasons for excluding such a high proportion of candidate vessels was limiting the temporal period of coverage only to the month of August. Such a brief study made it impossible to gather enough data from vessels calling at German harbours at intervals longer than one month.

Of the 131 vessels (11% of the input set), 97 (74%) were estimated to have the GNSS reference located on the afterdeck, and 34 (26%) were determined to have it on the foredeck. Visual assessment of the photographs corroborated these ratios. The AIS-reported location of the GNSS reference was then examined among the 97 vessels with appropriate data. The results of this examination are shown in Figure 7.

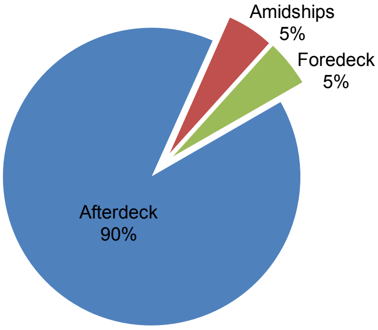
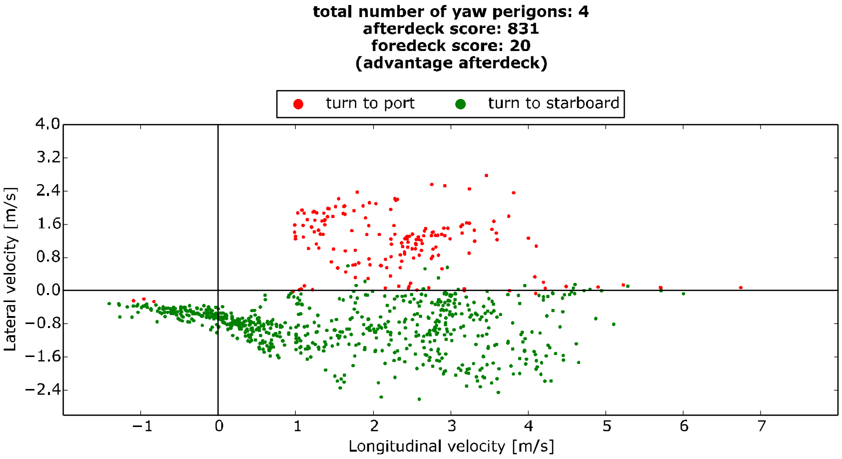


Figure 7. The percentage of the locations of the GNSS reference as reported by static AIS data on board vessels exhibiting the "afterdeck" motion pattern

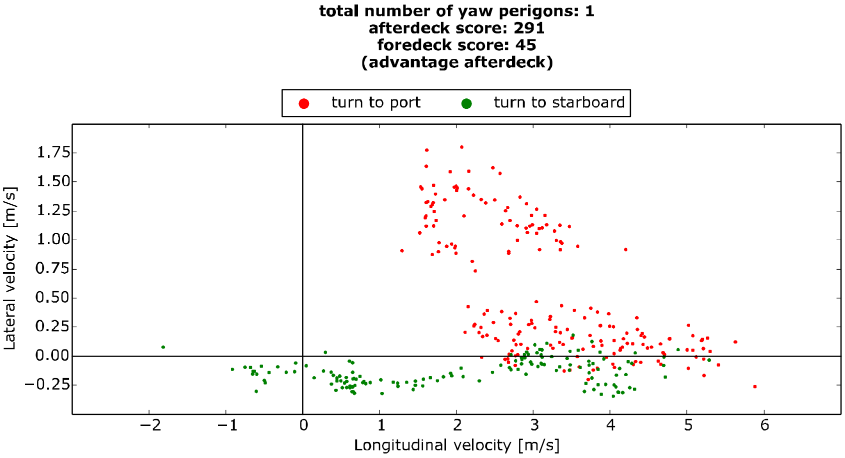
One tenth of the vessels, with their antennas positioned on afterdeck, reported an erroneous mounting point for the GNSS reference: 5% of such vessels reported the reference to be amidships, while the other 5% reported a foredeck location. The remaining vessels (90%) reported their hull configuration accurately in AIS transponder broadcasts. An example of a vessel sharing reporting accurate hull configuration data over the AIS communication channel is given in Figure 8.



AIS-reported length overall: 140 m
AIS-reported GNSS reference located 10 m from stern and 130 m from bow (afterdeck)

[MarineTraffic.com]

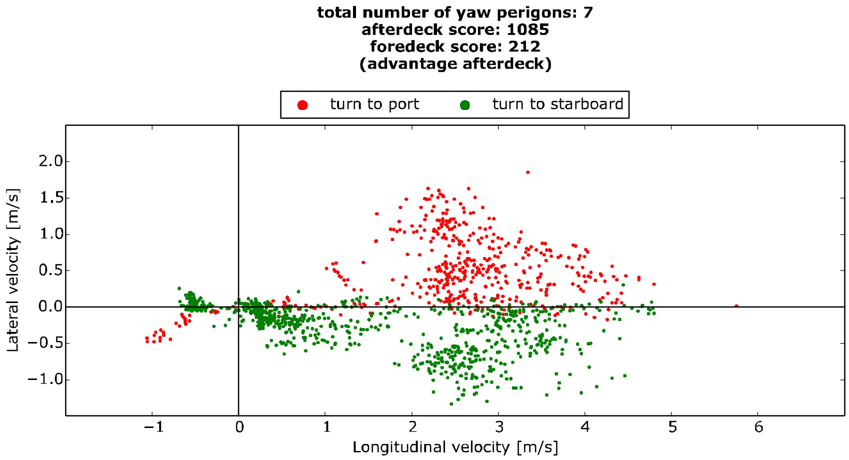
Figure 8. An example of a vessel with static AIS data pointing to the correct afterdeck location of the GNSS reference



AIS-reported length overall: 100 m
AIS-reported GNSS reference located 50 m from stern and 50 m from bow (amidships)

[MarineTraffic.com]

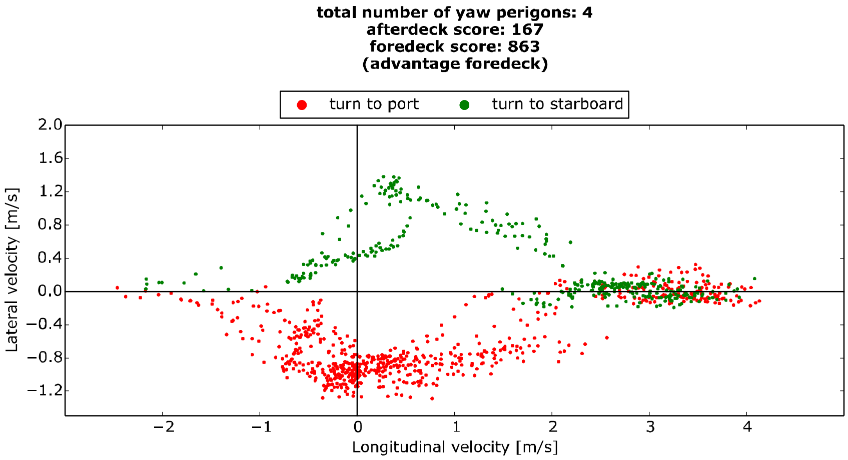
Figure 9. Example of a vessel with erroneous static AIS data indicating a GNSS location amidships



AIS-reported length overall: 139 m
AIS-reported GNSS reference located 127 m from stern and 12 m from bow (foredeck)

[MarineTraffic.com]

Figure 10. Example of a vessel with the incorrect static AIS data indicating a foredeck location of the GNSS reference



AIS-reported length overall: 187 m
AIS-reported GNSS reference located 167 m from stern and 20 m from bow (foredeck)

[MarineTraffic.com]

Figure 11. Example of a vessel with correct static AIS data pointing to the foredeck as the location of the GNSS reference

The top of the figure shows the basic parameters describing the motion pattern assessment of a vessel. The total number of full turns made by the vessel under investigation is given, as well as the number of points awarded by the motion pattern conditionals favouring a foredeck or afterdeck location for the GNSS reference. The verdict of the motion pattern evaluation, based on the score, is also given as well as a plot, of the vessel velocities and a colour-coded indication of the steady change of heading – red for port and green for starboard. Finally, the location of the GNSS reference aboard the vessel is given as it was determined from the static AIS data communication channel, A photograph providing an overview of hull characteristics is also provided.

Examples of vessels broadcasting erroneous static AIS data regarding the GNSS reference are shown in Figures 9 and 10.

Of the 34 vessels whose motion pattern indicated a foredeck GNSS mounting point, no AIS transponder broadcast abnormal static AIS data describing the position of the reference antenna. The example of one of those vessels is illustrated in Figure 11.

Conclusions

The analysis based on visual examination of photographs of vessels compared to static AIS data showed that in the majority (92.6%) of cases, the vessels whose reference antennas were located on the afterdeck broadcasted a correct GNSS reference in their static AIS data. The remaining 7.4% of AIS transponders had an erroneous GNSS reference configuration pointing either to a amidships or foredeck mounting point. Almost 90% of the vessels with a midship location of GNSS reference antennae reported the correct location through the static AIS data communication channel. The other 10% incorrectly indicated their GNSS reference was located wither on the afterdeck or the foredeck. For vessels with all antennae on the foredeck, 93.7% of AIS transponders provided the correct parameters of the GNSS reference location. No vessel happened to be reporting an afterdeck mounting point of the GNSS reference, and in the remaining 6.3% of cases, AIS transponders transmitted the location of the GNSS reference to be amidships. The overall impression of the quality of the static AIS data describing the hull configuration, following the visual assessment of the GNSS reference locations on board investigated vessels, is that the internal setup of the AIS transponders can be expected to contain errors, some of which are substantial. Human error is considered to be the primary cause of the observed configuration errors. One of the probable mistakes made during the configuration of an AIS transponder might have entailed confusing the distance from antenna to bow with the distance from antenna to stern.

Assessment of the GNSS reference location based on motion pattern indicated that the method is capable of correctly determining the GNSS reference point and categorising it as either a foredeck or afterdeck location. However, the motion-based approach, in the form used in this study, cannot be used to explicitly detect the GNSS reference amidships because of the ambiguity of vessel movement characteristics as described by velocity vectors. It should be clearly emphasised that the only purpose of the motion pattern method presented here was to detect configuration mistakes made during the configuration of the GNSS reference of on board AIS transponders. The motion pattern approach must not be used to replace the sophisticated models used to model the vessel and fluid dynamics. It is also important to emphasise that the AIS dataset used during this analysis had a temporal span of only one month. Therefore, even the 28,723 available AIS position reports from vessels in turning areas may have been inadequate to categorically determine a total usefulness and error rate for the motion pattern technique. Therefore, a larger volume of static AIS data may be recommended for future applications of the motion pattern method. Nonetheless, it is worth mentioning that the simplicity of the motion pattern approach is certainly a substantial advantage, one which much promise for further development and testing.

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