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COMPARISON OF AIS-BASED PREDICTION OF THE DISTANCE AT THE CPA WITH FACTUAL SEPARATION BETWEEN VESSELS

ABSTRACT

Since its deployment in 2004, the Automatic Identification System (AIS) has been considered a significant improvement of watchkeeping duties at sea. According to current regulations, AIS has not been recognised as an approved anticollision instrument yet. However, it would be difficult to rule out a possibility that AIS, being an essential part of the onboard SOLAS — compliant configuration, is unaidedly used for collision avoidance tasks. Recent research activities of DLR's Department of Nautical Systems have shown that AIS transmissions may contain a lot of incomplete data and the system does not have any dependable information on its data integrity. For that reason, the computation of the closest point of approach (CPA) and the time to the CPA (TCPA) are analysed based on AIS data involving multiple vessels, in order to compare the predictions with factual approaches between vessels and to evaluate the usability of AIS data, in its present form, for the appraisal of the traffic situation around each vessel.

Keywords:
AIS, anticollision, Colreg.

INTRODUCTION

Current research activities of DLR's Department of Nautical Systems concentrate on the development of algorithms and techniques, which are able to provide integrity information describing the current usability of sensors, services and data used in the maritime traffic system. This includes various analyses on the usability of data acquired from the Automatic Identification System (AIS).

Since its deployment in 2004, AIS has been considered a significant improvement of watchkeeping duties at sea. Its main purpose is the assessment of traffic situation in the proximity of own vessel or in the area of responsibility covered by VTS surveillance. Among the main advantages of having AIS equipment on board is the seafarer's ability to evaluate the general intentions of other seaborne objects equipped with AIS, and to identify such traffic participants by their names or call signs in order to avoid confusion in case of establishing a VHF voice communication in conflict situations.

Due to an ongoing computerisation of the bridge equipment and onboard procedures, the crews tend to utilise digital technology in order to ease their everyday work. Therefore it would be difficult to rule out a possibility that AIS, being an essential part of the onboard SOLAS — compliant configuration, is unaidedly used for collision avoidance tasks. At present, the International Regulations for Preventing Collisions at Sea (Colregs) have not mentioned AIS as an approved anticollision instrument yet. However, the Rule 5 of the Colregs states that 'every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision' [IMO, 2003].

Taking that into consideration and the e-Navigation strategy of the International Maritime Organization (IMO), which is devoted to 'the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment' [IMO, 2008], authorising the use of AIS as part of 'all available means' supporting the collision avoidance maneuvers might become a reality in foreseeable future. For that reason, the computation of the closest point of approach (CPA) and the time to the CPA (TCPA) are analysed based on AIS data involving multiple vessels, in order to compare the predictions with factual approaches between vessels and to evaluate the usability of AIS data for the appraisal of the traffic situation around each vessel.

CONCEPT

The AIS data used in the analysis was acquired in September 2011. It covers the vessel traffic in a particular area of the Strait of Fehmarn-Belt. The waterway between the Danish island of Lolland and the German island of Fehmarn and is an important part of the shipping route connecting the Baltic Sea with the rest of the world. Vessels of all types are engaged in many kinds of encounters, including overtaking, head-on and crossing, the latter one mostly related to dense ferry traffic between both islands. The area vertices are listed in the table 1. All AIS data was provided by the German Federal Waterway Authority as a query from the Helsinki Commission (HELCOM) AIS database server.

Table 1. The coordinates of points defining the analysed area (WGS-84)

Point	**Longitude** [°]	**Latitude** [°]
1	11.34562	54.65007
2	11.64479	54.51809
3	11.58534	54.43906
4	11.23134	54.50728
5	11.01763	54.59092
6	11.05821	54.71682
CENTROID	11.31128	54.57263

The AIS data obtained from HELCOM was in raw VDM format. A plaintext timestamp originating from the database, indicating the moment of data reception at one of the HELCOM AIS base stations, was attached to each VDM sentence. The whole AIS dataset, including the timestamps, was converted into JSON format for ease of processing. Then the dynamic AIS messages of type 1, 2 and 3, totalling 99970704 records, were extracted from the data collection. All data records, in which any of latitude, longitude, speed over ground or course over ground contained the value of ‘unknown’, were discarded, because they would be useless during the calculation of CPA and TCPA. The incomplete data detected during the check process amounted to 675601 AIS messages, which made up about 0.6% of all preprocessed dynamic AIS messages.

After the preliminary preparation of AIS data, all WGS-84 ellipsoidal coordinates of the vessels were transformed into the transverse Mercator projection, in order to simplify the calculations of distance and bearing by using a local Cartesian coordinate system. The latitude of origin and central meridian of the projection were set to the location of the research area centroid, to minimise the distortion. Then, the positions of vessels were filtered geographically. Only the vessels located inside the area of interest defined by the blue-dotted polygon shown in figure 1 were selected for further analysis. As it was technically impossible to acquire the AIS data from all vessels in the area at the same instant, it was necessary to create a series of time windows of 180 seconds, thus allowing the AIS dynamic position reports within an epoch to be no older than 3 minutes. The choice of that period was based on the update rates used by the AIS transponders [ITU, 2010]. Within every three-minute collection of vessel positions, a snapshot of the traffic data, not older than ten seconds starting at the latest timestamp of the three-minute time window being processed, was extracted.

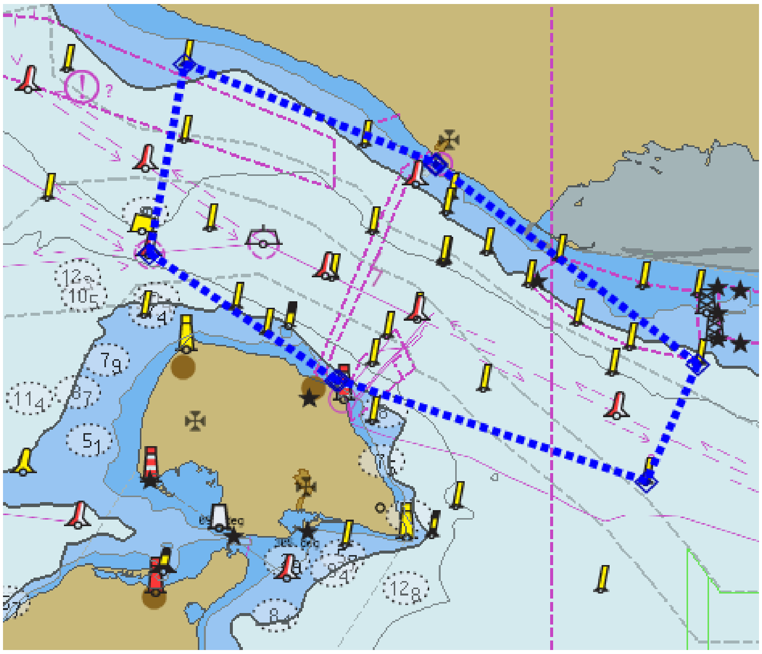

Fig. 1. The analysed area in the Strait of Fehmarn-Belt

It was then possible to plot a quite consistent set of dynamic positions of vessels inside the research area at any given timestamp obtained from the AIS data-set. This could be referred to as a momentary traffic situation. In order to assess all the closest points of approach between the vessels within a single traffic situation snapshot, a set of pairs of vessels had to be generated. It was important to avoid evaluating all 2-combinations of a whole set of vessel positions, because not every pair of traffic participants was relevant in terms of their proximity and kind of encounter. Therefore a Delaunay triangulation was chosen as a fast method of linking the vessel positions with one another. It created triangular proximity zones around every vessel within a given traffic situation, as it is shown in figure 2.

Every edge of a triangle, which was not longer than 6 NM, defined a pair of vessels in a close proximity from each other. Their CPA and TCPA were then computed and stored in a time series together with their positions reported by AIS within their temporary traffic situation. The time series, containing all those snapshots of traffic, was a foundation for further analysis, because it allowed a comparison of predicted values of the CPA and the TCPA, as they changed over time, with the factual approaches that occurred between two vessels and were clearly spotted within their AIS data.

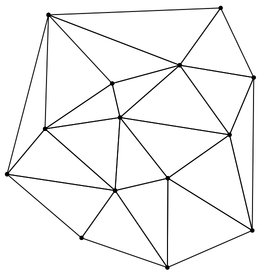

Fig. 2. An example of the Delaunay triangulation applied to a set of 14 vessel positions

ANALYSIS

The examination of vessel traffic, which had traversed the research area during September 2011, produced a list of 8658 encounters between different pairs of vessels. There were 457 overtaking maneuvers, 3180 crossings and 5021 head-on situations. Their percentage is shown in figure 3.

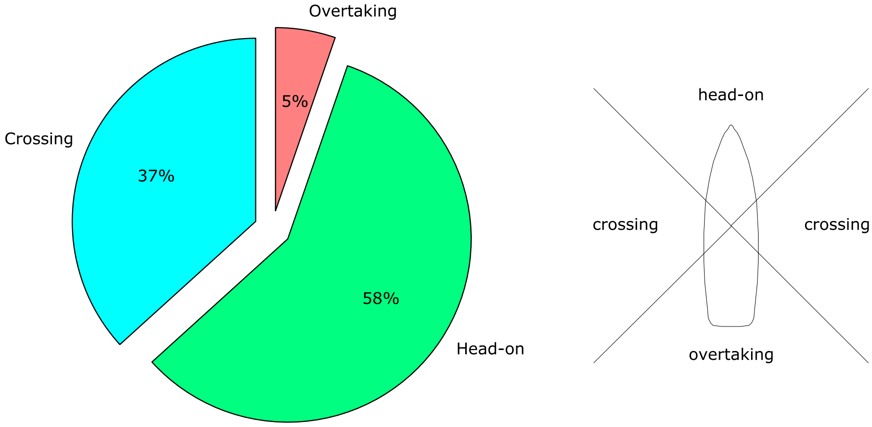

Fig. 3. The percentage of encounters between vessels in the area of research and the predefined relative approach sectors of a vessel

The factual distances between two vessels at the moment of their closest approach ranged from zero to six nautical miles. According to the Lloyd's List Intelligence, there were no reports of either collision or allision in the Strait of Fehmarn-Belt during September 2011 [Lloyd's, 2014]. The situations involving two watercraft being brought into contact with each other occurred only in case of vessels engaged in special operations, during which wide berth was not required.

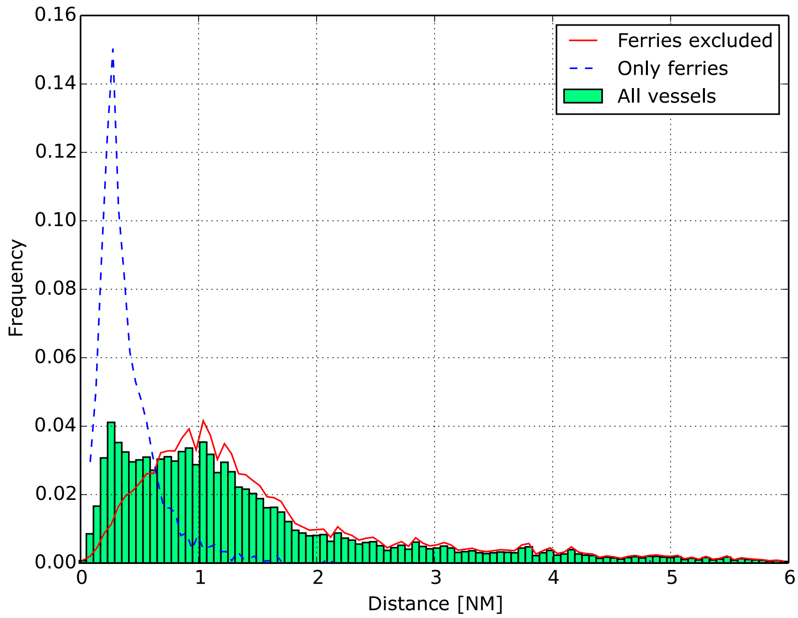

Fig. 4. The histogram of distances between vessels at their closest point of approach

The overview of all measured distances between pairs of vessels at their closest point of approach together with their frequency of occurrence is presented in figure 4. The bar plot has two distinct peaks. The one around the abscissa of 1 NM is related to the situation of two vessels underway on roughly parallel courses, which falls into either 'head-on' or 'overtaking' category. The distance of 1 NM is correlated with the breadth and shape of the recommended route centreline marking the safe water channel in the Strait of Fehmarn-Belt. The other peak observed at about 0.3 NM might have at first falsely suggested a seafarer's disregard to the observance of good seamanship, especially in such a dense traffic area. However, a closer check of the types of vessels, based on their MMSI, revealed that the motor ferries en route between Denmark and Germany contributed in majority of cases to the crossing situations at the distance of 3 cables abeam. Such behaviour, however risky it might seem, could be explained by an everyday routine of crews, familiar with one another, recognising the vessels and relying on their well-established schedules of the Denmark — Germany ferry routes.

For each of all 8658 encounters detected within the analysed AIS data, a set of four plots was generated. It showed the tracks of two vessels from the moment they were in 6 NM range from each other until the point of their closest approach was reached. The chart also presented the changes of the predicted values of the CPA distance and the TCPA plotted over time. Additionally, a histogram of differences between the factual distance and the predicted distance at the closest point of approach was provided. Red bars indicate situations, in which a predicted distance at the CPA is longer than the factual one. This might result in a too optimistic interpretation of the upcoming encounter with other vessel. Green bars, on the other hand, refer to a pessimistic variant of having a prediction of shorter distance at the CPA than it really occurred. In such case, taking appropriate countermeasures would be encouraged by the AIS — based prediction in order to increase the desired CPA distance between two vessels. The red lines on the plots serve as a visual reference of either the distance at the closest point of approach (upper left and upper right) or the time to the CPA reaching a value of zero (lower left), at which the closest approach occurs.

The example situation presented in figure 5 involved a general cargo vessel of length overall 152 meters overtaking a general cargo vessel of length overall 79 meters, both westbound. The plot of the predicted CPA distance shows at first a clear indication of a close encounter. Then a significant change occurs about 28 minutes prior to the approach due to an alteration of course over ground and the predicted distance at the closest point of approach increases to a level above 1 NM. About 15 minutes before reaching the CPA, one of the vessels adjusted her course over ground again and the plotted predicted distance drops again to finally stabilise at around 1 NM. The slight deviations of the predicted distance on the plot were caused by the yaw. The factual minimal distance between both vessels, as reported by AIS, was 0.98 NM abeam. The histogram shows that the prevailing differences between real and predicted distance at the CPA were negative, which might give a proper incentive to the officers of the watch to improve the safety of that maneuver.

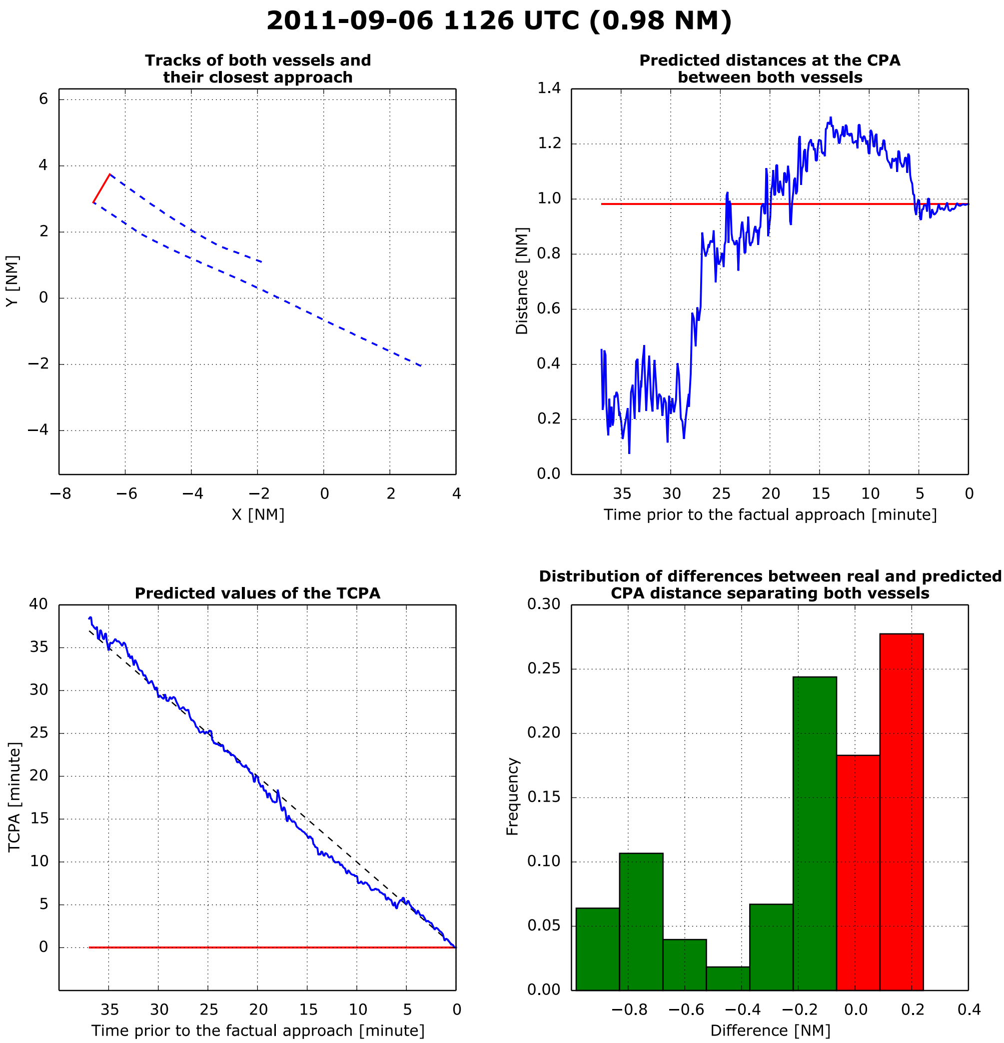

Fig. 5. The charts illustrating one of the overtaking maneuvers observed in the area of research

The example case shown in figure 6 took in a westbound general cargo vessel of length overall 59 meters ahead of an eastbound container vessel of length overall 179 meters. The location of the point of their closest approach stayed close to a safe water mark, at which two major lanes came together. During the early 7 minutes after the two vessels had entered their proximity zone, the predicted value of the CPA distance oscillated between 0.4 NM and 0.5 NM. Assuming the safety margin of 1 NM, which is the dominant passing distance between vessels in the area of research, the initial value of the CPA distance might trigger an alarm on board of both vessels. About 4 minutes prior to the predicted close encounter, the container vessel altered her course over ground to starboard and increased the expected value of the CPA distance. Finally, both vessels passed each other at 0.97 NM abeam, according to their AIS data. The histogram of that situation produced negative differences between real and anticipated CPA distance between both vessels, requiring the seafarers' prompt attention, so the level of anticollision safety was not dangerously overrated.

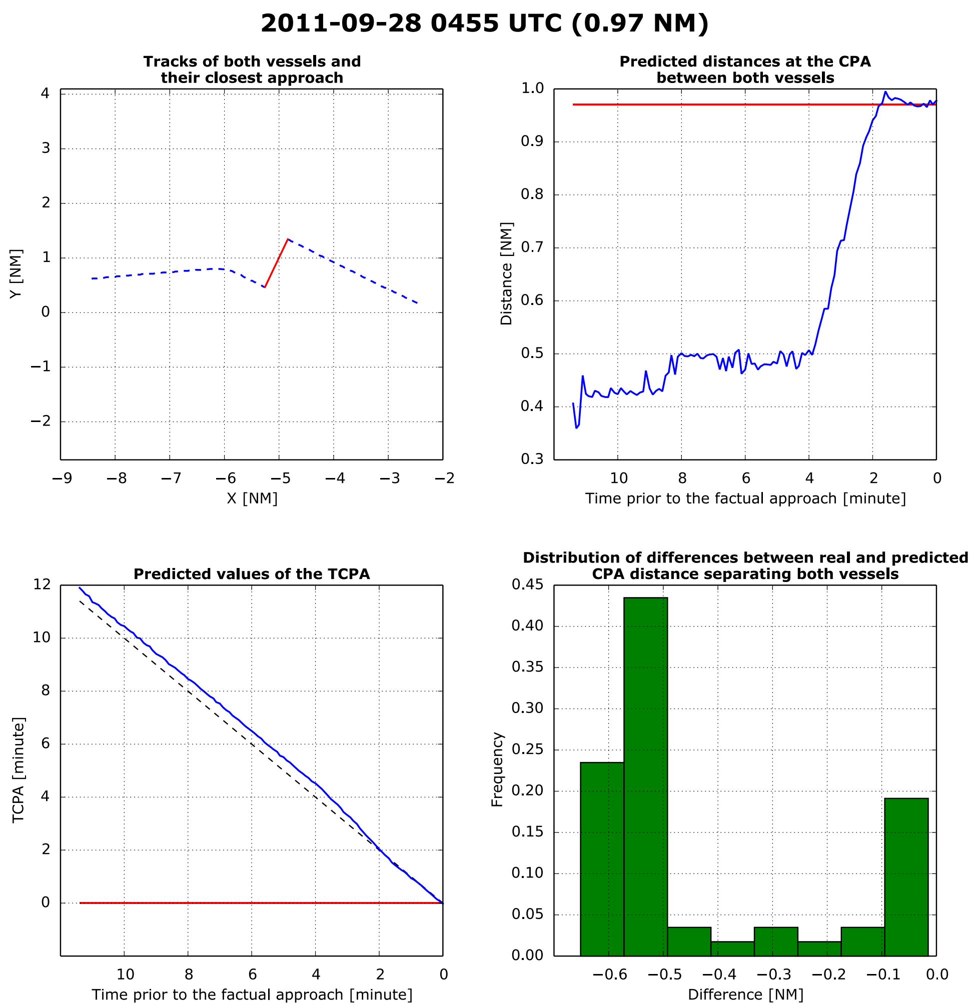

Fig. 6. The charts illustrating one of the head-on situations observed in the area of research

The example situation depicted in figure 7 involved a northbound motor ferry of length overall 142 meters and a westbound general cargo vessel of length overall 143 meters crossing each other. During the initial 2 minutes after entering their proximity zone, the ferry was altering her course over ground and thus decreasing the predicted value of their CPA distance from 2 NM to about 1 NM. The forecast distance was then sustained at that level, until both vessels reached the positions of their closest encounter. The factual value of their CPA separation, according to AIS data, was 1.03 NM. The histogram shows a dominant difference between real and forecast CPA distance set close to zero, which may indicate a good quality of the CPA distance estimate throughout that crossing maneuver.

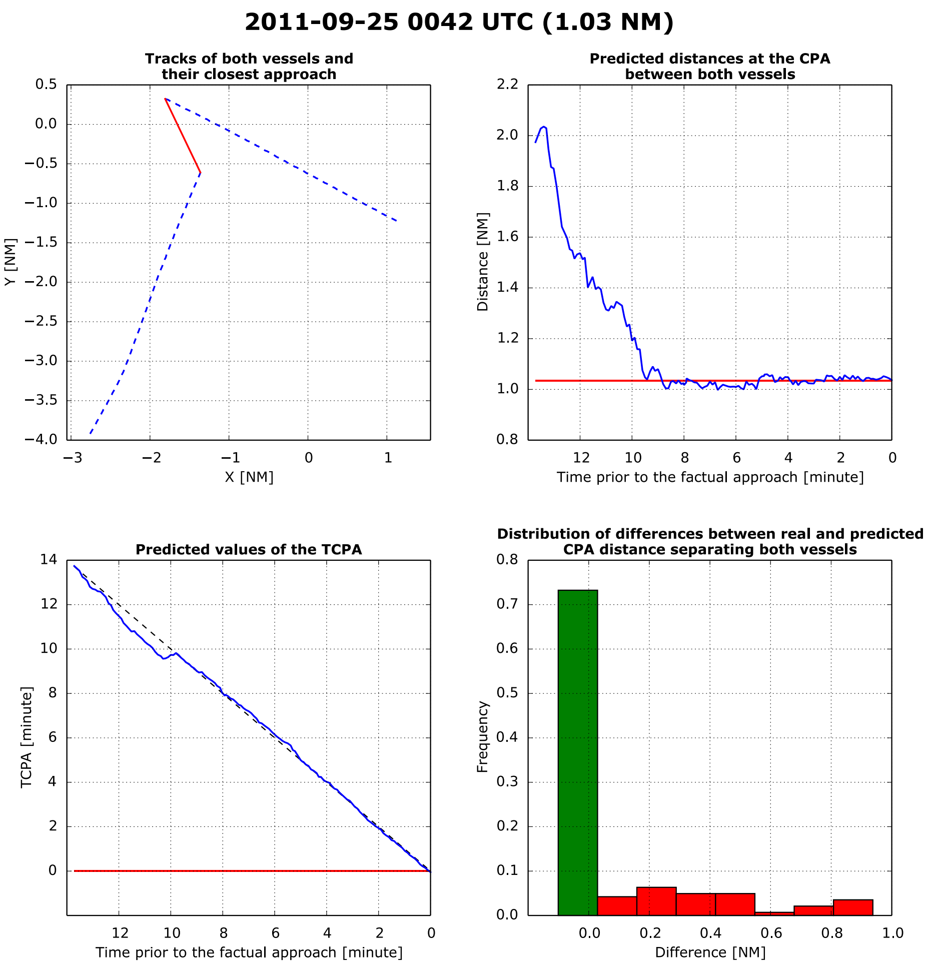

Fig. 7. The charts illustrating one of the crossings observed in the area of research

The histogram presented on every encounter chart covers all the differences between the factual and the predicted CPA distances gathered over the whole period, during which two vessels stayed in the same proximity zone. However, a look at the anticipated CPA distances plotted over time may suggest that the projected CPA distance stabilises close to the value of factual separation at various moments prior to the encounter. In figure 5 the predicted CPA distance stabilises 5 minutes before one of the vessels is overtaken, in figure 6 it occurs 2 minutes prior to the CPA, and in figure 7 the CPA prediction becomes fixed 8 minutes before the end of the crossing. Therefore it is important to examine how early a CPA prediction stays fixed close to the factual distance measured at the moment of the closest approach between two vessels.

The quality of the AIS-based prediction of the distance between two vessels at their closest point of approach is shown in figure 8. It can be observed that the plots related to various safety margins all descend relatively smoothly until they reach the abscissa of about 20 minutes prior to the encounter. Farther beyond that point the curves are characterised by a lot of variations. If a seafarer, having assessed the traffic situation and the conditions of visibility, requires their CPA predictions to remain within, say, 0.5 NM from the true minimal distance both vessels are going to reach shortly, they could expect that 20 minutes before the encounter 70% of the AIS-based predictions of the CPA distance would not deviate more than 0.5 NM from the factual CPA distance, and 10 minutes prior to the closest approach 90% of the predictions would meet that requirement, too. However, if safety precautions are more relaxed, as in case of open ocean navigation with a lot of room for maneuver and few vessels in proximity, picking a higher acceptable difference between the CPA prediction and the factual separation distance, for example 1 NM, could produce more than 80% of satisfactory predictions even 30 minutes before reaching the closest point of approach.

The examination of the AIS-based timestamp prediction of the closest point of approach is shown in figure 9. It can be observed, similarly to figure 8, that the plots corresponding to different safety margins all drop relatively smoothly until they reach the moment of about 20 minutes prior to the encounter. After that abscissa the curves are characterised by a lot of fluctuations. If an officer of the watch requires the calculation of the time to the closest point of approach to vary no more than, say, 1 minute from the factual CPA instant, they can expect that 20 minutes before the final approach about 30% of the timestamp predictions will meet that safety requirement, and 10 minutes later their share will rise to almost 80%. If the slopes of the curves during the final 20 minutes before the encounter are compared between the distance safety chart and the time safety one, it can be noticed that the curves plotted in figure 9 are equally steep, while the gradient of the lines in figure 8 changes significantly at different safety levels.

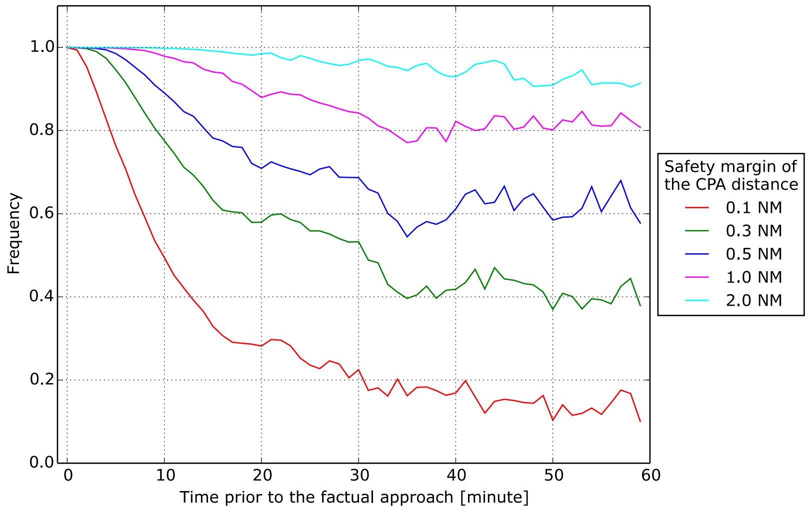

Fig. 8. The percentage of the CPA distance predictions deviating from the factual CPA distance no farther than the specified safety margin

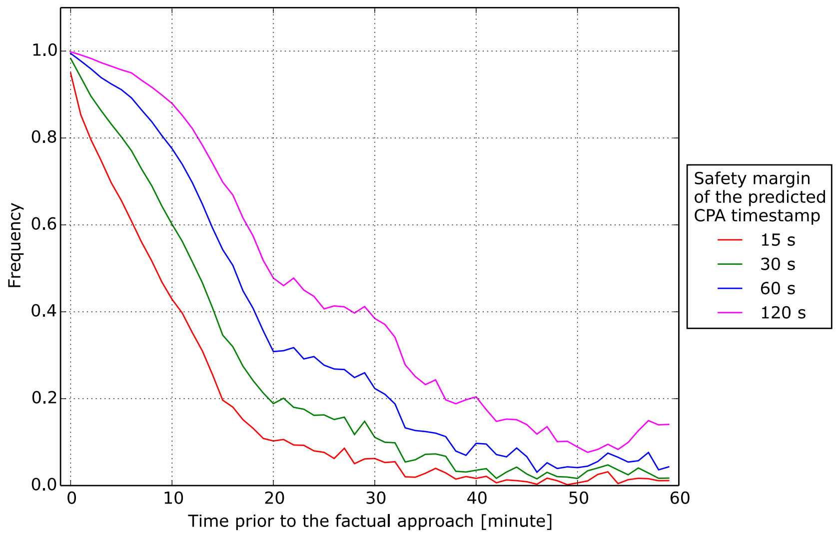

Fig. 9. The percentage of the CPA timestamp predictions deviating from the factual CPA timestamp no farther than the specified safety time margin

It means that loosening the safety margin of the CPA distance may improve the quality of the CPA distance prediction to higher extent than relaxing the safety margin of the TCPA can contribute to obtaining better prediction of the time to the CPA. Since the accurate forecast of the distance at the CPA is more important for collision avoidance than the TCPA prediction, choosing the safe separation between vessels and adapting it to the current traffic conditions seems to be a crucial task for a seafarer who would use AIS data for decision making.

CONCLUSIONS

The analysis has shown that the AIS data can be practically used as an input for predicting the distance at the point of the closest approach between two vessels and forecasting the time left to their final encounter. It is important to notice that those predictions can be trusted, only if an appropriate margin of error is deliberately chosen, with due regard for the current circumstances in the proximity of own vessel. Since the AIS transmissions received during September 2011 within the research area of the Strait of Fehmarn-Belt contained about 0.6% of dynamic position messages, which were useless for calculating the CPA due to missing parameters, a seafarer must keep a possibility in mind that not every AIS message received on board is fully usable for assessment of the closest points of approach with other vessels in proximity. The examples of three different types of encounter: head-on, crossing and overtaking, have demonstrated that collision avoidance measurers, be it changing course or adjusting speed, are clearly visible on the CPA and TCPA plots, although the curves are characterised by a lot of fluctuations and noise resulting mostly from the yaw of analysed vessels. The examination of the quality of CPA and TCPA predictions has revealed that relaxing the safety margin of the CPA distance can substantially increase the number of the CPA distance predictions, which meet the requested safety requirement. The forecasts of the time to the closest point of approach are more volatile and may be trusted only shortly prior to the final encounter. However, the projection of distance at the CPA is more important for collision avoidance tasks than the prediction of the time to the CPA. Finally, an introduction of additional data integrity parameters to AIS dynamic position reports and improving the internal performance of AIS transponders on board vessels, in order to reduce the percentage of faulty transmissions, may all contribute to authorising the use of AIS for collision avoidance procedures in the future.

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STRESZCZENIE

System automatycznej identyfikacji (AIS) rozwinął się w 2004 roku i odtąd jest uważany za istotny czynnik poprawiający jakość pełnienia wachty morskiej. W aktualnych regulacjach AIS nie jest uznawany za urządzenie antykolizyjne, jednak trudno nie dostrzec możliwości, jakie ma ten — wedle konwencji SOLAS — zasadniczy element obowiązkowego wyposażenia. Badania prowadzone w Wydziale Systemów Nawigacyjnych DLR wykazały, że informacje przekazywane za pośrednictwem AIS mogą zawierać wiele danych niepełnych, a system nie ma żadnego mechanizmu zapewniającego przesyłanie informacji o wiarygodności tych danych. Dlatego w artykule zaprezentowano obliczenia punktu największego zbliżenia (CPA) oraz czasu do tego punktu (TCPA) na podstawie danych z AIS od różnych statków, by porównać prognozy z faktycznymi manewrami, a następnie ocenić użyteczność danych AIS w obecnej postaci dla szacowania sytuacji kolizyjnych w warunkach rzeczywistych.