The Role of Integrity for Maritime Traffic Situation Assessment

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Abstract: Starting from the E-Navigation concept of IMO this paper will give an overview about integrity in maritime traffic awareness. Derived from a DLR study a concept is presented which introduces the provision of integrity maritime traffic awareness. This is based on common techniques like Automatic Radar Plotting Aid (ARPA) and Automatic Identification System (AIS) and a PNT-Unit which gives ship position, navigation, and time with integrity.

1. Introduction

One of the main objectives of the International Maritime Organisation (IMO) is the safe, secure and efficient realisation of all processes inside the Global Maritime Traffic System. Therefore IMO has initiated the E-Navigation strategy to use all available electronic methods of situation assessment, all channels of information exchange on vessel-to-vessel and vessel-to-shore levels, and to merge them into vessel steering and traffic management processes to improve safety at sea. It is particularly important due to the vessel traffic volume being on the increase. On the other hand, E-Navigation is an important concept of developing a global model of data exchange and defining areas of responsibility for the maritime traffic system.

One of the core elements of improving the safety of vessel traffic is the implementation of integrity monitoring of all sensors and services with special focus on data processing methods and communication channels being used aboard and ashore [IMO-NAV54/25].

The idea of integrity has already been utilised in the world of global navigation satellite systems (GNSS) and now it is also being established in the area of maritime traffic systems. In order to incorporate the idea of integrity into the whole maritime technology system, two independent schemes may be considered.

First one is a bottom-up approach. Hereby, the integrity of every single sensor and parameter is applied, using dedicated integrity monitoring procedures and integrity models. The basis of the integrity monitoring is a measurement redundancy. If two or more independent measurement methods can be used, their results can then be compared and they should be the same within specified tolerance. The integrity models are defined by a parametric description of all partial errors encountered during a measurement and an assessment of an overall error in respect to error interactions. The parameters of the integrity model can be determined by measurements and can help adapt the model to the real situation. If the integrity of the parameters and its monitoring is completely provided, it can be implemented in high-level systems.

The second scheme is a top-down approach. This requires a high-level definition and implementation of the “integrity” term throughout the whole maritime traffic system. The definition can be based on a mathematically parameterized model, which is able to figure out whether a vessel is in a safe condition. The parameters can be obtained e.g. from the traffic situation, waterway specifics, vessel type and navigational status. The model of safety level of a vessel can be determined statically or dynamically. In former case, the attention is focused on modelling of a transition from one safe state to the other safe state of every vessel in a traffic area. In latter case, at any moment the safe state of a vessel has to be guaranteed by the model. The whole maritime traffic is then declared safe, when all the participating vessels are classified as safe. The classification based on an integrity model helps define the integrity requirements for systems, services, on both sensor and algorithm levels.

In this paper the former described bottom-up approach is used to find gaps in the current set of used sensors and methods related to data and system integrity. An approach for a traffic situation assessment which overcomes current shortcomings is presented.

2. What Is Integrity?

According to International Maritime Organization (IMO) and International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), the integrity is the ability to provide users with warnings within a specified time when the system should not be used for navigation [IMO-A.915(22)-Annex 1 & IALA-R-121]. Specific integrity parameters are already defined in

[IMO-A.915(22)] as revised maritime Policy and Requirements for a future Global Navigation Satellite System (GNSS): the threshold value or alert limit, the time to alarm and the integrity risk. Furthermore, one has to distinguish between integrity and integrity monitoring, whereby integrity monitoring can be described as the implementation of integrity. It is the process of determining, whether the system performance (or individual observations) is sufficient for navigation purposes. The output of integrity monitoring tells the users that either individual (erroneous) observations or the overall GNSS system can not be used for navigation.

In order to describe the reliability of several parameters or a whole system, it is necessary to specify the performance requirements of those elements. The properties of performance and quality are based on a function, which should be performed, and a target, that is to be reached. An example of the vessel-based function is a permanent determination of its position, which is primarily done by the on-board sensors. In that case, their performance and quality description states, how frequent and how precise the position should be provided to the crew aboard.

The baseline of quality and performance description is their existing specification of global navigation satellite systems and the augmentation services provided to maritime users because their wide usage aboard vessels has led to a very active development in that area.

One of the performance and quality descriptors is the data integrity. In order to support the process of decision making on board, it is necessary to have a complete view of the traffic situation, based on all available parameters. In case of manoeuvres critical to safety, like collision avoidance, it is important to know the percentage of truth contained within the values of the parameters. To know the level of that consistency, the sensors also need to have the capability of determining the current error followed by the usefulness of a given sensor or a multi-sensor system. This can be done in reference to the accuracy requirements, which help decide on whether to use the data for navigation.

3. State of the art Integrity Approaches for Sensors

The integrity can be monitored either internally or externally. The former one is performed on board a vessel, whereas the latter one is provided by services outside. One of the most used sensors serving as a position source aboard is the GNSS receiver, usually operating with GPS constellation. If the number of available satellites is sufficient, it is possible to use an internal RAIM (Receiver Autonomous Integrity Monitoring) algorithm to identify, if a specific signal is induced by errors, and if yes, to exclude them from the position calculations. This process can be considered as a single sensor specific internal integrity monitoring.

If more than one GNSS receiver or other additional independent positioning equipment is available on board, redundancy and backup functionalities are created. Using input from multiple sensors, it is possible to implement more complex algorithms to compute the position and compare the results of the different sensors. So the performance of each sensor can be observed by another sensor. This process is also regarded as multi-sensor internal integrity monitoring.

The utilization of differential ground based augmentation system following IALA standard is an example for external integrity monitoring. Here satellite signals are proven related to reachable accuracy and augmented information including integrity information is provided to the user aboard.

In case no GNSS sensors, devices or systems aboard, their basic function is to output data like measurements, information or steering signals. The output data is generated as a result of measurements or a processing of input data from other sources. For example, an AIS device (Automatic Identification System) on board is expected to deliver dynamic, static and voyage-related data, which is complete and depicts the real situation around a vessel. It is, however, unclear at any given moment, whether that basic set of functions inside an AIS device is working correctly and feeding the other devices with proper data. It is possible to apply different techniques to ensure a satisfactory performance of the basic functions.

First, an error model can be applied to control the output data and compare them with a nominal error distribution. If the error model verifies that the data has a required quality, the sensor generating the data is allowed to be used. In case of mission critical systems, the error model is checked during homologation. Nonetheless, this method cannot ensure data integrity according to the integrity definition mentioned above.

There are two reasons. On one hand, a change or interference in usage conditions of a device may increase error rate and exceed the nominal error margins. On the other hand, the error rate could be influenced by a device malfunction or simple system ageing. In order to narrow the error margin, the systems undergo regular checkups, during which the error models can be tuned. However, it is not possible to warn a user within a specified time (near real time), that the system is not working within the accepted error level defined by specifications and requirements.

Second, a core system can be equipped with an integrity check function and it is then expected to survey its own performance operations and data output, and to compare them with the requirements. In order to accomplish that, two standard aspects of data quality can be tested: plausibility and consistency.

A check of data plausibility is based on threshold values and ranges. The data stops being plausible, as soon as the output values violate those predefined limits and the sensor is no longer reasonable or worthy of belief. For example, a positioning device on board a vessel outputs a point (0, 0, 0) in CCS and because the vessel cannot be in the center of the Earth, the position is implausible. Similar case of plausibility loss would happen, if an AIS transponder of a vessel transmitted an extremely high value of speed over ground, which could never be reached ship-borne. Those tests of plausibility are helpful, but cannot indicate data errors, which are hidden below the reasonable limits.

In case of a consistency check, the data quality is analysed in respect to its continuance and coherence. The data has to have a specified emplacement in space and time. In order to decide, whether the data is consistent, the default value ranges are to be known. For instance, a vessel receives an AIS position of another craft. The calculated distance to the AIS transmission source is larger than the horizontal range of radio waves on marine frequencies. If the AIS data packet does not have a nonzero repeat indicator, the received position is inconsistent. Another example of data inconsistency could be a sudden change of sensor output values. If the AIS data is updated once per two seconds and the vessel is underway using engine, a single jump of position point faraway from her currently reported position, which is physically impossible to occur, could indicate a loss of data consistency.

4. GAP Analyses

A gap analysis is considered to be an important part in the strategy of E-Navigation. It identifies gaps between the optimized allocation and integration of the inputs, and the current allocation level. This can help to reveal areas that can be improved. That way, a review of existing technologies and systems, and the evaluation of their performance can measure their capability of meeting the requirements of users. The development of marine traffic systems can then continue towards countering the deficiencies identified during the gap evaluation. The process of finding gaps can also define a path of transition towards a quality level, which is desired by the users.

The essential document on the gap analysis was created by IMO [IMO-NAV53/13-Annex3]. Its authors analysed from different angles the elements that make up a mariner’s life: nautical charts, bridge operations, shore systems, communication channels, data storage, crew management, equipment on board, aids to navigation, decision support and collision avoidance systems. Each area of interest was examined in three categories: the current status, how it is going to look like under the auspices of the E-Navigation ideology, and what aspects have to undergo change or adaptation. The work on the document is still in progress by IMO and IALA.

There are four different approaches used to set up a gap analysis [IMO-NAV56/8]. The operational analysis presents a limited concept of E-Navigation, which is based on currently available systems and technologies. The technical analysis, on the other hand, compares the systems being used nowadays with the requirements derived directly from the user needs, in order to define a path for system development. The aim of the regulative analysis is to identify the weaknesses of current performance demands on institutional levels. A provision of maritime services outside territorial waters and its responsibility could be the example of that. Finally, the training-related analysis focuses on minimal requirements needed to teach the users to handle the new navigational tools implemented by the E-Navigation rules.

Concentrating on data and system integrity, which is one high-level user need [IMO-NAV54/25-Annex12], DLR has done its own gap analysis, which can be treated as technical analysis in the IMO classification. It focuses on research, what conceptual definitions, standards, sensors and methods are currently available, and which of them can deliver integrity information about parameters that describe a traffic situation. The main results of the Gap analysis can be summarized as following:

- missing consistent performance standards concerning accuracy and integrity for all measured and derived parameters (position, SOG, ROT etc.)
- missing methods (services) for external integrity monitoring for AIS data
- missing standards for the transmission of integrity information from shore based services to the vessels
- insufficient resolution of nautical charts in critical areas (e.g. harbour)

5. First concept Of An integrity Demonstrator for maritime Traffic awareness

One of the essential steps towards implementation of the integrity concept is the creation of a demonstrator. It is necessary to have a base system, which can visualise the new ideas and concepts of E-Navigation and, particularly, that of integrity. The starting point of building the demonstrator system is a collection of user requirements within E-Navigation and their references to the current gaps between supply and demand of the integrity coverage within the nautical systems.

The demonstrator system brings together such fields of expertise like complete position estimation in a traffic area, decision support, time synchronisation, data integrity check and augmentation functions. The need to deal with the above subjects is especially evident, when it comes to mission critical operations. Using the demonstration platform it is possible to show, by means of specified performance parameters, the value-added aspects of proposed technical innovations, which can later define new standards and be passed to the industry.

The design of the demonstration system is modular and consists of separate sub-demonstrators, which are interconnected and can exchange data. Each sub-demonstrator is responsible for one of the three domains: traffic situation assessment, PNT, and augmentation. It is important to select an appropriate set of sensors and to define, how they will feed the demonstrator systems with data.

Afterwards, it is necessary to design the internal interfaces, which will be used to exchange data between the sub-demonstrators.

The basic functions of the sub-demonstrator responsible for traffic assessment are: data processing, linkage of the traffic participants, evaluation of the traffic situation, and finally a presentation of data and results. As far as the system architecture is concerned, the traffic estimate can be either vessel-based or shore-based.

In case of the traffic evaluation on board a vessel (**Fehler! Verweisquelle konnte nicht gefunden werden.**), the basic sources of information are the relations between the vessel and other ship-borne objects in her surroundings. The situation around the vessel is derived from the standard parameters like relative or absolute position, speed over ground, course over ground, heading, rate of turn, and navigational status. The navigator on board the vessel can determine her movements, based on the output data from their own PNT device.

The sources of information on other vessels are radar and AIS. Since the SOLAS convention requires AIS to be fitted aboard international voyaging ships with gross tonnage of 300 or more tons, and all passenger ships regardless of size, the availability of AIS data on major shipping routes is substantial. The AIS channel can also be used to obtain auxiliary nautical information and warnings from the VTS centers. Furthermore, an electronic nautical chart (ENC) together with its database of aids to navigation will be used within an ECDIS (Electronic Chart Display and Information System) to visualise the traffic situation.

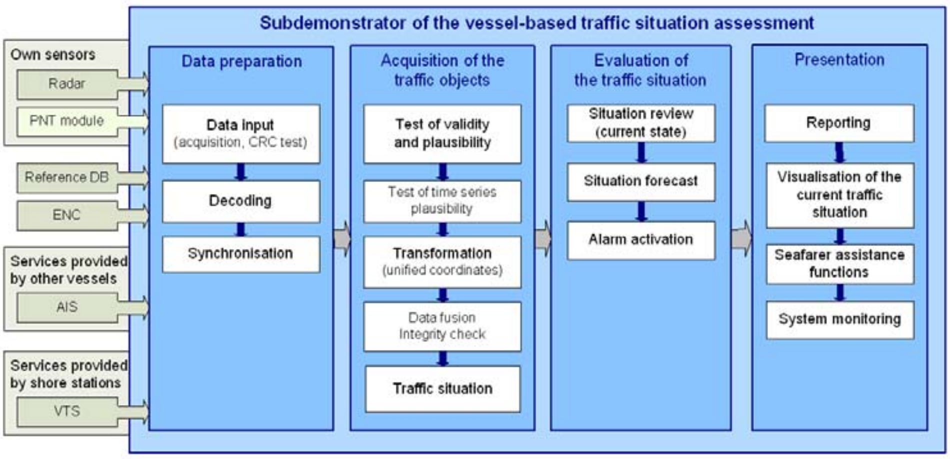

Fig. 1. First concept of vessel-based traffic situation assessment demonstrator.

The shore-based traffic evaluation, on the other hand, has a similar arrangement of the components (**Fehler! Verweisquelle konnte nicht gefunden werden.**). Small differences may be noticed in the way how sensors and data sources are used. However, more important is the alternate approach to the traffic situation assessment. Every maritime vessel within a specified traffic area has to be analysed in correspondence with the other traffic participants in the vicinity. It creates a higher level of complexity during the evaluation process.

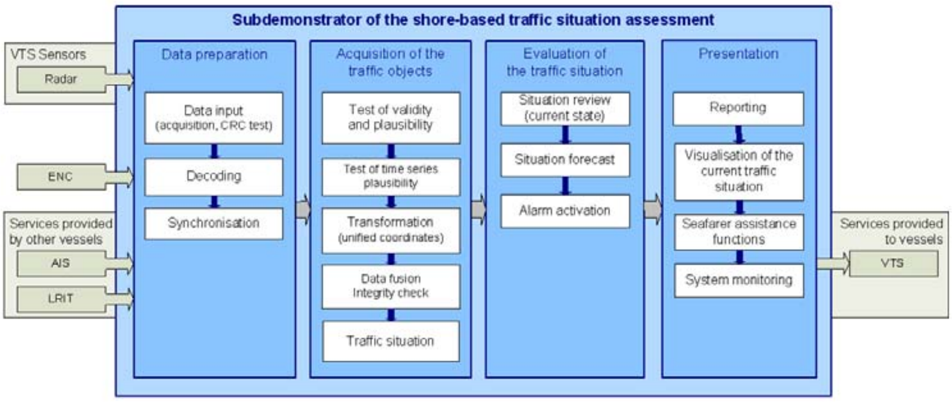

Fig. 2. First concept of shore-based traffic situation assessment demonstrator.

For example, it would be necessary to spot all possible situations of close encounter between any group of vessels, which could lead to a collision. In similar case, a VTS center coordinates the traffic within its area of responsibility and has to plan when and where the vessels on the waterway can pass one another safely. And this involves calculations of the estimated time of arrival at specified sidings for all the parties.

The sub-demonstrator, as shown in **Fehler! Verweisquelle konnte nicht gefunden werden.** and **Fehler! Verweisquelle konnte nicht gefunden werden.**, consists of separate processing blocks. At first, the data are received from various sensors and taken into the preparation chain. To make sure that the data were transferred without interference, a cyclic redundancy checksum (CRC) is generated and, when compared, it has to be equal to the origin CRC.

Next, the data have to be decoded. In most cases the standard in use is NMEA, which stores comma separated values in ASCII sentences. The values simply have to be extracted and broken down into variables. It is also important to have a unified time synchronisation of all data sources. GPS is nowadays the most common time reference. Nevertheless, not every NMEA sentence has a time stamp and that poses a big challenge for future development of marine equipment, as well as for usage of existing data inside the demonstrator system.

After the first processing phase is completed, the data are passed to the acquisition block, in which a process of conjoining takes place. Apart from checking the data flags and statuses, the data undergoes validity and plausibility checks. This is where the reference database is deployed. It contains threshold values related to the input data categories, for example the maximum speed of the vessel, and it can help determine whether the data is plausible. Parallel to that, plausibility of the time series is diagnosed. It can distinguish sudden and irrational changes of data values as compared to the previous ones. For instance, if a vessel is going steady and at one point her position jumps faraway just to return to its previous track a moment later, this location change could be considered a loss of plausibility, because it would be technically impossible.

During transformation, the data containing spatial information has to be transformed in order to conform to the so-called consistent common reference point. It is the base of all measurements on board a vessel, and is usually located on the bridge at the conning station. The collection of functions responsible for the data fusion and the integrity check is where the actual conjoining takes place. The acquired targets are associated with one another. Depending on the number of data sources, it is possible to apply different processing options. In case of a single data stream describing the traffic objects, the state of the data integrity cannot be fully determined. However, if more data sources are available, they can be transformed and compared. For example, the AIS data of a vessel, which contains her geographic position, speed and course, can be matched with the same set of parameters calculated by ARPA. Both data sources can then be combined, producing a certain degree of integrity evaluation.

Finally, after the traffic object data is collected and stored, the evaluation of the traffic situation can be initiated. Special attention is laid to the levels of uncertainty related to the vessel movements. For example, the precision of the position and its reliability can be analysed and compared against the parameterised requirements. The idea is to assess dangerous situations, which can lead to collisions or grounding within the current traffic environment.

Another part of the evaluation process is the forecast of the traffic situation. The prediction subroutines are based on a specified future time intervals. The projected movements of the vessels are examined in respect to possible unsafe close approaches. The influence of data uncertainty on forecasting is also taken into consideration. In case of dangerous situations requiring a seafarer's reaction, special alarm and warning management system is introduced. It can report problems with unreliable input data received from the sensors, as well as warn against the violation of safety levels, when the vessels are on collision course or too close to one another.

With these sub-demonstrators determined integrity information about all presented data of single sensors and complex systems will help decision making in complex situation because of proven and reliable information.

Summary and Conclusions

IMO initiated user survey on marine user needs identified data and system integrity as one of eight important generic high-level user need. Our technical gap analysis shows shortcomings in the current definition of alert limits, times to alarm and integrity risk for a plenty of sensors and systems in marine use. For this reason an overall traffic situation assessment including integrity is not feasible in time. An approach based on sensor fusion and use of measurement redundancy show in bottom-up way the propagation of integrity of single sensors to complex system like traffic situation assessment to fulfil the E-Navigation user needs of data and system integrity.

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