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E-Navigation - Integrity in the maritime traffic system

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An article by *Evelin Engler, Frank Heymann* and *Ralf Ziebold*

Comprehensive and reliable situation recording and monitoring are basic prerequisites to avoid collisions and groundings in the maritime traffic system. Due to the technical advance in the last century both tasks are more and more overtaken by a variety of sensors, services and systems. As a result, a steadily increasing number of data is provided to describe the current situation on board the ships and in traffic areas. This opened the door for the application of integrated data processing techniques to perform the analysis of situation up to identification of threats at the soonest. But with the enlarging system complexity the necessity arises to evaluate the current usability of components and data in use to avoid misinterpretations of the situation. Usability evaluation becomes feasible in real time, if suitable integrity monitoring functions can be applied. In consequence, the implementation of system and data integrity into the maritime traffic system is considered as high-level user need of e-Navigation, a framework initiated by the IMO to enhance the maritime traffic system. The article gives an overview about DLR's project »Maritime Traffic Engineering« (2010-2014), which is pursued on the feasibility of integrity monitoring in the maritime position, navigation, and timing system (PNT) as well as during traffic situation assessment (TSA).

reliability | integrity | resilience | position, navigation, and timing (PNT) | traffic situation assessment (TSA)

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Introduction

Comprehensive and reliable situational awareness is a basic prerequisite to avoid collisions and groundings as well as to protect life, goods, and the maritime habitat. For this purpose the reliable knowledge of ship's position and movement is necessary, taking into account the current traffic situation and the usable traffic area. In this context PNT data characterises the sum of information needed to describe ships' position, movement and attitude in time and space. Typical PNT data are amongst others latitude, longitude, time, speed over ground (SOG), course over ground (COG), heading and rate of turn (ROT). The Automatic Identification System (AIS) as communication platform supports the exchange of static, dynamic, and voyage-related data between ships operating in the same sea area. Dynamic AIS data are extracted from ship's PNT data, whereby the combined use of own and received AIS data enables the assessment of traffic situation up to the identification of collision threats. Due to the fact that the availability of AIS data depends on achieved resilience of AIS based data transfer as well as the willingness of involved traffic participants for cooperation RADAR (RAdio Detection And Ranging) is recognised as the primary aid for onboard traffic situation assessment. However, the combined use of RADAR and AIS data creates the opportunity for an improved description and analysis of traffic situation. In order to achieve a safe and efficient traffic management the traffic situation should be associated with the usable traffic area. For this purpose all PNT and TSA relevant data as well as nautical charts should be handled in one and the same reference system.

The development of the e-Navigation implementation plan started in the year 2006 with the collection of user needs and the identification of regulative, administrative and technical gaps in the current maritime traffic system. At present

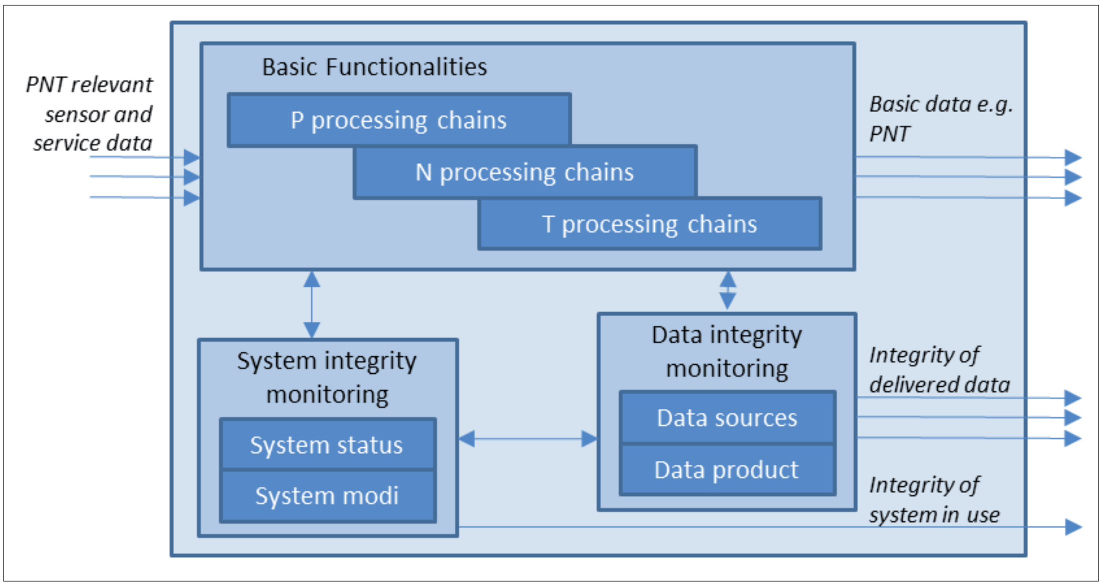


Fig. 1: Generic view on onboard PNT system with basic and additional integrity monitoring functionalities

five e-Navigation solutions are given top priority for realisation, whereby the »improved reliability, resilience and integrity of bridge equipment and navigation information« is one of them. Due to its importance for collision avoidance special attention is laid on the improvement of onboard PNT system by acting as risk control option.

Challenges: reliability, integrity, and resilience

Reliability, integrity, and resilience are descriptive characteristics stressed in the frame of e-Navigation to formulate user needs, gaps as well as objectives for the further enhancement of the maritime traffic system. Without technical detailing and harmonised meaning of the descriptive characteristics it will be impossible to determine the real need on research and development regarding the maritime PNT and TSA system.

Reliability is the ability of a system to perform its required functions under specified conditions for a certain period of time. Therefore reliability can be applied either on the basic functionalities or additionally on functionalities monitoring the system and data integrity (Fig. 1). An increased level of difficulties represented by the specified conditions as well as higher requirements on quantity and quality of data products determine in the end which sensors, services and methods should be applied in minimum.

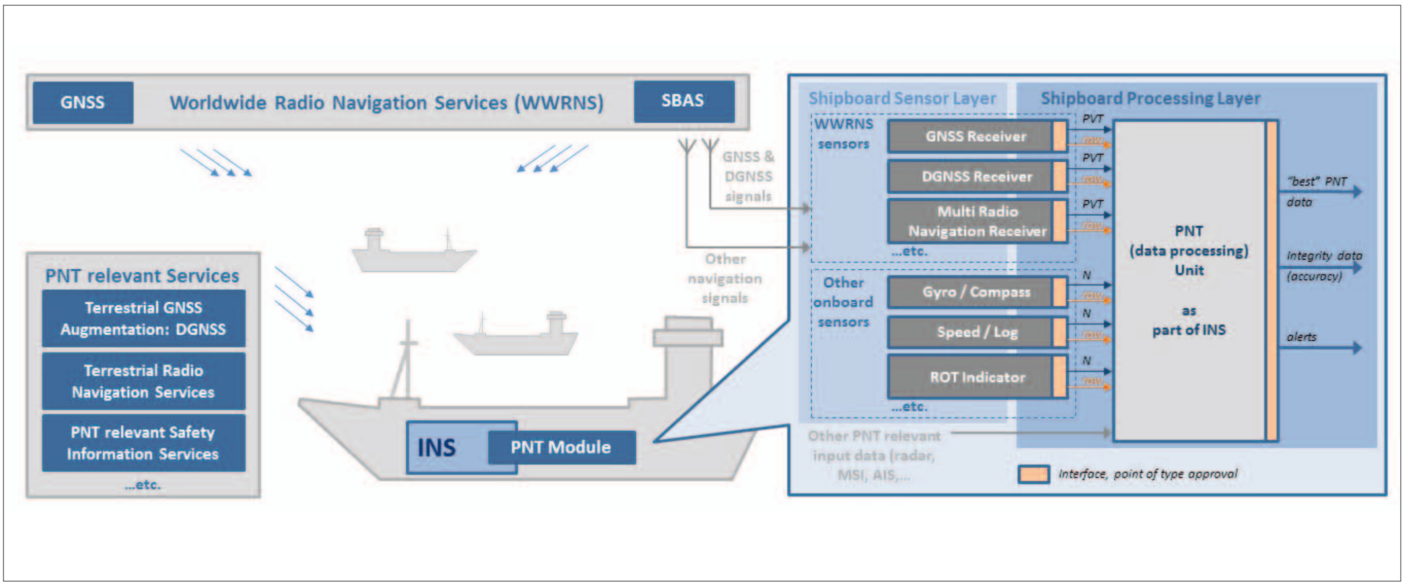
The maritime community associates integrity with the ability of systems to provide the user with information about the current usability of the system or delivered data products. The meaning of integrity information depends strongly on applied integrity indicators and used methods for their determination. Plausibility tests allow the detection of large errors. Consistency tests applied on data coming from similarly or complementary data sources enable the detection of malfunctions and failures in parts of the system. However, in case of nautical information systems the completeness, validity, and accuracy of provided data products should be the preferred measures to determine their usability. For this purpose intrasystem redundancy is necessary to enable the detection of single error sources and to estimate the resulting accuracy losses.

Resilience is a requirement especially claimed for safety-critical systems. A resilient system is able to detect and compensate external and internal sources of disturbances, malfunctions and breakdowns in parts of the system. For this purpose the system needs internal integrity monitoring functions whose results are used to manage and steer the system operation. The compensation of error sources shall be achieved without loss of system functionalities and preferably without degradation of their performance. In order to achieve resilience the need on intrasystem redundancy increases to enable besides integrity monitoring the compensation of detected errors. Both, the requirements on integrity as well as resilience in safety-critical systems, have implications on the architecture design and the interface specification. On the one hand the chosen system architecture reflects a certain level of redundancy determining the feasibility of integrity monitoring and the achievable significance of provided integrity information. On the other hand additional components and functions should be foreseen in the architecture to perform integrity monitoring up to system steering. Finally, the exchange of integrity and steering data should be supported by internal and external data interfaces.

Resilient onboard provision of PNT data

Fig. 2 gives an overview of the maritime PNT system as it is discussed in time at the level of IALA and IMO. Recognised core elements for the worldwide determination of position, velocity, and time data (PVT) are Global Navigation Satellite Systems (GNSS), whereby the additional use of Satellite Based Augmentation Services (SBAS) and terrestrial GNSS augmentation services (e.g. DGNSS) increases accuracy and integrity of GNSS based positioning. Due to GNSS's vulnerability the need on ter-

Fig. 2: Overview of maritime PNT system: used and usable components and services



restrial radio navigation systems such as eLORAN (see the article on page 26) or R-Mode (Ranging Mode) is questioned to enable a GNSS independent determination of PVT data in the future. In the classic approach of an onboard PNT module each sensor is responsible for the provision of specific PNT data: the sensors of World Wide Radio Navigation Systems (WWRNS) for PVT data and the other shipboard sensors for navigation data such as SOG, COG, speed through water (STW), heading, or ROT.

The shipboard processing layer is part of the applied sensors and represents the intra-sensor used methods for the provision of respective PNT data. Only in cases of intra-sensor redundant dimensioning (e.g. more than five GNSS signals) integrity monitoring methods such as RAIM (Receiver Autonomous Integrity Monitoring) can be applied. Fig. 3 (left graphic) shows the achievable improvement of Single Point Positioning (SPP) with Receiver Autonomous Integrity Monitoring (RAIM) by using a standard GPS receiver operating with L1 signals. In general, the horizontal position errors are below 10 m. Nominal operation conditions are achieved in 99.8% indicating the usability of provided PNT data.

Ships using an Integrated Navigation System (INS) as shown in Fig. 2 have the opportunity to exploit the multi-sensor based redundancy to detect failure and malfunctions in the applied PNT sensors, to assess the usability of provided PNT data, and to improve the alert management. A check matrix performs plausibility and consistency tests on the basis of a sensor-overarching measurement model. Due to the fact that plausibility tests can only detect large errors and consistency tests can only determine relative errors, the current INS approach lacks of insufficient navigational integrity monitoring and error compensation. A loosely coupling of RAIM assessed PVT data coming from the GPS L1 sensor with movement data provided by an Inertial Measurement Unit (IMU) is a proceeded INS approach to decrease all horizontal position errors below 5 m (Fig. 3, right graphic).

The PNT Unit is an enhanced concept of the shipboard processing layer developed by the MTE project in cooperation with industrial and administrative partners (Ziebold et al. 2010). The concept opens the door for the multi-dimensional harmonisation of resilient PNT data provision covering carriage requirements, required accuracy and integrity levels, coordinated exploitation of intrasystem redundancy, need on PNT relevant services, consolidation of PNT relevant data formats and contents, as well as the enhancement of PNT relevant alarm management under consideration of actual requirements originating from service area and high-priority navigation tasks. The developed initial PNT Unit demonstrates the feasibility that such an enhanced data processing layer is able to detect and compensate external and internal sources of disturbances, malfunctions and breakdowns in parts of the PNT system.

As shown in Fig. 4 improved position results are only achieved, if applied integrity monitoring techniques (RAIM, innovation filtering) enable the error detection and uncorrelated data sources (GPS and IMU) ensure their compensation. Continuing developments are in preparation to clarify the need, role and benefits of PNT relevant services (e.g. future role of PNT relevant Maritime Safety Information, MSI) taking into account the diversity of accuracy and integrity requirements and inhomogeneity coming from scalable carriage requirements. For this purpose the PNT Unit will be upgraded with further processing chains utilising the advance in services, sensors and data processing techniques.

Comprehensive and reliable traffic situation monitoring

RADAR is recognised as the primary aid for onboard traffic situation assessment because it enables the autonomous localisation of targets based on two-way propagation measurements of own radio signals. Against this, the reliability of AIS based target identification is influenced by the willingness of traffic participants for coopera-

References

IMO MSC (2008): Report of the Maritime Safety Committee on its eighty-fifth Session (MSC 85/26). Annex 20: Strategy for the Development and Implementation of eNavigation; London, 19 December 2008

Engler, Evelin; Thoralf Noack; Michael Hoppe; Ralf Ziebold; Zhen Dai (2011): Resilient PNT: Vision and mission; International Conference on e-Navigation »E-NAVIGATION UNDERWAY«, M/S Crown Seaways; Copenhagen-Oslo-Copenhagen, 18-20 January 2012

Ziebold, Ralf; Zhen Dai; Thoralf Noack; Evelin Engler (2010): Concept for an Integrated PNT Unit for Maritime Applications; Proceding of 5th ESA Workshop on Satellite Navigation Technologies (Navitec); Noordwijk, 8-10 December 2010

Heymann, Frank; Paweł Banyś; Thoralf Noack; Evelin Engler (2013): Is ARPA Suitable for Automatic Assessment of AIS Targets?; Advances in Marine Navigation, London, pp. 223-232, 2013

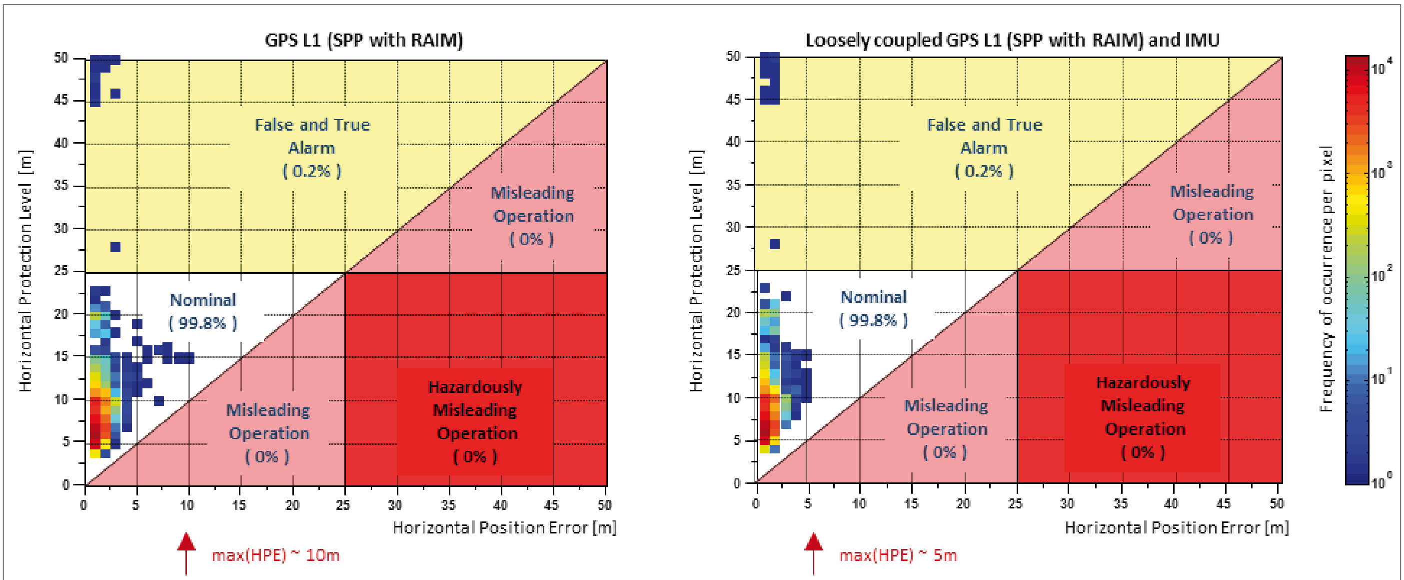


Fig. 3: Horizontal position errors and protection levels gathered during a 12 h trial run in October 2013: left graphic from GPS L1 (SPP with RAIM) and right graphic from loosely coupled GPS L1 (SPP with RAIM) and IMU

tion. Measured distances and bearing angles are analysed by RADAR to determine the position of targets relative to the own position. However, the RADAR based identification and tracking is complicated by signal propagation effects as well as the absence of reliable methods to separate between traffic participants, obstacles and artefacts. Similarly, the quality of AIS based target identification varies in dependence on the capability and resilience of PNT and AIS equipment and communication.

Initial investigations of the project MTE confirmed that neither the automatic acquisition of RADAR targets using ARPA (automatic RADAR plotting aid) nor AIS alone are able to provide reliable and complete traffic pictures. In case of AIS it was shown that at the Baltic Sea 3% of AIS data includes default and 1% inconsistent values. Default values are defined in the AIS standard. Values are considered as critical, if increased deviations between successive positions and assigned speed and course indications are observed. Therefore it is also plausible that the sum of default and inconsistent AIS data increases up to 20% in harbour areas as a result of slowly moving and mooring vessels.

In the MTE project a method was developed to associate targets identified by AIS and RADAR (Heymann et al. 2013). It was found (Fig. 5), that in open water (in this case the Baltic Sea) nearly 90% of AIS targets can be associated with a RADAR target, whereas in harbour areas the association rate drops below 50%. The observed distance between associated AIS and RADAR targets is in the order of 140 m up to 160 m for open sea and harbour areas and is compliant to the accuracy specifications of both systems (Fig. 5). The RADAR performance slightly decreases in harbour areas which can be explained with impaired RADAR signal propagation conditions.

An improved description and monitoring of traffic situation can only be achieved by fusion of traffic relevant data coming from different sources such as RADAR and AIS. For this purpose it is evident that each data source supports an automatic target detection and time synchronisation. Due to existing technical gaps in the case of RADAR, the MTE project realised initial investigations, how well astronomical methods can be used for automatic target identification based on raw RADAR images. First trials have shown that automatic target identification becomes possible and opens the door to separate between static and dynamic targets. Additionally it becomes possible to extract information of the target dimension for ongoing analysis. ⚓

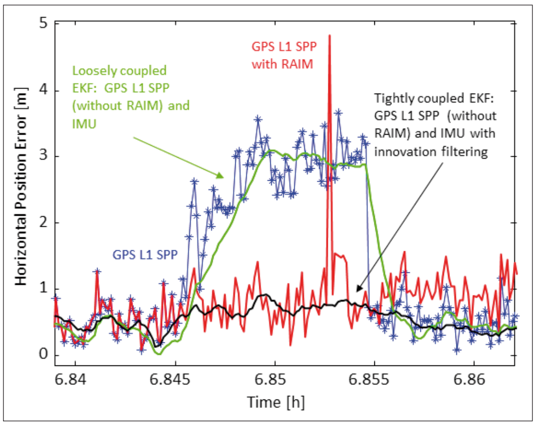


Fig. 4: Error compensation by PNT Unit V1.0 (EKF: Extended Kalman Filter)

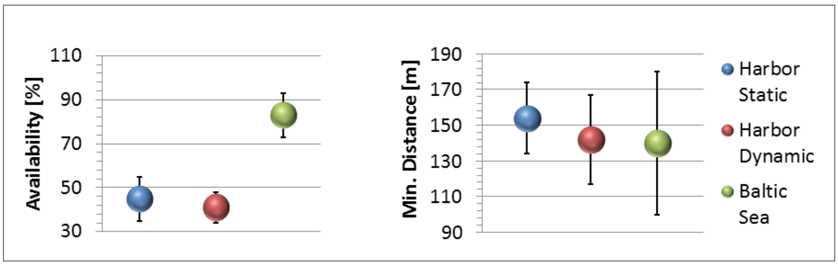


Fig. 5: Availability of targets identified by RADAR and mean distance between associated AIS and RADAR targets

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