

Research on Onboard PNT Information Integrity Monitoring

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Abstract

With the Global Navigation Satellite System (GNSS) development, the GNSS applications have been widely used in the maritime field, especially for onboard equipments. As GNSS signals are susceptible to interference, the International Maritime Organization (IMO) has been investigating resilient PNT as the primary resolution for Positioning, Navigation and Timing (PNT). Resilient PNT is based on all available PNT sources and integrated positioning algorithms, not dependent on GNSS completely. It improves the PNT information integrity by the error compensation capability of the different navigation systems. This paper summarizes technology standards related to navigation systems and PNT integrity in the maritime field. On the basis of these analyses and investigations, a framework for onboard PNT integrity monitoring is proposed. It can provide a timely alarm to users when the navigation system cannot be trusted or used for regular operation. The proposed integrity monitoring framework is in line with the IMO e-Navigation strategy. It can provide resilient PNT information for the Maritime Autonomous Surface Ship (MASS) and the future intelligent development of the maritime field.

Keywords: e-Navigation, GNSS, resilient PNT, integrity monitoring, data fusion

INTRODUCTION

The Global Navigation Satellite System (GNSS) as an inclusive term, recognized by the International Maritime Organization (IMO), includes GPS, GLONASS, Galileo, and BDS [1]. The application of GPS and GLONASS promoted IMO's research on the policy and future development of GNSS in the maritime field [2].

The improved reliability, resilience, and integrity of bridge equipment and navigation information are one of the e-Navigation priority solutions, according to IMO's e-Navigation Strategy Implementation Plan (SIP) [3]. Resilient PNT proposed by IMO generally integrates shipborne multi-sensor to increase the availability and reliability of PNT services [4]. According to IMO Maritime Safety Committee (MSC).401(95) [5] and MSC.1/circ.1575 [6], the IMO requires WWRNS to provide multi-source PNT services. The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) proposed an alternative system to provide redundant PNT information in order to mitigate GNSS vulnerability in R-129 [7].

According to IMO resolution A.915(22), when the system is not properly used for navigation, the integrity should warn users within a specified time. Generally speaking, integrity parameters include alert limit, time to alarm, and integrity risk [8]. In order to avoid excessive waste of resources and ensure the safety of ship navigation, integrity parameters should be required to vary spatially. In addition, referring to IMO Sub-committee on Navigation, Communications and Search and Rescue (NCSR) guidelines for PNT data processing [9], the results of PNT integrity monitoring are presented in four levels: High(H), Medium(M), Low(L), and None(N). However, few specific methods have been given for PNT information integrity monitoring in a maritime field. Therefore, it is essential to establish and implement the framework of onboard PNT information integrity monitoring to ensure the safety and security of ship navigation.

FRAMEWORK OF ONBOARD PNT INFORMATION INTEGRITY MONITORING

To enhance ship navigation's safety, a framework of onboard PNT information integrity monitoring is proposed to provide resilient PNT, as shown in Figure 1. It is divided into three parts: PNT data collection unit, PNT data detection unit, and integrity assessment unit.

The orange dotted line represents the PNT data collection unit. Since any single source of PNT information can be risky, the satellite-based, ground-based, and ship navigation sensors are combined to obtain redundant PNT information. The red dotted line represents the PNT data detection unit, which ensures the accuracy and reliability of the output navigation solution by checking the rationality and consistency of the single PNT source and integrated navigation. The green box represents the integrity assessment unit. The navigation solution and the integrity assessment results are displayed on the Integrated Bridge System (IBS), allowing operators to obtain the ship's PNT information directly without paying attention to the internal process.

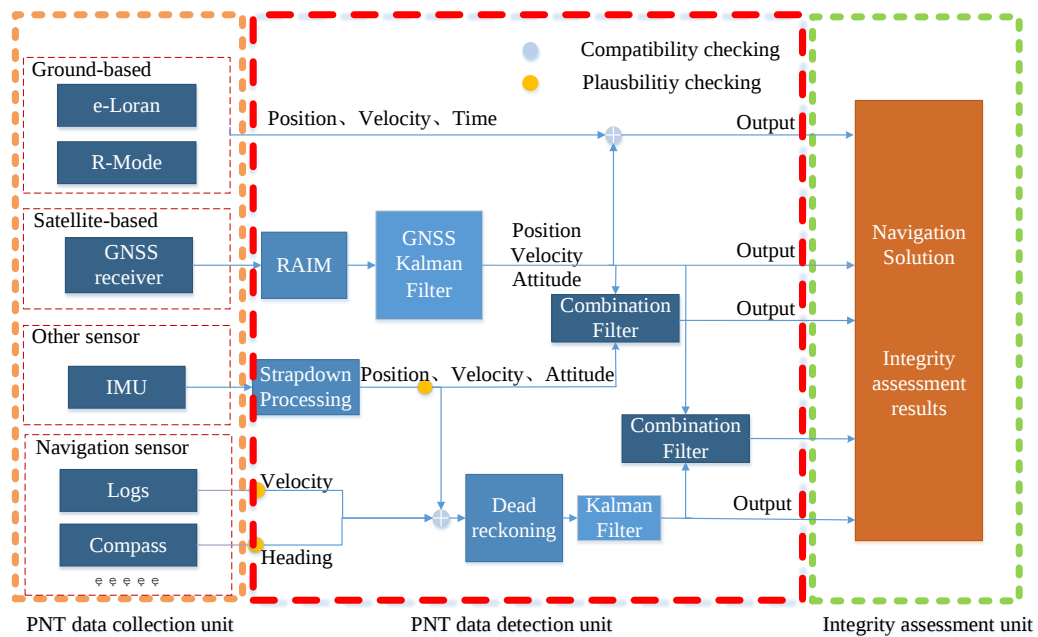


Figure 1. The framework of onboard PNT information integrity monitoring

COLLECTION AND DETECTION METHOD FOR SHIP PNT INFORMATION

To provide resilient PNT, the collection of sensors should consider two points. Firstly, each output parameter should be independently obtained from at least one onboard PNT sensor. Secondly, each output parameter needs to implement integrity detection.

SENSORS' SELECTION

According to the IMO required onboard equipments in the Safety of Life at Sea (SOLAS), the following output parameters and corresponding sensors in the maritime field are shown in Table 1. The rows with white backgrounds represent SOLAS mandatory navigation equipment, and the rows with gray backgrounds represent SOLAS recommended navigation equipment. M indicates the primary sensor; R is the redundant sensor; B indicates the backup sensor; C means contingency.

Table 1. Ship navigation sensors and output parameters

	Pos	COG	SOG	True Heading	ROT	Time	UKC
Major GNSS	M	M				M	
Second GNSS	R	R				R	
Doppler Log			M				
Electromagnetic Log			B				
gyrocompass				M	B		
Magnetic compass				B	B		
ROT indicator					M		
Echo Sounder							M
IMU	C	C	C	C	C		
Loran C	B					B	
Changhe II	B					B	

eLoran	B					B	
R-Mode	B					B	

COLLECTION OF ONBOARD PNT DATA

After analyzing the mitigation measures of GNSS vulnerability, resilient PNT must be realized based on redundant information from different schematic navigation sources. Figure 2 shows a combination of satellite-based, ground-based, and onboard components that can provide more accurate and reliable PNT information.

DETECTION OF PNT DATA

PNT detection unit can be divided into single sensor rationality tests and multi-source PNT data consistency tests [10]. When invalid data is detected, it should not be used, and the alarm system should provide a warning in the meantime.

Signal Sensor Rationality Test

Due to the onboard PNT containing many sensors, it is necessary to detect and eliminate invalid data to ensure output parameters quality. The single sensor rationality tests include the plausibility check and the validity check. First, the plausibility test checks whether the raw output data and the navigation results from different sensors are within the defined range of the corresponding data type. The validity test checks whether the sensor data and the output navigation results are consistent with the data format in the official standard. Suppose the output of the speed log is larger than the maximum nominal speed of the vessel [11].

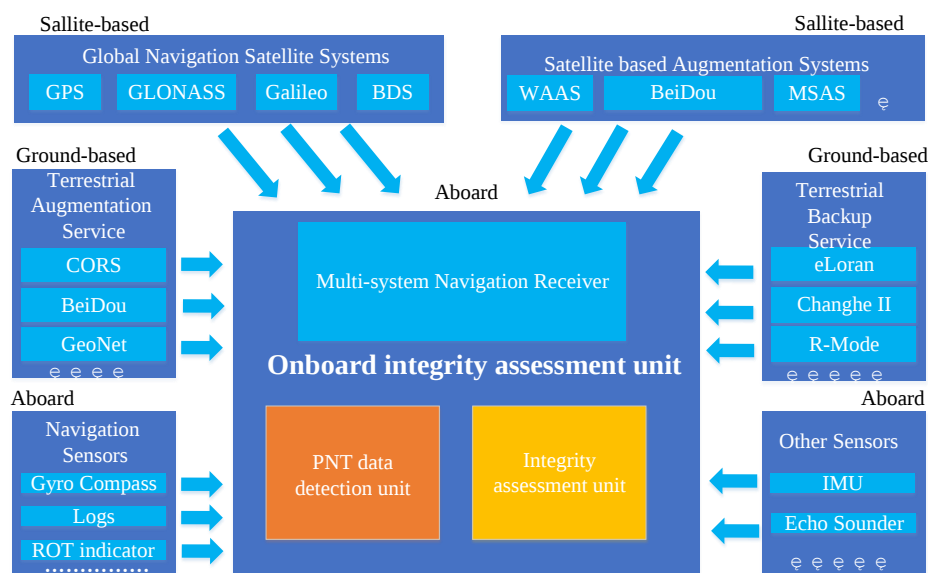


Figure 2. Integrated PNT information sensors

Multi-source PNT Data Consistency Test

Navigation systems rely heavily on accurate PNT information, so similar types of output parameters should be checked for consistency in multi-source PNT.

With the adoption of low-cost jammers and weak satellite signals, Receiver Autonomous Integrity Monitoring (RAIM) should be required before the consistency test. The basic principle of RAIM is to detect, identify and eliminate faulty satellites by using redundant satellite data to provide users with reliable position information.

INTEGRATED NAVIGATION SYSTEM

Today, each single navigation system presents advantages and disadvantages. An integrated navigation system improves accuracy and integrity by applying data fusion processing technology such as the Kalman filter.

the GNSS/IMU combination is a standard solution. Due to the inherent drift of IMU, the navigation data will produce numerous errors at a specific time. Improving accuracy to meet long-term stability requirements will bring high research and development

costs and cycles. With the characteristics of GNSS all-weather, high coverage, and high precision navigation service, the combination of the GNSS/IMU can eliminate error accumulation and obtain the best PNT output.

RESULTS AND DISCUSSION OF ONBOARD PNT INFORMATION INTEGRITY ASSESSMENT

The final step of integrity monitoring is to output navigation solutions、 integrity assessment results and display them on the IBS interface. The integrity assessment results include integrity level and integrity parameters. Operators do not need to be concerned with internal processing to confirm the vessel's current status. At the same time, the integrity assessment unit is connected with the alarm system, which can warn users when dealing with emergency maritime situations and reduce the risk of ship navigation in time.

INTEGRITY LEVEL

Referring to guidelines for PNT data processing issued by IMO, NCSR uses four levels to describe requirements on integrity, that is none(N), low (L), medium (M), and high (H). The four integrity levels are analyzed as follows:

Level N represents that none of the navigation systems can be trusted. There are two situations: one is that the vessel is not equipped with an integrity assessment unit; secondly, the vessel is equipped with an integrity assessment unit, but the navigation system is disrupted.

Level L: integrity assessment is based on rationality tests of data provided by single sources.

Level M: integrity assessment is based on consistency tests of PNT data from uncorrelated error sources.

Level H means the highest level of integrity. It is based on level M, using data fusion techniques such as Kalman filter to achieve positioning.

INTEGRITY PARAMETER

In addition to the integrity level, the output data includes different integrity parameters. The integrity parameters include time to alarm, alert limit, integrity risk. To avoid excessive waste of resources and ensure the safety of navigation, requirements for integrity parameters may vary spatially. The definition of these integrity parameters is given as follows:

- (1) Time to alarm: The time elapsed between the occurrence of a failure in the system and its presentation on the IBS.
- (2) Alert limit: During integrity monitoring, the maximum allowable error in the measured position before an alarm is triggered.
- (3) Integrity risk: The probability that a user will experience a position error larger than the threshold value without an alarm being raised within the specified time to alarm at any location in the coverage area.

ALARM SYSTEM MANAGEMENT

The integrity assessment unit alarms are classified by resolution MSC.302(87), as shown in Table 2. The resolution of IMO A.1021(26) classifies the alarms into emergency alarms, alarms, warnings, and cautions. According to the priority order, each kind of alarm adopts a specific visual and auditory display. The emergency alarm is usually used in emergencies such as fire and flood detection, which is not described in Table 2.

Table 2. Classification of onboard PNT information integrity alarm

Source	Cause	Alarm	Warning	Caution
Heading control unit	Failure or reduction in power supply	√		
	Off heading alarm		√	
Track Control unit	Failure or reduction in power supply		√	
	Sensor failure (heading, position, speed)	√		
	Course difference (heading deviates from track course)		√	
GNSS unit	HDOP exceeded			√
	Loss of position		√	

	Loss of differential signal		√	
	Differential corrections not applied		√	
Integrity assessment unit	The integrity assessment is N (not equipped with an integrity assessment unit)			√
	The integrity assessment is N (navigation system interruption)	√		
	failure of Integrity assessment		√	
	Failure of rationality test (main sensor)		√	
	Failure of rationality test (backup/contingency sensor)			√
	Failure of consistency test (multi-source)		√	
	integrity parameters cannot meet the minimum requirements		√	
Echo sounder	Depth below keel alarm	√		
	Failure or reduction in power supply		√	

The record module in the alarm system can store video and confirm the reliability of the integrity assessment unit through inquiry, play, and export. In addition to sending alarm information to the alarm system, the integrity assessment unit can automatically switch to a better navigation solution and show the integrity assessment results to facilitate the crew to make a response according to the vessel's PNT information.

CONCLUSIONS

The monitoring framework for onboard PNT integrity is proposed in this paper. Firstly, the status quo of the maritime navigation systems and related technical standards in the maritime field are investigated. On this basis, the accuracy and integrity requirements of onboard PNT information are given according to the different navigation areas. Then, the mitigation measures of GNSS vulnerability are analyzed. Moreover, the framework of onboard PNT information integrity monitoring is designed. Based on modularization ideology, the framework comprises three parts: PNT data collection unit, PNT data detection unit, and integrity assessment unit. The PNT data collection unit uses satellite-based, ground-based, and shipborne navigation sensors to provide more accurate and reliable PNT information to ships in order to solve the high risk of a single PNT source. The PNT data detection unit provides the identification capability for the fault of shipborne sensors and navigation performance of multi-source PNT information. The integrity assessment unit presents the user's navigation results in a hierarchical form. When there is onboard false PNT information, it will send an alarm to the operator in time and automatically identify and switch to the best navigation solution internally.

It should be pointed out that this paper can only be seen as a starting point for the onboard PNT information integrity assessment; the next step is to develop a demonstration system for PNT integrity assessment.

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REFERENCES

- [1] ZIDAN J, E. I. ADEGOKE, E. KAMPERT, S. A. BIRRELL and M. D. HIGGINS, (2020) GNSS vulnerabilities and existing solutions: A review of the literature. *IEEE Access.*, 9(2), 153960-153976.
- [2] CHEN Q, (2020) Application and standardization of Ship Emergency Search and Rescue of Beidou Navigation satellite system. *Information Technology and Standardization.*, 62(6), 18-22.
- [3] IMO, (2008) Development of an E-Navigation Strategy, NAV54/WP.6 Report.
- [4] Yang Y., (2008) Resilient PNT Concept Frame. *Acta Geodaetica et Sinica.*, 47(7), 893-898.
- [5] IMO, (2015) Radionavigation Receiver Performance Standard, MSC. 401(95).

- [6] IMO, (2017) Guidelines for Shipborne Position, Navigation and Timing (PNT) Data Processing, MSC.1/circ.1575.
- [7] IALA, (2012) On GNSS Vulnerability and Mitigation Measure Edition 3, Recommendation R-129.
- [8] IMO, (2001) Revised Maritime Policy and Requirements for a Future Global Navigation Satellite System (GNSS), Resolution A. 915(22).
- [9] IMO, (2016) Guidelines Associated with Multi-systems Shipborne Radionavigation Receivers Dealing with Harmonized Provision of PNT Data and Integrity Information, NCSR4.
- [10] IEC, (2006) Maritime navigation and radiocommunication equipment and system-Integrated navigation systems, Operational and performance requirements, methods of testing and requirement test results.
- [11] ZIEBOLD R, Z. DAI, T. NOACK and E. ENGLER (2011) Concept for an integrated PNT-unit for maritime applications. 2010 5th ESA Workshop on Satellite Navigation Technologies and European Workshop on GNSS Signals and Signal Processing (NAVITEC).