IALA

IALA GUIDELINE

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SYSTEMS AND SERVICES FOR HIGH-ACCURACY POSITIONING AND RANGING

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1. PURPOSE, SCOPE AND STRUCTURE OF DOCUMENT

1.1. PURPOSE

The purpose of this document is to provide an overview of systems and services enabling high-accuracy positioning or ranging in specific areas such as waterways, traffic separation schemes, traffic zones with limited manoeuvring space, ports and harbours, and congested waters, with increased risks of collisions or groundings.

In this Guideline, the term “high-accuracy positioning and ranging” refers to accuracies at sub-metre level for 95% of the time.

Each high-accuracy system or service will require its own Guideline to clarify the different architecture and system parameters. This document provides a framework for such guidelines to support their consistency.

1.2. SCOPE

The document provides guidance to stakeholders, operators, and end users regarding principal aspects, which should be considered for deployment and operation of systems as well as utilization of services. These include applications, performance requirements, functional principles, and generic descriptions concerning the main aspects that have to be considered during implementation and operation.

1.3. STRUCTURE OF DOCUMENT

Chapter 2 provides background information about GNSS as the primary means for worldwide high-accuracy positioning.

Chapter 3 gives an overview of nautical tasks and specific nautical applications to explain conditions under which an increased demand for accuracy of positioning becomes necessary. This approach is compliant with IMO Resolution *A.915(22)* providing the “Revised Maritime Policy and Requirements for a Future Global Navigation Satellite System (GNSS)” [4] and defining performance requirements in relation to specific navigational phases, nautical applications as well as diversity of maritime professions.

Chapter 4 starts with a short summary about existing performance specifications and general aspects of positioning and ranging. The chapter also discusses performance identifiers and the key elements to take into account such as reference frames

Chapter 5 gives an overview of technical systems and services supporting positioning and ranging and their capability to provide high-accuracy.

Chapter 6 describes from a high level perspective methods for high-accuracy positioning and ranging. It classifies these methods into those that are able to provide an absolute positioning in a given datum, and those that provide ranging and attitude information from a given point.

For a harmonized description of high-accuracy systems and services, chapter 7 provides a list of implementation and operation aspects which must be considered from an operational point of view and that should be covered by specific guidelines for each high-accuracy technology.

Chapters 9 and 10 list abbreviations and references used, respectively.

2. BACKGROUND

By using one of the first GNSS (GPS, GLONASS) it was possible to determine horizontal position with an accuracy of several tens of metres. In the 1990s, GNSS augmentation systems such as IALA Beacon DGNSS [1,2] were developed and established to provide correction data for GPS or GLONASS signals. These services made it possible to meet the IMO requirements for position accuracy and integrity for navigation in coastal areas. Where GNSS is not able to provide sufficient positioning accuracy and integrity for more demanding applications, enhanced GNSS augmentation services, as well as alternative and complementary localization systems are suitable approaches for high accurate positioning and ranging.

The demand for systems and services for high-accuracy positioning and ranging results from specific navigational manoeuvres (e.g., automatic docking) as well as specific nautical applications (e.g., automatic track control in critical areas, dynamic positioning, pilotage). Due to the safety critical aspects of such situations and areas the system and data integrity should be monitored and evaluated.

3. APPLICATIONS

Numerous existing and potential navigational applications may only be realized if appropriate systems and services enable high-accuracy positioning and ranging. Navigational applications may require assistance functions supporting bridge teams with respect to situation awareness, evaluation, and management. The partial or complete realization of navigational tasks by system functions (e.g., automatic docking) represents a more challenging scenario.

An increasing level of automation reduces the potential influence of bridge teams to detect and compensate for uncertainties, inaccuracies, and malfunctions in navigational systems. This reinforces the need for integrity of high-accuracy positioning and ranging.

Each application determines the requirement for either absolute or relative positioning or ranging. For certain applications it may be sufficient to determine the distance to obstacles or other traffic participants.

Table 1 gives example tasks and applications for high-accuracy positioning and ranging and describes the purpose of assistance or system functions. These examples cover a range of activities applicable to coastal, ports and inland waterways.

Table 1 - Example tasks and applications for high-accuracy positioning and ranging

Tasks and applications	Purpose of assistance or system function	Ranging approach	Positioning approach
Docking	During docking it is necessary to prevent collision of ship's hull with infrastructures.	Distance measurements to determine ship's hull in relation to infrastructure	Position based determination of attitude of ship hull in relation to infrastructure within georeferenced frame
Locking	During entry and exit of the lock it is necessary to prevent collision of ship's hull with the lock infrastructure.		
Passage of narrow channels	During the passage of narrow channels, it is necessary to prevent collision of ship's hull with side of channel.		

Tasks and applications	Purpose of assistance or system function	Ranging approach	Positioning approach
Turning	Turning manoeuvres of ships are necessary in port and harbours to arrive or depart the shipping berth. Especially during the turning of large-size vessels in areas with limited manoeuvring space it is necessary to prevent groundings or collisions with harbour infrastructure.	Distance measurements to determine ship's hull in relation to available navigation space	Position based determination of attitude of ship hull in relation to available navigation space within georeferenced frame
Passage under bridges	The size of bridge arches determines the available passage width (similar to passage of narrow channels) as well as the available clearance. Size of bridge arches, varying water levels and load-dependent ship air draughts have to be taken into account to avoid collision.		
Passage over shallows (under keel clearance)	Varying water levels and load-dependent ship draughts have to be taken into account to avoid groundings.		
Track control	Track control systems serve the automatic steering in a variety of navigational situation ranging from sailing through narrow straits to transoceanic voyages. The demand for accurate positioning may increase to sub-metre level if ship navigation uses track control in areas temporary or permanently restricted by obstacles at sea or on ground.	n/a	Position based determination of achieved position in relation to target position
Dynamic positioning (DP)	A dynamic position system maintains ship's position and heading in relation to a fixed point over ground (absolute) or to the position/attitude of an object (relative).	Distance measurements supporting relative DP	Position and heading reference systems to determine difference between current and required position/attitude

n/a: not applicable

4. PERFORMANCE SPECIFICATION

4.1. MARITIME APPLICABLE REGULATION

IMO Res. *A.1046* (27) [5] provides recommendations on radio navigation systems and services used worldwide for ship positioning. The document specifies for general ship navigation in ocean waters that the horizontal position accuracy (HPA) should be better than 100 m with a probability of 95%. If practicable, integrity warnings should inform about the occurrence of system malfunctions, non-availability or discontinuities by future Maritime Safety Information (MSI) systems. The position error should be below 10 m with a probability of 95%, if radio navigation systems serve the determination of ship's position in harbour entrances, harbour approaches, and coastal waters.

Position accuracies in the sub-metre range are expressed only by IMO Resolution *A.915(22)* [4] providing the "Revised Maritime Policy and Requirements for a Future Global Navigation Satellite System (GNSS)". The document specifies that the absolute HPA should be better than 1 m for ship's navigation in port areas. The same criteria apply to hydrography, cable and pipeline laying, management of marine aids to navigation (AtoN), and subsidence monitoring of offshore platforms. An increased HPA requirement (< 0.1 m, absolute) is specified for automatic docking, construction and dredging. In addition, hydrography, dredging and construction work are application areas, which require vertical position accuracies (VPA, absolute) better than 0.1 m. For the operation of tugs, pushers and icebreakers, resolution *A.915*(22) [4] specifies a requirement for relative position accuracy better than 1 m. Most of these application scenarios are safety-relevant and encompass additional requirements for integrity. Integrity may be assumed if the position data meets the requirements for data performance e.g., accuracy and latency.

Resolution *A.915*(22) [4] states integrity monitoring requirements for alert limits (AL), time to alarm (TTA), and integrity risk (IR). Alert limits, the thresholds for tolerated inaccuracy, are defined as two-and-a-half times given HPA and VPA. The TTA (tolerated time delay between the occurrence of a significant error and its indication) should be less than 10 s in all cases. The IR (probability that an alert-relevant event remains undetected or unindicated) should be less than 10^{-5}. The specification of performance parameters is a prerequisite for the implementation of integrity monitoring and the indication of monitoring results.

There may be other tasks and applications, which may benefit from high-accuracy positioning and ranging which are not covered by these IMO standards.

4.2. POSITIONING AND RANGING

Absolute positioning provides the position of an object in a specified coordinate system. Each task or application specifies the demand on position either as point in a horizontal plane on the earth surface or as a point in the 3-dimensional space. Relative positioning provides position information of an object in relation to the position of another object.

Ranging stands for techniques to measure the distance between two objects or points. The techniques may use one-way or two-way runtime measurements of electromagnetic waves. Alternatively, distance measurements can be derived from relative or absolute positioning. In both cases the measuring principle as well as environmental conditions determine, if long or short distances are reliably measurable with the intended accuracy.

The performance of systems and services enabling high-accuracy positioning or ranging should be specified in relation to the aimed results. Results at user site may be:

a absolute position X(t)=[x, y, z, t] in a defined reference system;

b relative position ΔX(t)=[Δx, Δy, Δz, t] in relation to a static or dynamic reference point in the same reference system;

c distance |ΔX(t)| in relation to a reference point or distance between 2 positions;

d distances of ship's hull to certain obstacles (e.g., distance to quay wall, clearance to bridge arches).

Systems for high-accuracy positioning and ranging provide data products containing 3-dimensional, horizontal or vertical positions, distance vectors, or distances (see Table 2). These systems are often composed of a combination of a basic system (e.g., GNSS), augmentation systems (e.g., DGNSS services) and user terminals (e.g., GNSS/DGNSS receiver). The chosen system architecture determines which positioning and ranging techniques may be applied and, consequently, whether the system can meet the performance requirements with its data output (demand on data, data rate and data quality taking into account the diversity of intended applications). An unambiguous meaning of provided positions and range measurements may be assumed if the used reference systems and the applied transformation are specified too.

Table 2 - Potential output data of systems for high-accuracy positioning and ranging

positions			**distances**			**time**
component x	horizontal position	3-dimensional position	component dx	distance over ground	3-dimensional distance	reference to UTC
component y			component dy			
component z	vertical position		component dz	altitude, depth, or clearance		

Positioning and ranging are related to each other, from a mathematical as well as a methodical viewpoint:

- A vector is able to describe the absolute as well as the relative position of a point in the 3-dimensional space. Effectively, each vector component indicates the distances in the direction of a single axis to the origin of coordinate system (absolute position) or to a reference point in the same coordinate system (relative position). Therefore, the magnitude of the vector provides the distance to the origin or to the used reference point.
- For hundred of years combinations of distance and bearing measurements to distinct points (e.g., stars, lighthouse, church steeple) enabled the determination of relative and absolute positions. Today, modern technologies use the interconnection between ranging and positioning. A representative example is positioning with GNSS, where the availability of 4 or more distance measurements to GNSS satellites is the prerequisite to determine the coordinates of the unknown spatial antenna position including the offset between GNSS receiver and system time.
- Specialized DGNSS (e.g., real-time kinematic (RTK)) services exploit relative measuring and processing techniques in signal and position domain to support high accurate positioning in their coverage area.

4.3. PERFORMANCE PARAMETERS

The performance of systems and services proposed for high-accuracy positioning and ranging should be described unambiguously to enable the identification of suitable solutions in relation to specific needs. Furthermore, monitoring and evaluation of operational systems and services require the specification of suitable performance criteria as well as the provision of methods for their determination.

This section gives an overview of performance terms[1] and parameters, which are used to describe required system or data performance:

- *Accuracy*, specified by the *PROBABILITY* [%] that the data provided is within the specified *ERROR THRESHOLD* [m] (e.g., horizontal position error should be below 10 m in 95% of all provided positions);
- *Latency*, specified as the maximum *TIME DELAY* [s] between data surveying (time point of measuring) and providing (time point of provision or indication);
- *Continuity*, specified as the *PROBABILITY* [%] that in a certain (short) *TIME PERIOD* [s] the data provision is performed continuously and meets the accuracy and integrity requirements;
- *Availability*, specified as the *PERCENTAGE OF TIME* [%] that in a certain (long) *TIME PERIOD* [s] the data provision is performed and meets the accuracy and integrity requirements;
- *Update rate*, specified by the *FIXING INTERVAL* [s] (time increment between data provided succesively) to define the time resolution of data determined;
- *Coverage*, specified as specific area (e.g., *GEO-REFERENCED PARAMETERS*, *CO-ORDINATES*) where high-accuracy positioning or ranging is required and supported; and
- *Alert limit*, specified as the *THRESHOLD* [m] for the maximum allowed error before an alarm is triggered.

Integrity is defined as the ability of a system to provide users with information within a specified time when the system should not be used for navigation [4]. Requirements for integrity monitoring performance parameters are specified by:

- *Time to Alarm*, specified as the tolerated ***TIME DELAY*** [s] between the occurrence of an error and its indication; and
- *Integrity Risk*, specified as the ***PROBABILITY*** [%] for a certain (short) ***TIME PERIOD*** [s] that a violation of accuracy requirements remains undetected.

The provision of positions or distances should be time-synchronized with the provision of associated integrity data.

Further infomation regarding interdependencies of the performance parameters for latency and accuracy are described in Appendix A.

The performance terms and parameters listed above are sufficient to specify the requirements for system data output. During system development the requirements for the whole system (e.g., availability of output data or accuracy of data content) should be mapped on single system components. During formulation of technical requirements for shore systems and services, the performance terms and parameters should be used.

Due to the diversity of user equipment as well as unknown environmental conditions it is impossible for the system and service provider to determine the accuracy and integrity of data output achieved at the user equipment. At best, systems and services can only provide estimates for accuracy and integrity achieved at system output. The confidence of provided alerts and integrity data depends on the significance and correctness of determined performance indicators.

Coordinates determined using an electronic positioning system should preferably be in the same reference frame (see section 4.4 for more information) as the (electronic) nautical charts that are in use and the charts accuracy should be also taken into account.

Most of the performance terms and parameters are probability statements regarding the operational performance of systems and services. Unambiguous specification of them requires information concerning measuring periods and evaluation conditions.

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[1] Various definitions can be found in IMO Resolution *915 [4]* or IALA dictionary [12].

4.4. PRECISE REFERENCE FRAMES

In order to accurately determine absolute position coordinates, a reference system and its real-life realization called reference frame are needed. There exist multiple reference systems globally and locally with their associated reference frames and datum. These three different concepts are defined as:

- Reference system: It constitutes a set of prescriptions and conventions together with the modelling required to define origin, scale (in distance and time), orientation and time evolution to define a point location in the space along the time. There are several definitions that may be done, although the most used in the maritime domain is the ITRS[2]
- Reference frame: It is a set of points with their 3-dimensional Cartesian coordinates which realize an ideal reference system. The realization of ITRS, the ITRF[3], is based on the coordinates and velocities of a set of stations observed by VLBI, LLR, GPS, SLR, and DORIS.
- Datum: Set of parameters defining a coordinate system (latitude, longitude and height), together with a collection of points whose geometrical relationships are known through measurement or calculation. They usually define a reference revolution ellipsoids that represent the Earth surface. The datum commonly used in GNSS is the WGS84, which is also based in successive realization of ITRF.

Use of different reference frames without coordinate transformation may cause offset between the actual position and position shown in the chart or when two position are compared.

5. CLASSIFICATION OF SYSTEM AND SERVICES

Generally, systems for high-accuracy positioning and ranging comprise several technological components to perform the diversity of functions – from measuring, via analysing to service and data provision. Representative examples of positioning and/or ranging systems are Global Navigation Satellite Systems (GNSS), Radar systems, Lidar systems, or Sonar systems. Augmented GNSS and Laser Ranging Systems are most likely to deliver "high-accuracy" capability. Moreover, augmented GNSS systems are able to provide the user not only with correction data but also with integrity information. In addition, the combined use of different systems (e.g., augmented GNSS and Lidar) is a typical approach to increase continuity and availability of positioning and ranging for a user.

The following Table 3 and **Error! Reference source not found.** give an overview about the wide range of systems and assigned services used for positioning and ranging in the maritime domain. It should be noted, that not all of the systems listed are able to support high-accuracy positioning or ranging. More information is provided by the IALA NAVGUIDE [9] and IALA World Wide Radio Navigation Plan [11].

Table 3 - Example systems enabling positioning and ranging

Type of system	Primary means for	Examples	Service(s)	Coverage	Provides high-accuracy
Global Navigation Satellite System (GNSS)	Positioning and timing	GPS GLONASS Galileo BEIDOU	SPS, PPS SPS, PPS OS, PRS, HAS OS, PRS, PPP	Global	No, No No, No No, No, Yes No, No, Yes

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[2] https://www.iers.org/IERS/EN/DataProducts/ITRS/itrs.html

[3] https://www.iers.org/IERS/EN/DataProducts/ITRF/itrf.html

Type of system	Primary means for	Examples	Service(s)	Coverage	Provides high-accuracy
Regional Navigation Satellite System	Positioning and timing	QZSS NavIC(a)	SPS, SLAS, CLAS SPS, PPS	Regional	No, No, Yes No, No
Terrestrial Navigation System	Positioning and timing	LORAN-C, eLORAN, CHAYKA, R-Mode	n/a	Regional	No
Radar	Radio detection and ranging	X-band radar S-band radar	n/a	Local	No(b)
Lidar/Laser	Light detection and ranging	Laser Ranging	n/a	Local	Yes
Ultrasonic	Sound detection and ranging	Eco Sounder	n/a	Local	Yes
Sonar	Sound detection and ranging	Active Sonar Passive Sonar	n/a	Local	No

n/a – not applicable

(a) Former known as IRNSS

(b) May enable high-accuracy in the future.

Table 4 - Example systems improving positioning and ranging

System	Primary means for	Examples	Service(s)	Coverage	Provides high-accuracy
Satellite Based Augmentation Systems (SBAS)	Provision of GNSS-related correction and integrity data	WAAS	n/a	Regional	No
		EGNOS	OS, SOL		No
		MSAS	n/a		No
		GAGAN	n/a		No
		SDCM	SPS, PPS(a)		TBC
		KASS	OS		No
		BDSBAS	OS		No
Terrestrial augmentation systems – code based DGNSS	Provision of GNSS-related correction and integrity data	IALA Beacon DGNSS	n/a	Regional, Local(b)	No, Yes
Terrestrial augmentation systems – phase based DGNSS	Provision of GNSS-related augmentation and integrity data	MGBAS, RTK	n/a	Local(b)	Yes
Systems that support Precise Point Positioning (PPP)	Provision of GNSS-related correction and integrity data	IGS	RTS	Global	Yes

System	Primary means for	Examples	Service(s)	Coverage	Provides high-accuracy
Radar Beacon (RACON)	Radio detection and ranging	Lighthouses, Navigation buoys	n/a	Local	No

n/a – not applicable
(a) Restricted service for the area 200 km around base stations
(b) Different communication channels provided by e.g., AIS or VDES could be used

Besides the systems and services mentioned in Table 3 and Table 4 there are commercial systems and services available which can provide high-accuracy positioning and ranging.

6. METHODS FOR HIGH-ACCURACY POSITIONING AND RANGING

The following sections provide a high-level view about the systems and assigned services used for positioning and ranging in the maritime domain. They are classified in those technologies able to provide high-accuracy positioning and ranging respectively. Finally, the most used integrity concepts and interfaces are described

6.1. ABSOLUTE POSITIONING

High-accuracy technologies able to provide an absolute positioning are those which outputs a complete state vector that allows mariners to know their position on the Earth surface. All of the following technologies are augmentation of core GNSS constellation services. Some of these technologies make use of the known position of a reference station within their computation.

There are other elements that shall be taken into account in order to provide a precise positioning and make positioning comparisons. Elements such if positioning is referred to phase centre of the antenna the vessel geometry are some of those key elements.

6.1.1. DGNSS

DGNSS includes several techniques, which increase accuracy and integrity of user position by decreasing the influence of ranging errors.

IALA Beacon DGNSS is a dedicated code based maritime service providing range and range rate corrections for each GNSS signal received at a reference station. The augmentation data is transmitted to users in the vicinity of the reference station to enable them to correct their own range measurements. Due to spatial decorrelation of propagation effects, the accuracy of correction techniques decreases with increasing distance from the reference station. Although the coverage area of IALA Beacon DGNSS is usually around 100 km from a reference station, sub-metre accuracies may only be possible at close distances.

6.1.2. RTK

Real Time Kinematic (RTK) is a phase based differential GNSS technique providing code and carrier measurements for all in-view satellites via a reference station. RTK may operate with single frequency and dual frequency GNSS measurements; however, multi-frequency data processing is expected to become practicable soon. The use of dual frequency RTK should be preferred due to a better mitigation of ionospheric propagation effects, faster ambiguity solution, and consequently an improved availability of high-accurate position results. A successful fixing of unknown ambiguities of phase measurements is a prerequisite for high-accuracy position results. Therefore, RTK requires stable receiving conditions of radio signals in order to provide the required performance.

RTK based positioning assumes a high correlation between ranging errors observed at reference station site and ranging errors occurred at user site. Therefore, the preferred application area should be close to a reference station (up to 10 and 20 km) depending on the available radio link for the transmission of RTK augmentation data.

Furthermore, the application of RTK requires that range and phase measurements at the reference station are transmitted to the user with a sufficient update rate and preferably without significant latencies. The communication channel should have a sufficient bandwidth to distribute RTK augmentation data.

With network RTK approach the decorrelation effects are negligible.

Typically, RTK services do not provide integrity information, however, future methods for RTK integrity monitoring which consider safety relevant maritime applications are being developed.

RTK with fixed ambiguities enables position accuracies better than 0.1 m. With unfixed ambiguities (float solution), the inaccuracy of position may achieve few decimetres.

6.1.3. PPP

Precise Point Positioning (PPP) is a method for global absolute positioning combining usually multi-frequency GNSS phase measurements with provided precise satellite orbits and clock corrections. PPP data products are generated based on the measurements of a global or regional network of GNSS monitoring stations. Local effects must be compensated at the user side when the PPP service provider does not offer data for regional or local corrections. If single frequency phase measurements are used, additional precise ionosphere models have to be considered. Once the PPP corrections are calculated, they are delivered to the end user via satellite, over the Internet or any other dissemination mean. These corrections are used by the receiver, resulting in decimetre-level or centimetre-level positioning with no close GNSS reference station required to have communication with.

PPP enables high accurate positioning, but it strongly depends on precise satellite orbit and clock error estimations, the number of tracked satellites and the time of continuous phase measurements without signal interruption. The main error sources for PPP are mitigated by Dual-Frequency Operation, External Error Correction Data, Modelling or PPP Filter Algorithms. A typical PPP solution requires a period of time to converge to dm or cm accuracy in order to resolve any local biases such as the atmospheric conditions, multipath environment and satellite geometry. The actual accuracy achieved, and the convergence time required is dependent on the quality of the corrections and how they are applied in the receiver.

A communication channel from computation centre to the user is continuously needed.

Currently, there are two types of consolidated PPP implementations. One is to obtain post-processed solutions and the other is to have real-time solutions. Post-processed PPP solutions have been in use for many years and generally achieve better results than real-time solutions. The main difference between the two implementations is that, post-processed solutions the correction is applied after taking the measurements using the corrections available from the manufacturer, while real-time solutions require precise orbit information and clock corrections to be sent in real-time to the GNSS receiver location.

6.1.4. PPP/RTK

The PPP-RTK method combines the advantages of precise positioning accuracy and fast convergence time in the RTK method and the wide coverage and low data bandwidth of the PPP method. It is a technology that enables users to obtain centimetre-level performance within several minutes by estimating from a reference station network. Instead of observation space representation (OSR) that requires a lot of bandwidth like RTK, correction information can be provided to many users using a variety of communication media by using a state space representation (SSR) with a small bandwidth like PPP. In particular, as multi-constellation is used, only the number of satellite-related correction information increases, so the bandwidth burden of correction information is reduced compared to RTK.

The correction information of PPP-RTK provides atmospheric errors as well as satellite orbit and satellite clock like PPP. In particular, in RTK, as the distance from the reference station increases, the ionospheric delay increases, resulting in service coverage restrictions. And PPP provides a float solution because it is not possible to accurately eliminate ion layer errors. However, PPP-RTK can be provided based on a global reference station network as well as a regional or national reference station network like RTK. By providing users with not only satellite-related errors but also atmospheric correction information, centimetre-level accuracy can be obtained with fixed ambiguity solution like RTK.

6.2. RANGING

High-accuracy technologies able to provide ranging are those which outputs a very accurate distance measurement from the emission device to a specific target. They allow to know a high rate measurement of distance to the objective and some of them also provide the relative angle towards or from these measurements are taken.

6.2.1. LASER RANGING

Laser ranging is a method where a bundled light beam is used to measure the distance between an emitter of the light beam and an object which reflects the light beam. With respect to navigational applications, runtime measurements are used to calculate a range between emitter and object.

For runtime measurement a light pulse is emitted, and the time is measured until the ray of light is reflected to the emitter. The distance L can be estimated by $L = c^* \Delta t/2^*n$ (with c = speed of light, Δt = measured runtime, n – refraction index). The runtime measurement has a very short reaction time and covers a measurement range up to tens of kilometres. The accuracy is in the range of a few centimetres.

Mirrors and prisms can be used as dedicated reference objects to improve reflection capability of the object and enhance accuracy.

Those systems usually with an onshore deployment are focused on the measurement of distance of the vessel hull to the shore/dock. One LASER ranging sensor is typically used for each distance measure at different points of the remote object/vessel. Depending on the type of application, accuracy of cms or even less could be achieved.

6.2.2. LIDAR

At first glance, the technical approach of LIDAR technology is similar to the one of LASER ranging. It measures the distance from a laser emitter to an object or surface to be determined using a pulsed laser beam or phase based. The distance to the object is determined by measuring the delay time between the emission of the pulse and its detection through the reflected signal.

However, LIDAR applications are focused on obtaining a *cloud of points* by taking them by means of a laser scanner. Two movements are combined to perform this scan when used in a dynamic emitter scenario. A longitudinal one given by the emitter trajectory and another transversal by means of a mobile mirror that deflects the laser light beam emitted by the scanner.

Measures from vessels, drones or others can be made using LIDAR technology into different applications. Accuracy of the measured distance under several tens of cms to cms could be achieved depending on the application and sensor features. Augmentation systems, motion sensors or other external aids could be applied to the emitter in order to improve the absolute position of the cloud of points.

6.2.3. ULTRASONIC SENSORS

Those sensors are used in different applications over and under the water in several applications even beyond the maritime one. For the scope of this guideline, eco sounder technology is relevant and using ultrasonic sensors to measure the distance to the depth of the water. A transducer into the eco sounder transmits the sound pulses under the water. Concurrently, the eco sounder is able to receive the echo reflected from the depth. The measure of the distance to the bed is estimated based on the measure of the time between the emission of the sound pulses and the received echo.

The use of digital nautical charts versus the measures of the water depth (based on an eco sounder) could lead to a relative positioning of the vessel with high accuracy when an estimated location is known in advance.

Similarly, as laser ranging, ultrasonic sensors may be used also for the measurement of distance of the vessel hull to the shore/dock.

Typical distance accuracy of 0.5 metres at 20m range could be obtained in line with required standards as the example of US Army Corps of Engineers publication *EM110-2-1003*.

6.3. INTEGRITY CONCEPTS

Integrity will be considered in detail as part of the Resilience PNT guideline. The Resilient PNT Guideline is currently under development and a reference will be added here in due course.

6.4. INTERFACES

High accuracy systems and services provide various types of information through various channels. In particular, in the high accuracy system and service, not only single information-based positioning but also multiple information-based positioning can be made. In addition, as the use of unmanned aerial vehicles becomes possible, the integrity and accuracy of information become important. In the end, the interface should be defined so that the system considers the correction age and information combination of the corresponding information. This is important not only for absolute positioning but also for ranging.

In the high accuracy service, there is a proprietary message for each service and system in addition to the information currently defined in RTCM. However, in common, information for time synchronization of correction information and correction age should be specified. Nowadays, the most common used interfaced messages on this topic are following RTCM 3.3.[4]

7. SYSTEM IMPLEMENTATION AND OPERATIONAL ASPECTS

This chapter provides guidance for the description of high-accuracy positioning and ranging systems as individual Guideline. Furthermore, the implementation principles for harmonized system architectures of shore-based infrastructures written in IALA Guideline G1113 [6] should be taken into account.

7.1. SHORE SITE ARCHITECTURE

Table 5 - Shore Site Architecture

Topic	Description
Schematic structure of the system and/or service	Block diagram and general description of all required hardware and software components and their functions
Data acquisition and dedicated interfaces	Description of the interfaces and methods for the collection of the required input data (e.g. single site approach or network based approach)
Data processing	Description of methods for the processing of the input data and integrity monitoring
Composition of data products	Description of methods for the provision of all output data

7.2. TRANSMISSION SERVICES

Table 6 - Transmission Services

Topic	Description
Interfaces	Description of the required hardware interfaces between the system/service and a user device

Topic	Description
Protocols and formats	Specification of the used layers, the encapsulation, and protection of data (including data security)
Performance parameter	Description of details concerning the aspects of operational performance specification e.g., bandwidth, latency, coverage, availability, and continuity

7.3. TECHNICAL IMPLEMENTATION

Table 7 - Technical implementation

Topic	Description
Components for the acquisition and processing of data	Detailed description concerning the installation of all system and/or service components required for data acquisition and processing
Components for the transmission of data	Detailed description concerning the installation of all system and/or service components required for data transmission
Adjustment of a measuring system	Operations for the calibration of measuring sensors and systems

7.4. OPERATIONAL ASPECTS

Table 8 - Operational aspects

Topic	Description
System Performance	Specification concerning accuracy, integrity, continuity, availability, coverage of the system and/or service
System Safety Performances	Specification regarding the safety level provided by the system and/or service
System Maintenance	Activities (e.g., tests, measurements, replacements, adjustments and repairs) intended to retain or restore the functionality of the system and/or service
System Performance Verification	Activities covering the verification of the offered services by monitoring service performance
Publication of information	Information about the system and/or service (e.g., MSI, handbooks, papers etc.)

8. DEFINITIONS

The definitions of terms used in this Guideline can be found in the *International Dictionary of Marine Aids to Navigation* (IALA Dictionary) and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

9. ABBREVIATIONS

AIS	Automatic Identification System
AL	Alert Limit
AtoN	Marine Aid(s) to Navigation
BEIDOU	Chinese Global Navigation Satellite System
CHAYKA	Russian long range navigation system
CLAS	Centimetre Level Augmentation Service
DGNSS	Differential GNSS
DP	Dynamic Positioning
EGNOS	European Geostationary Navigation Overlay Service
eLORAN	enhanced LORAN
GAGAN	GPS Aided Geo Augmented Navigation
Galileo	European GNSS
GBAS	Ground Based Augmentation Service
GLONASS	Russian Global Navigation Satellite System
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite System such as Galileo, GPS, GLONASS or BEIDOU.
GPS	U.S. Global Positioning System
HPA	Horizontal Position Accuracy (absolute)
HPE	Horizontal Position Error (absolute)
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IEC	International Electrotechnical Commission
IGS	International GNSS Service
IMO	International Maritime Organization
IR	Integrity Risk
IRNSS	Indian Regional Navigation Satellite System
LORAN-C	Version three of Long Range Navigation system
MGBAS	Maritime GBAS
MSAS	Multi-functional Satellite Augmentation System
MSI	Maritime Safety Information
NavIC	Navigation with Indian Constellation
OS	Open Service
P	Probability
PNT	Position, Navigation, and Time
PVT	Position, Velocity, and Time
PPP	Precise Point Positioning
PPS	Precise Positioning Service
PRS	Public Regulated Service
QZSS	Quasi-Zenith Satellite System
RACON	Radar Beacon
RTK	Real Time Kinematic

RTS	Real-Time Service
SBAS	Satellite-based Augmentation System
SDCM	System of Differential Correction and Monitoring
SLAS	Sub-meter Level Augmentation Service
SOL	Safety of Life
SPS	Standard Positioning Service
TTA	Time to Alarm
VDES	VHF Data Exchange System
VPA	Vertical Position Accuracy (absolute)
VPE	Vertical Position Error (absolute)
VRS	Virtual Reference Station
WAAS	Wide Area Augmentation System
WWRNS	World Wide Radio Navigation Systems

10. REFERENCES

[1] IALA Recommendation R-121 Performance and Monitoring of DGNSS Services in the Frequency Band 283.5 – 325 kHz, Edition 2.0, May 2015.

[2] IALA Guideline G1112 Performance and Monitoring Of DGNSS Services in the Frequency Band 283.5 – 325 kHz, Edition 1, May 2015.

[3] IALA Guideline G1113 Design and Implementation Principles for Harmonized System Architectures of Shore-based Infrastructure, Edition 1.0, May 2015.

[4] IMO Resolution A.915(22), Adopted on 29 November 2001 (Agenda item 9), REVISED MARITIME POLICY AND REQUIREMENTS FOR A FUTURE GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS).

[5] IMO Resolution A.1046(27), Adopted on 30 November 2011 (Agenda item 9), WORLDWIDE RADIONAVIGATION SYSTEM.

[6] IMO MSC/Circ. 645, Adopted on 6 June 1994, Guidelines for Vessels with Dynamic Position Systems.

[7] IALA Recommendation R-135 Future of DGNSS, Edition 1, December 2006.

[8] IALA Recommendation R-129 GNSS vulnerability and mitigation measures, Edition 3, December 2012.

[9] IALA NAVGUIDE 2014.

[10] IMO Guideline MSC.1/Circ.1575, GUIDELINES FOR SHIPBORNE POSITION, NAVIGATION AND TIMING (PNT) DATA PROCESSING.

[11] IALA World Wide Radio Navigation Plan, Edition 2, December 2012.

[12] IALA Dictionary

[13] IEC 61108, Maritime navigation and radiocommunication equipment and Global Navigation Satellite Systems. Receiver equipment. Performance standards, methods of testing and required test results

ANNEX A FURTHER INFORMATION ABOUT PERFORMANCE PARAMETERS

A.1. LATENCY AND ACCURACY

High-accuracy positioning and ranging is more sensitive to latencies in processing, provision, utilization and indication of data.

Moving satellites and users as well as changing environmental conditions are the main reasons that augmentation data provided by DGNSS services are limited to their temporal validity. The applied positioning and ranging method as well as the required accuracy determine the maximum tolerable time delay between generation and use of augmentation data. A correction technique is less sensitive to dynamic errors, if the temporal behaviour of these errors may be described and predicted (e.g., by first coefficients of a Taylor series around a reference time point).

It is also understandable that with increasing requirements for accuracy the necessity arises to decrease residual errors by improved determination of dynamic errors and additional mitigation of small-scale errors. Code-based DGNSS are based on range and range rate correction provided for ship positioning in coastal areas. Position accuracies better than 10 meters may be achieved using correction data generated by the DGNSS system few minutes before. In comparison, phase-based DGNSS techniques achieves only position accuracies in the sub-meter level, if at user site single- and double differenced observations may be derived from GNSS ranges and phases measured almost simultaneously at service and user site.

Decision finding in the context of navigational tasks is realized on position data provided and/or indicated by user equipment. Especially the provision of augmentation data (generation at service site and transmission to user site) takes time and leads to the situation that the indicated user position is not the current true position. The difference between both results from error in determined position and user movement during latency time. This should be taken into account, if requirements for position accuracies will be specified.

Figure 1 illustrates the problem, whereby the minimum update rate is used as the measure for the inverse of tolerable latency to reach a certain difference between the current and indicated position (below 1 metre or 0.1 metre) for a given change of position. So, a vessel with 5 knots speed needs at least a 2.5 Hz position update rate (assumed latency lower than 0.4 s) to provide the nautical staff with an accurate position of at least 1 metre on their displays, assuming an error-free position determination. The demand for higher accuracies (blue vs. red curve) results into requirements for higher update rates or lower latencies.

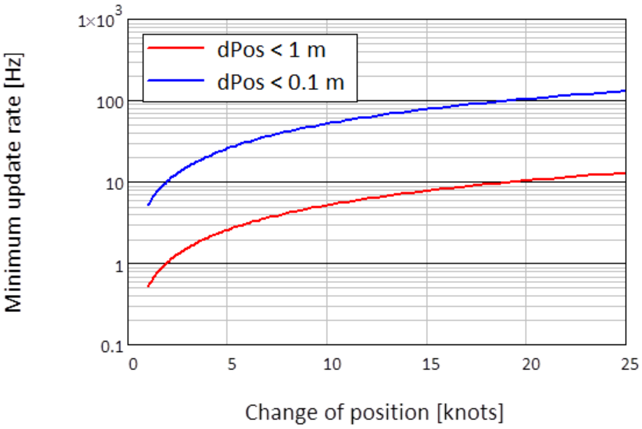

Figure 1 Inaccuracies of indicated positions due to latency of information

A.2. REMARKS ON AVAILABILITY

The term continuity and availability in section 4.2.1 is specified by the probability that data provided over a specific time period has fulfilled defined performance requirements. An availability of 99.8% over 30 days may stand for an interruption of data provision taking not more than 86.4 minutes over 30 days or 2.88 minutes per day (assuming unavailability is equally distributed over the days of a month).

If the availability considers the fulfilment of a certain accuracy level, the 0.2% will be spread across times of interrupted data provision and times of degraded data provision. However, then the 95% accuracy is automatically met. Alternatively, the availability evaluation considers only service level parameter as a prerequisite for accurate positioning or allows higher inaccuracies (e.g., alert limit as 2.5 times of desired accuracy).