|  |
| --- |
| IALA Guideline |

1XXX

Systems AND sERVICES for high accuracy positioning aND ranging

Edition 1.0 (Draft)

Document date

**19/09/2016**

Revisions to this IALA Document are to be noted in the table prior to the issue of a revised document.

|  |  |  |
| --- | --- | --- |
| Date | Page / Section Revised | Requirement for Revision |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

1. PURPOSE, SCOPE AND STRUCTURE OF THE DOCUMENT 5

2. REQUIREMENTS 5

3. USE CASES FOR HIGH ACCURACY POSITIONING 7

4. METHODS AND TECHNIQUES FOR HIGH ACCURACY RANGING AND POSITIONING 7

4.1. DISTANCE 7

4.1.1. OPTICAL RANGING 7

4.1.2. RADIO RANGING 7

4.2. POSITIONING 8

4.2.1. CODE BASED DGNSS 8

4.2.2. REAL TIME KINEMATIK 8

4.2.3. PRECISE POINT POSITIONING 8

4.2.4. DYNAMIC POSITIONING 8

5. HIGH ACCURACY SYSTEMS AND SERVICES 8

6. SYSTEM IMPLEMENTATION 9

7. ACRONYMS AND DEFINITIONS 9

7.1. Acronyms 9

7.2. Definitions 9

8. REFERENCES 12

List of Tables

Table 1 Requirements on system and service level parameters for specific maritime operations and applications with demand on high accuracy positioning [3] 5

Table 2 Use Cases for high accuracy positioning 7

Table 3 Methods/Techniques vs. Use Cases 8

Table 4 Performance levels of RTK services enabling high-accurate positioning in harbours 15

List of Figures

Figure 1 Main stages of GNSS data processing during service provision 16

Figure 2 Implementation of a phase-based DGNSS service taking into account supported transmission 17

# PURPOSE, SCOPE AND STRUCTURE OF THE DOCUMENT

Over the last decades, Global Navigation Satellite Systems (GNSS) have evolved as primary mean in the maritime community for worldwide absolute position fixing. By using one of the first GNSS (GPS, GLONASS) horizontal position accuracies (HPA) in the order of several 10 meters became possible. In the nineties, GNSS augmentation systems such as IALA Beacon DGNSS [1][2] has been developed and established to meet the requirements on position accuracy and integrity for ship’s navigation in coastal areas. Currently operational GNSS enable horizontal position accuracies of few meters under nominal conditions.

Specific applications or manoeuvres, as for example automatic docking but also the passing and operation of vessels in critical areas, may require very accurate positioning information for their safe and efficient execution.

To meet this requirement, additional systems, services and/or techniques are necessary to implement. Appropriate approaches are for example the extension of GNSS with augmentation systems or the use of systems supporting alternative localisation methods.

This Guideline describes maritime systems and services, which enable high accuracy positioning in specific areas with safety related requirements. Such specific areas are waterways and traffic zones with limited manoeuvring space, ports and harbours and areas with increased risks of collisions and groundings.

The term “high accuracy positioning” in this Guideline defines horizontal, and for some applications vertical positioning accuracies at sub-meter level.

Based on the requirements on high accuracy systems defined by IMO resolutions as well as additional user demands the document lists use cases, which are in relation to high accuracy positioning. Furthermore basic techniques and methods are described, which are suitable to achieve high accuracy ranging and positioning.

The Annexes are prepared as placeholder for a consecutive update of available and possible solutions for systems and services and contain the technical details within the scope of the design and implementation principles.

The document serves as information for stakeholders, operators and end users and supports the harmonization between service provision and their utilisation at shipside.

This guideline has drawn up as additional input for the further harmonisation of PNT-relevant service provision in the maritime domain.

# REQUIREMENTS

Minimum requirements on position and integrity are defined in IMO Res. A.1046 (27) [4]. Therein positioning accuracies for the shipping and navigation in ocean waters, coastal regions and/or port approaches are addressed.

The defined sub-meter level of accuracy is only in conformity with IMO Resolution A.915(22) providing the “Revised Maritime Policy and Requirements for a Future Global Navigation Satellite System (GNSS)” [3]. In the appendix 3 of this resolution three tables with minimum maritime user requirements for positioning for different operations and applications[[1]](#footnote-1) are given, whereby high accuracy requirements at sub-meter level are addressed to following operations and applications:

1. Requirements on system and service level parameters for specific maritime operations and applications with demand on high accuracy positioning [3]

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Operation Application | System level parameters | | | | | Service level parameters | | | Fix Interval |
|  | Accuracy | | Integrity | | | Availability | Continuity | Coverage |  |
|  | Hori-zontal | Vertical | Alert Limit | Time to alarm | Integrity risk |  |  |  |  |
|  | (metres) | (metres) | (metres) | (seconds) | per 3 hours | % per 30 days | % over 3 hours |  | (seconds) |
| Automatic Docking | 0.1 | N/A | 0.25 | 10 | 10-5 | 99.8 | 99.97 | Local | 1 |
| Hydrography | 1-2 | 0.1 | 2.5-5 | 10 | 10-5 | 99.8 | N/A | Regional | 1 |
| Dredging | 0.1 | 0.1 | 0.25 | 10 | 10-5 | 99.8 | N/A | Local | 1 |
| Construction works | 0.1 | 0.1 | 0.25 | 10 | 10-5 | 99.8 | N/A | Local | 1 |
| Cargo Handling | 0.1 | 0.1 | 0.25 | 10 | 10-5 | 99.8 | N/A | Local | 1 |
| Offshore platform subsidence | 1 | 0.1 | 2.5 | 10 | 10-5 | 99.8 | N/A | Regional | 1 |
| TBE |  |  |  |  |  |  |  |  |  |

For the sake of completeness, other manoeuvres may require high accuracy in positioning too, as for example bridge clearance (vertical accuracy), passing of locks (horizontal and vertical positioning), instantaneous operations between very close to each other operating vessels (horizontal accuracy), passing of vessels in narrow channels(horizontal accuracy) or automatic track control (horizontal accuracy).

In addition to the service and system level parameters, other performance parameters should be taken into account due to their direct or indirect influence on the determination of positioning solution. These cover:

1. Latency

Latency describes time lags induced by signal and data processing. Therefore at service site the latency describes the time lag between the tracking of signals and provision of service data. Latency at user site should also consider the additional delay induced by transmission of service data to the user.

Requirements on latency will be specified by demand on synchronisation accuracy and tolerable age of corrections.

1. Adjustment of a measuring system

The formal definition of calibration by the [International Bureau of Weights and Measures](https://en.wikipedia.org/wiki/International_Bureau_of_Weights_and_Measures) is as follows: “Set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured… Adjustment of a measuring system should not be confused with calibration, which is a prerequisite for adjustment.” [5]. For specific methods (see chapter 4) an adjustment will be mandatory.

1. Interfaces between systems
2. Protocols and formats
3. Required bandwidth

# USE CASES FOR HIGH ACCURACY POSITIONING

1. Use Cases for high accuracy positioning

|  |  |
| --- | --- |
| Use Case | Description |
|  |  |
| Automatic Docking | The docking of a vessel in a port/harbour or within an offshore area in an automatic way |
| Locking | The process of passing a vessel through a lockage including the process of entering and exit the lock |
| Bridge passage | The passage to a bridge with a very limited passage width and/or clearance |
| Cliff region passage | The passage of a safety relevant areas where either the pass through is temporary or permanently restricted by obstacles at sea or on ground |
| *Automatic track control* | TBE |
| *Passing of vessels in narrow channels* | TBE |

# METHODS AND TECHNIQUES FOR HIGH ACCURACY RANGING AND POSITIONING

## DISTANCE

### OPTICAL RANGING

Optical distance measurements comprise methods based on runtime measurements, phase relation or laser triangulation of light waves.

For a pure *runtime measurement* a light pulse is emitted and the time is measured until the ray of light is reflected to the source. The distance L can be estimated by L = c\* Δt/2\*n (with c = speed of light, Δt = measured runtime, n – refraction index).

The measurement of *phase relations* is a method to estimate the relative change of the distance between measurement object and reference mirror. The measurement range is frequency-depended and limited to a few hundreds of m.

*Laser triangulation* is an appropriate technique for range measurements on moved objects. In combination with a camera, a photodiode or a charge-coupled device sensor (CCD) the change in the angle is measured. Based on the change in position the range between the sensor and the measured object can be estimated using trigonometric functions. The measurement range is limited to shorter distances (around100 m) and depends on the surface of the measured object as well as the intensity of the laser-beam.

### RADIO RANGING

Radio ranging is based on a transmitter producing a short pulse of an electromagnetic wave. For the distance measurement the time is measured which the signal takes for the reflection to return. The distance is one-half the product of the round trip time and the speed of the signal (speed of light).

## POSITIONING

### CODE BASED DGNSS

The DGNSS technique consists of the determination of the GNSS position for an accurately-surveyed position known as reference station. Given that the position of the reference station is accurately known, the deviation of the measured position to the actual position and more importantly the corrections to the measured pseudoranges to each of the individual satellites can be calculated. These corrections can thereby be used for the correction of the measured positions of other GNSS user receivers [6].

### REAL TIME KINEMATIK

RTK is a relative positioning techniques combining GNSS measurements of one or more reference stations with own GNSS measurements to improve the accuracy of positioning. The technique applies carrier phase measurements from a reference station to a rover [7]. An essential prerequisite is the knowledge of the exact coordinates of the reference station(s). With RTK techniques, accuracies better than 0.1 m are possible. An individual RTK base station covers a service area spreading about 10 or 20 km.

### PRECISE POINT POSITIONING

The Precise Point Positioning (PPP) technique belongs to the absolute positioning techniques and is based on code and carrier phase measurements. It requires the availability of precise satellite orbit and clock correction data, which are estimated in real time by a network of worldwide distributed GNSS monitoring stations. It is a global position approach because its position solutions referred to a global reference frame defined by the geodetic datum of used satellite orbit data. To achieve accuracies better than 0.1 m a dual-frequency GNSS receiver is mandatory to remove the first order effects of the ionosphere [8].

PPP provides much greater coverage than the RTK approach. Otherwise, it requires a longer convergence time to achieve maximum performances. The convergence time can be in the order of tens of minutes but has to be considered for the initialization process only. Related to the accuracy it has to be taken into account, that the quality of the PPP solution is always depending on the quality of the provided data (satellite clocks and orbits).

### DYNAMIC POSITIONING

Dynamic positioning (DP) is a computer-controlled system to automatically maintain a [vessel](https://en.wikipedia.org/wiki/Marine_vessel)'s position and heading by using its own propellers and thrusters. Position reference sensors, combined with wind sensors, motion sensors and [gyrocompasses](https://en.wikipedia.org/wiki/Gyrocompass), provide information to the computer pertaining to the vessel's position and the magnitude and direction of environmental forces affecting its position. Dynamic positioning may either be absolute in that the position is locked to a fixed point over the bottom, or relative to a moving object like another ship or an underwater vehicle [9].

TBC by Kongsberg

# HIGH ACCURACY SYSTEMS AND SERVICES

The following table gives a generalized overview about the application of methods and techniques in relation to the use cases and reflects to the dedicated annexes.

1. Methods/Techniques vs. Use Cases

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Use Case  Method | Automatic Docking | Locking | Bridge passage | Cliff region passage | Automatic track control | Passing of vessels in narrow channel |
| Optical based distance measurement | x | X | x |  |  | x |
| Radio based distance measurement | x | x | x |  |  | x |
| Code Based DGNSS | - | - | x | x | x | x |
| Phase based DGNSS (RTK) | Annex A | Annex A | Annex A |  |  |  |
| PPP |  | x | x | x | x | x |
| DP 2 |  |  |  |  |  |  |

# SYSTEM IMPLEMENTATION

For the aspects of system implementation the implementation principles for harmonised system architectures of shore-based infrastructures written in IALA Guideline 1113 [10] should be considered and applied.

# ACRONYMS AND DEFINITIONS

## Acronyms

|  |  |
| --- | --- |
| BeiDou | Chinese Global Navigation Satellite System |
| DGNSS | Differential GNSS |
| GALILEO | European GNSS |
| GLONASS | Russian Global Navigation Satellite System (Глоба́льная навигацио́нная спу́тниковая систе́ма) |
| GNSS | Global Navigation Satellite System |
| GPS | U.S. Global Positioning System |
| HPA | Horizontal Position Accuracy (absolute) |
| HPA | Horizontal Position Accuracy (relative) |
| IALA | International Association of Marine Aids to Navigation and Lighthouse Authorities |
| IEC | International Electrotechnical Commission |
| IMO | International Maritime Organisation |
| MGBAS | Maritime Ground Based Station |
| PNT | Position, Navigation, and Time |
| PPP | Precise Point Positioning |
| RTK | Real Time Kinematic |
| WWRNS | World Wide Radio Navigation Systems |
|  |  |

## Definitions

|  |  |
| --- | --- |
| Accuracy | Accuracy is the degree of conformance between the estimated or measured parameter of a craft at a given time and its true parameter at that time. (Parameters in this context may be position co-ordinates, velocity, time, angle, etc.). Absolute accuracy (Geodetic or Geographic accuracy) means, that the accuracy of a position is estimated with respect to the geographic or geodetic co-ordinates of the Earth. Relative accuracy means, that the user is determining the position relative to that of another user of the same navigation system at the same time. |
| Alert Limit | The maximum allowable error in the measured position – during integrity monitoring - before an alarm is triggered. |
| Availability | Availability is the percentage of time that an aid, or system of aids, is performing a required function under stated conditions. Non-availability can be caused by scheduled and/or unscheduled interruptions. Signal availability is the availability of a radio signal in a specified coverage area. System availability specifies the availability of a system to a user, including signal availability and the performance of the user's receiver. |
| Continuity | The probability that, assuming a fault-free receiver, a user will be able to determine position with specified accuracy and is able to monitor the integrity of the determined position over the (short) time interval applicable for a particular operation within a limited part of the coverage area. |
| Coverage | The coverage provided by a radio-navigation system is that surface area or space volume in which the signals are adequate to permit the user to determine position to a specified level of performance. |
| Fix interval | The maximum time in seconds between fixes. position to a specified level of performance. |
| Integrity | The ability to provide users with warnings within a specified time when the system should not be used for navigation. |
| 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 instant of time at any location in the coverage area. |
| Latency | Latency is the time lag between the navigation observations and the presented navigation solution. |
| Precision | Precision is the accuracy of a measurement or a position with respect to random errors. |
| Time to alarm | The time elapsed between the occurrence of a failure in the system and its presentation on the bridge. |
| Differential system | An augmentation system whereby radio-navigation signals are monitored at a known position and the corrections so determined are transmitted to users in the coverage area. |
|  |  |
|  | |

# REFERENCES

1. IALA Recommendation R-121 on the Performance and Monitoring of DGNSS Services in the Frequency Band 283.5 – 325 kHz, Edition 2.0, May 2015
2. IALA Guideline No. 1112 on Performance and Monitoring Of DGNSS Services in the Frequency Band 283.5 – 325 kHz, Edition 1, May 2015
3. 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)
4. IMO Resolution A.1046(27), Adopted on 30 November 2011 (Agenda item 9), WORLDWIDE RADIONAVIGATION SYSTEM
5. JCGM 2008, International vocabulary of metrology — Basic and general concepts and associated terms (VIM), page 37
6. <http://www.navipedia.net/index.php/GNSS_Augmentation#Classical_DGNSS>
7. <http://www.navipedia.net/index.php/RTK_Fundamentals>
8. <http://www.navipedia.net/index.php/Precise_Point_Positioning>
9. <https://en.wikipedia.org/wiki/Dynamic_positioning>
10. IALA Guideline 1113 on Design and Implementation Principles for Harmonised System Architectures of Shore-based Infrastructure, Edition 1.0, May 2015
11. IALA Recommendation R-135 on the Future of DGNSS, Edition 1, December 2006.
12. IALA Recommendation R-129 on GNSS Vulnerability and mitigation measures, Edition 3, December 2012.
13. PERFORMANCE AND MONITORING OF MARITIME GROUND BASED AUGMENTATION SYSTEMS (MGBAS) FOR HIGH-ACCURACY POSITIONING IN PORTS
14. INTRODUCTION

This Annex to the Guideline ‘’ provides the design and implementation principles of Maritime Ground Based Augmentation Systems usable in a port/harbour environment for high-accurate absolute and/or relative positioning. High-accurate positioning means that the absolute and/or relative position accuracy (95%) is 0.1 m or better.

* 1. Scope of document

Global Navigation Satellite Systems (GNSS) are space-based systems providing navigation signals and information, whose use enables world-wide the determination of positioning, navigation and time data. GPS and GLONASS are the first GNSS available. Modernised GNSS include enhanced GPS and GLONASS along with new core constellations such as Galileo and BeiDou.

Differential GNSS (DGNSS) are means to provide augmentation services to improve the accuracy of GNSS-based positioning and to monitor the integrity. DGNSS involves having reference stations, at precisely known locations that provide real-time corrections and integrity information for GNSS signals. Therefore, DGNSS is not a stand-alone radio navigation system. DGNSS systems provide shore-to-ship services.

This existing IALA Guideline 1112 on Performance and Monitoring of DGNSS Services in the Frequency Band 283.5-325kHz describes the generation and broadcast of code based corrections with a focus on the maritime domain. The application of code-based DGNSS services enables that position accuracies of few meters up to few decimeters can be achieved depending on distance between reference site and user. IALA Recommendation R-135 on Future of DGNSS is introducing alternative technologies such as Real Time Kinematic (RTK) under consideration of technical progress of last decades. RTK has been identified as service supporting the application of phase-based differential positioning algorithm to achieve position accuracy of 0.1 m or better.

Neither GNSS nor DGNSS do inherently provide integrity information. However, code-based as well as phase-based DGNSS services are in the position to provide also integrity information in relation to used GNSS and provided DGNSS service. System failures as well as disturbances can result into significant errors for extended periods of time, without notifying the user. Maritime augmentation services should provide the user with integrity information to support the situation awareness of mariners in relation to current reliability and usability of applied navigation aids. The service provider should publish that they follow IMO and IALA Recommendations for the provision of DGNSS services, giving emphasis to the provision of integrity information. In addition to these Guidelines the following recommendations from IALA should be taken into account:

* Future DGNSS options are captured in R-135 [2]
* Vulnerability of GNSS systems is discussed in R-129 [3]
* Recommendation to National Members to provide DGNSS is captured in R-115 [4]
* IEC61108-4
  1. Structure of document

Chapter 2 …..

Chapter 3 …..

Chapter 4 ……

Chapter 5 ……

Chapter 6 …..

Appendices include various technical settings for evaluation and indication of GNSS and DGNSS status and integrity. The following appendices are included:

• Appendix A: Technical settings for GNSS and DGNSS evaluation

• Appendix B: Technical settings for integrity indication

1. PERFORMANCE REQUIREMENTS
   1. Definitions

System performance is characterized by a number of different aspects, including Accuracy, Integrity, Continuity, Availability and Coverage as defined in [2].

* 1. Positioning Performance Requirements

IMO Resolution A.1046 (27) details the minimum requirements on worldwide radio navigation systems considering vessels operating in ocean and harbour entrances, harbour approaches and coastal waters. The requirements are described by accuracy, integrity, availability, and continuity for positioning……

1. Performance levels of RTK services enabling high-accurate positioning in harbours

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

RTK Service providers should consider the appropriate number, and location, of reference stations to achieve sufficient coverage to ensure that these requirements are met in selected and/or complete harbour areas.

1. SHORE SITE ARCHITECTURE

This chapter deals with the shore site architecture of phase-based DGNSS services and follows the generalized DGNSS architecture introduced by [2]. Therefore, a phase-based DGNSS is composed by 2 subsystems:

* subsystem for the generation of GNSS augmentation service and
* the subsystem realizing the transmission service.
  1. GNSS Augmentation Service
     1. GNSS Data Acquisition
        1. Single site Approach:

….

* + - 1. Network based Approach:

….

* + 1. GNSS Data Processing

1. Main stages of GNSS data processing during service provision
   * 1. Composition of Service data products
     2. Performance Aspects
        1. Accuracy Aspects:
        2. Integrity Aspects:
        3. Continuity Aspects:
        4. Availability Aspects:
   1. Transmission Services
      1. tbd
      2. tbd
      3. tbd
      4. tbd
      5. Performance Aspects
         1. Latency
         2. Availability
         3. Continuity
         4. Monitoring of transmission
   2. Technical Implementation
2. Implementation of a phase-based DGNSS service taking into account supported transmission
   * 1. Components of GNSS augmentation services
        1. Reference Stations
        2. Monitoring Stations
        3. Communications
     2. Components of Transmission services
        1. Transmitter
        2. Transmission Monitors
        3. Communications
     3. Components for Remote Control
     4. Components for enhanced Monitoring
3. OPERATIONAL ASPECTS
   1. Operation and Maintenance:
   2. Performance Verification:
      1. Availability in the coverage area
      2. Continuity
      3. Verification of integrity monitoring
      4. Verification of Accuracy
   3. Publication of information:
4. APPENDIX A
5. APPENDIX b

1. With respect to operational requirements for worldwide radio-navigation systems as described in IMO Resolution A.1046(27) [4], the requirements on positioning accuracy for the navigation in harbour entrances, harbour approaches and coastal waters are only generally defined to be better than 10 m without any further specification. [↑](#footnote-ref-1)