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Satellite navigation systems applications, the main utilization limits for maritime users

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Abstract
Nowadays (October 2013) information about ship's position is obtained generally from specialized electronic positioning systems, in particular, at present functionally satellite navigation systems (SNS) as GPS and GLONASS, and satellite based augmentation systems (SBAS) as EGNOS, WAAS and MSAS. Two next SNS, Galileo and BeiDou, and two next SBAS, GAGAN and SDCM, are under construction. After all the user of these systems, the maritime user also, continually meets and will meet with numerous different limitations of SNS coverage in restricted area, SBAS and DGPS reference stations coverage area, the lack of integrity information about the systems, and of many charts referred to WGS–84 datum, with problem of position fix in restricted area, etc.

Introduction

Nowadays information about ship's position is obtained generally from specialized electronic positioning systems, in particular, at present functionally global satellite navigation systems (SNS) as the GPS and the GLONASS, and satellite based augmentation systems (SBAS) as EGNOS, WAAS and MSAS. Next SNS and next SBAS are under construction [1, 2, 3, 4, 5, 6]. SNS and SBAS are being developed and deployed by governments, international consortia and commercial interests. The generic name given to all these systems is Global Navigation Satellite Systems – GNSS.

The accuracy of all SNS has improved continually over the last years. However, the accuracy which can be expected today (October 2013) remains in the order of several meters (95% confidence level), which can prove inadequate for certain applications. IMO A.915(23) summarizes requirements on GNSS based on the specification of several horizontal position errors taking into account operation areas and applications. Other main utilization limits in SNS and SBAS applications concern the lack of full information about all details of these systems, the lack of many charts referred to WGS–84 datum, the availability of SNS in restricted area and SBAS at high latitudes, local interference, sensitivity to ionospheric effects and scrambling.

Information about satellite and based augmentation systems

As performance parameters and operation capability of GPS and GLONASS change permanently the user must have access to information about current status of these SNS. The information can be found in Internet but at sea in many cases this medium is not available for navigator. SNS status, which satellites are healthy and which unhealthy, theirs azimuths and elevation angles etc. can be known by the user only if the ship's receiver is professional. However, the knowledge of these parameters can be very helpful for the accuracy and reliability estimation.

Information about current status of SBAS must be taken into account if on the ship's the navigator uses integrated, SNS, and one, two or three SBAS, receiver, but at the time of this writing the number of these receivers is on the ship's bridges small still. On the contrary many GPS receivers installed on the ships have the possibility to work in differential mode also, in this case the use of volume 2 of Admiralty List of Radio Signals (ALRS) is indispensable [7].

Since 2010 the edition of volume 2 (NP282) only lists the details of known operational radiobeacons used to transmit DGPS and DGLONASS corrections. Information about several dozen radiobeacons with status on trial or planned are now not published [7]. This change is very inconvenient for all DGPS users, maritime navigator, in particular. Volume 2 of ALRS should only be used once fully updated by Section VI Weekly Notices to Mariners [8]. As these Notices can be obtained from authorized Admiralty Distributors (in ports, but no all), or from the United Kingdom Hydrographic Office Website [8] and continually approximately only 50% of the ships has access to Internet at sea it means that many SNS and SBAS users during several weeks of the voyages can be deprived of current information about these systems.

The distribution in the world of more than 280 currently operational radiobeacons, with the information about theirs details (8 parameters) and integrity monitoring is showed in the table 1. The greatest and the lowest number of these radiobeacons are in Asia & Europe (both 95) and in Africa (6) & South America (13), respectively. In the case of some number of radiobeacons (59) this information is incomplete, in particular it concerns 40 radiobeacons without information about integrity monitoring, especially in Europe and North America. The most of radiobeacons (82%) provides integrity monitoring [7]. The IALA recommendation R-121 summarizes requirements on maritime differential GNSS (DGNSS) services in the MW frequency band. Though integrity aspects are mentioned, there doesn't exist a clear specification of integrity requirements and implementation guidelines.

Coverage, range and accuracy limitations

Currently, only SNSs have global coverage, but user's position with nominal accuracy can be obtained in open area solely. All SBAS and DGPS reference stations have limited coverage or range, respectively. Additionally, the users of these systems meet some limitations in restricted area, i.e. the area where because of the obstacles some satellites above horizon or masking elevation angle of the receiver cannot be visible by the observer.

Global satellite navigation systems in restricted area

Actually two SNS, GPS (American) and GLONASS (Russian) are fully operational, two next, Galileo (European) and BeiDou (Chinese) are under construction. All these systems assure or will assure the nominal accuracy but in open area only. However, considering the opportunity of dual frequency positioning in combination with an increased number of available GNSS signals, the position's accuracies in the order of several meters could meet the requirements for some coastal areas.

In restricted area the position accuracy can be decreased when the masking elevation angle causing by the obstacles is greater than masking angle of observer's receiver. The diminution of GPS position accuracy in restricted area is currently less than still few years ago because of the actual number of fully operational satellites, at least 30, is greater considerably than this number in nominal constellation (24 only).

This limitation concerns car navigation in urban canyon mainly, but in some cases maritime navigation also, e.g. ship sailing in the narrow strait or along the height coast. The increasing of dilution of precision (DOP) coefficients values depends then on the height of the coast, the distance between the observer and the coast, the ship course and the ship antenna height. The calculations of these coefficients and the study of the possibility of

Table 1. Distribution in the world of the radiobeacons transmitting DGPS and DGLONASS corrections, information about details of services and integrity monitoring [7]

Continent	Number of radiobeacons								
	Total	All details of services known		Integrity monitoring					
				Yes		No		No information	
		Number	%	Number	%	Number	%	Number	%
Africa	6	6	100	6	100	0	0	0	0
Asia	95	87	92	91	96	0	0	4	4
Australia	16	0	0	16	100	0	0	0	0
Europe	95	74	78	73	77	0	0	22	23
North America	58	45	78	44	76	0	0	14	24
South America	13	12	92	2	15	11	85	0	0
Total	283	224	79	232	82	11	4	40	14

position determination were made among others by author for different values of all mentioned above parameters [9, 10].

As in restricted area (e.g. on the ship's bridge), the accuracy of the user's position obtained with GNSS can be less than in open area, considerably, and in some cases cannot be obtained, additional provision of navigational data and correction to existing GNSS must be used. Actually one of these methods is Assisted-GPS (A-GPS), a support given to stand-alone GNSS receiver, new technology that uses an assistance server to cut down the time needed to determine a location using GPS (Time To First Fix – TTFF). With unassisted SNS TTFF including the process of locating the satellites, receiving the data and achieving a position fix, can take several minutes. A-GPS can be used in all SNS today and in the future. It can be defined as a system where outside sources, such as an assistance server and reference network, help a GPS receiver perform the tasks required to make range measurements and position solutions [11, 12].

Radiobeacons transmitting DGPS and DGLONASS corrections

One of the most important parameter of the radiobeacons transmitting DGPS and DGLONASS corrections is an approximate indication of the range in nautical miles within these corrections may be received. The range of 270 operational radiobeacons is presented in the table 2.

The range of the majority of radiobeacons (51.2%) is less than 150 Nm, range 250 Nm or greater has 5.3% of radiobeacons only (Table 2). In the case of 13 radiobeacons (4.6%), all 11 in Australia, in particular, information about range is not provided. The greatest (300 Nm) and the lowest (60 Nm) range has Kokole Point, Hawaii and Robinson Point, Washington, respectively, both in United States. Two polish radiobeacons have the same range 80 Nm [7].

Table 2. Range [Nm] of 283 radiobeacons transmitting DGPS and DGLONASS corrections [7]

Range [Nm]	50–99	100–149	150–199	200–249	250–299	≥ 300	No information	Total
Number	13	132	77	33	14	1	13	283
Percentage	4.6	46.6	27.2	11.7	4.9	0.4	4.6	100

The range of radiobeacons is limited because of the effect called "spatial decorrelation". With increasing distance of the user's receiver to the reference station, the atmospheric influences on the satellite signals get more different and the correction get less and less accurate. Even worse, due to the large distance the user's receiver may receive information about Pseudo Range Correction (PRC) from completely different satellite where no correctional information are provided in the correctional data.

Geostationary satellites transmitting SBAS messages

Actually, three SBAS, EGNOS (Europe and North Africa), WAAS (North America) and MSAS (Japan), are operational, two next, GAGAN (India) and SDCM (Russia), are under construction. The numbers of monitoring, master and land uplink stations for five SBAS are presented in the table 3 [2, 4, 5].

The area covered by SBAS depends on where monitoring stations are located and if signals from geostationary satellites are being received. These satellites positioned in the equatorial plane are vertically above a user located at the Equator. Therefore, the further a user travels towards the north or south pole, towards high latitudes, the more the satellite is too close to the horizon, it is no longer usable. At latitude 70° GEO satellite is visible at about 10° above horizon in open area, at latitude 75° this angle is 5° only. As 5 degrees is the most frequently used in the receivers masking elevation angle value, it means that beyond latitude 75° SBAS service becomes barely usable. Additionally, the user must take into account that if his longitude differs from GEO satellite longitude the highest latitude at which this satellite can be visible is less. The characteristic orbit of the GEO satellites may be degraded, and in consequence some far North regions of the service area may be covered with only one GEO satellite during some periods of the day and may experience some degradations in availability performance [13].

Currently, the coverage area of three operational mentioned above SBAS is limited to north hemisphere only, since there are no possibility to calculate corrections because of no sufficient number of monitoring stations in south hemisphere. Only then new additional stations in south hemisphere will be operational all three currently used SBAS will cover all continents (except for Arctic and Antarctica) as well as all principal offshore tracks.

At middle latitudes (40–60)° satellites GEO are visible by the user at angle 40° or lower. It means that in these areas, in urban canyons and mountains regions, in particular, SBAS cannot be used because its satellites are invisible to users. That's why Japan decided to create new augmentation system

Table 3. The ground segment of different Satellite Based Augmentation Systems SBAS, currently and in the future [2, 5, 6, 14]

System	Number of stations, regions			
	monitoring		Master (control)	Land (Earth) Uplink
	current	future		
EGNOS	39 29 – Europe, 1– Algeria, 1 – Israel, 2 – Egypt, 1 – Canada, 1 – RPA, 1 – Jordan, 1 – Tunisia, 1– Morocco, 1 – Mauretania	7 5 – South Africa, 2 – Madagascar	4 Europe	6 Europe
WAAS	38 20 – USA (CONUS), 7 – Alaska, 1 – Hawaii, 1 – Puerto Rico, 4 – Canada, 5 – Mexico	13 10 – South America (coast), 2 – Brazil (interior), 1 – Middle America	3 USA	4 USA
MSAS	6 Japan	9 6 – Australia, 2 – New Zealand, 1 – Indonesia	2 Japan	2 Japan
GAGAN	15 India	0	1 India	1 India
SDCM	21 19 – Russia, 2 – Antarctica	6 2 – Russia, 1 – Australia, 1 – Brazil, 1 – Indonesia, 1 – Nicaragua	1 Russia	1 Russia

QZSS (Quasi Zenith Satellite System) which will provide positioning services primarily to the users of urban transport, a GPS differential corrections service to a higher resolution than Japanese SBAS, MSAS, in particular. The QZSS constellation will comprise three satellites in separate geosynchronous orbits, inclined to the equator at 45°, there is always at least one satellite over Japan at a high elevation angle, 70° or more [15, 16]. QZSS is expected to improve positioning availability from 90% to 98%. This system will not improve positioning in the Asia-Pacific region, also at sea for maritime users, but is expected to improve the capacity to respond to natural disasters [5].

The main limitations

Each user of SNS and SBAS must take into account the different kinds of limits from the lack or incomplete integrity to the problem of receiver's antenna installation on the ship.

Problem of integrity

In the literature various definitions of integrity exist. According to [8] integrity can be defined as the ability of a system, SNS also, (structure and user) to provide positioning with an associated level of confidence. As today integrity is not available within all currently SNS (GPS and GLONASS), GPS is planning to implement it within the third generation of this system, the GPS III, in the case of Galileo system integrity will be assured by one from services, Integrity Monitoring Service. The former Safety of Life service is being re-profiled. SBAS have been developed with two main goals: accuracy improvements and requirements for integrity. The second is clearly identified as the most important and has been the main guide for system definition. As SBAS provides integrity externally the user is provided with differential corrections of known quality, and does not need to perform checks to mitigate the effect of large satellite biases. SBAS is enable to detect and estimate receiver errors at the user side [18]. It means that currently SBAS integrity is assured in these regions of north hemisphere only where the user can receive the corrections from GEO satellites. The integrity information but only about selected satellites and no about whole system can be provided by radiobeacons transmitting DGPS and DGLONASS corrections. Currently 82% of them has ability to provide timely warnings to users when it should not be used for navigation and also to verify the validity of the DGPS broadcast (Table 1). However, the timely warnings are generated on methods differing on the applied algorithms and used threshold.

Local interference, breakdown and malfunction

All SNS and SBAS use a frequency band, 1.1–1.6 GHz, that is protected by the International Telecommunication Union (ITU). It is possible that during some period in some specific locations, spurious transmissions from services operating in adjacent or more remote frequency bands could cause harmful interference to the signals of just used SNS and SBAS. Depending on the level of this interference, the effect on the user receiver may be a degradation of the position accuracy or a total loss of the navigation service in case the interfering signals preclude the tracking of navigation signals [13].

In the event of system breakdown or malfunction, e.g. clock drift, broadcasting of erroneous data, the pseudorange measurement can be biased by anything from a few meters to a few kilometres. Due to the system architecture, and specifically the limited number of SNS ground stations, these errors may impact the user for several hours (6 hours maximum) [19].

Sensitivity to ionospheric effects and to scrambling

Under some circumstances due to solar activity and in some specific regions of the Earth, for boreal and subtropical latitudes, in particular, ionospheric disturbances, called also scintillation, will affect the SNS and SBAS signals and may cause the complete loss of these signals for a short period time. It means that the position solution may be affected by sudden jumps when satellite signals are lost due to scintillation. If the number of tracked satellites drops seriously, the position accuracy decreases considerably, if this number is less than 4, a 3-dimensional position may not be available [13, 20]. It depends on HW and SW receiver design, some professional receivers have e.g. the capability to overbridge short term disturbances on single signals.

The physical parameters of ionosphere have a direct influence on propagation delay, therefore, they cause significant user's position error. That's why to eliminate ionospheric error single frequency GPS receivers get correction data from satellite message or, if it is possible, apply SBAS or DGPS ionospheric corrections, while dual frequency SNS receivers use the measurements on two transmitted satellite frequencies [21].

As all SNS and all SBAS signals are received on the ground at very low power levels, they are relatively susceptible to scrambling, deliberate or otherwise [19]. In the case of GPS system when the satellite signal reaches the user's receiver on the Earth, the received signal power is about 100 attowatts only, 1 atto means 10^{-18}. This power is when the receiver is outdoors; when this receiver moves indoors, the signals rapidly get weaker, by 10–100 times in a house, and by 100–1000 times or more in a large building. The weak signal is a problem outdoors, also, the standard GPS receivers have trouble acquiring satellites with even the slightest interference or blockage [12].

Horizontal datums on maritime charts and satellite-derived positions notes

World Geodetic System 1984 (WGS84) is applied for GPS system. The most frequently used charts, in particular in Europe, are published by United Kingdom Hydrographic Office. On ship's bridge there are several hundred charts at least, often several thousand, but many chart are not yet referred to WGS-84 geodetic datum (also known as horizontal datum). That's more a problem of provided charts and data fusion on screens, ECDIS and INS.

Currently, the total number of charts published by UKHO is greater than 8000; almost 3000 (37%) are referred to WGS84, in this case position obtained from GPS receiver can be directly plotting on the chart. However, about 3400 (43%) charts are referred to several dozen local datums, the user must now select in the receiver the datum of the chart. If this datum is not available the user must search for Satellite Derived Positions Notes showed on the chart and take it into account. If these notes are not available the user must know that this effect may be significant to navigation. Positions referred to different datums can differ by several hundred metres or even more. The same consequences are in the case of about 1600 (20%) charts referred to unknown datum [7, 22].

Installation marine satellite navigation system antenna and screen unit on the ships

In order for the SNS unit to function as expected, the antenna must be mounted properly and the position of the SNS screen unit suitable. That's why the SNS user's receiver should be a minimum of a meter away from any obstruction that may interfere with maintaining line-of-sight to the satellite. Radio whips, radar arrays and any metal assemblies on the roof of the ship must be accommodated. The receiver cable should be routed to pass through a vertical surface on the pilothouse if it is not being used on an "open" boat. The receiver cable cannot be spliced or extended, making if the most critical consideration. The user must keep the SNS screen unit out of direct sunlight will maximize screen visibility and prevent ultra-violet (UV) degradation of the screen [23].

Conclusions

- Differential mode of SNS have been developed in response to inherent and previously imposed limitations of SNS;
- SNS and SBAS users meet different kinds of limitations, some of them, e.g. propagation conditions are independent of the users, some depend on theirs decision, e.g. receiver's parameters. DGPS users meet apart from restricted range of reference station often limitations concerning the lack complete information, integrity monitoring, in particular;

- The lack integrity is one of the most important weakness and at the same time limitation of the current stand–alone GPS system, which is a paramount requirement for safety critical applications. Missing integrity information will be a problem, if it is needed but not provide. The next generation of this system, GPS III, will have very good accuracy and integrity, good enough for most navigation, maritime, in particular;
- Assisted-GPS technology offers significant performance advantages over either stand-alone GPS or mobile-station-based, particularly at low power levels often associated with consumer applications, as accuracy, availability, and coverage at a reasonable cost;
- The most frequently used SNS receivers are single-frequency receivers, all SBASs has been designed to operate in single-frequency mode; this can give rise to degraded service availability in the event of very strong ionospheric turbulence;
- SNS receiver designed for the ship navigating around the world must have in its software all datums on which the charts of navigation bridge, often several thousand, were published;
- SNS errors or breakdown can have serious repercussions for user safety if not detected in time and have the effect of restricting the number of possible applications. In particular, they make the system unsuitable for some applications, e.g. maritime navigation in restricted area.

References

1. Benedicto J.: Galileo Programme Status. Satellite Navigation Summit, Munich 2011.
2. Januszewski J.: New Satellite Navigation Systems and modernization of current systems, why and for whom? Scientific Journals Maritime University of Szczecin 32(104) z. 2, 2012, 58–64.
3. www.glonass-ianc.rsa.ru
4. www.gps.gov
5. www.gpsworld.com
6. www.insidegnss.com
7. Admiralty List of Radio Signals. (2011/2012) vol. 2, NP 282 The United Kingdom Hydrographic Office, Tauton.
8. www.ukho.gov.uk
9. Calini G.G.: Emerging challenges for GNSS in Maritime Transport. Munich Satellite Navigation Summit, 2012.
10. Januszewski J.: Satellite navigation systems in coastal navigation. Scientific Journals Maritime University of Szczecin 29(101), 2012, 45–52.
11. Januszewski J.: (2010) Assisted-GNSS, why, where and for whom? Communications in Computer and Information Science 104, 2010, 142–151.
12. Van Diggelen F.: A-GPS: Assisted GPS, GNSS, and SBAS. Artech House, Boston/London 2009.
13. EGNOS Open Service, Service Definition Document V. 2.0, 2013.
14. www.navcen.uscg.gov
15. Hofmann-Wellenhof B. et al.: GNSS Global Navigation Satellite Systems GPS, GLONASS, Galileo & more. Springer, Wien, NewYork 2008.
16. www.qz-vision.jaxa.jp
17. Samama N.: Global Technologies Technologies and Performance. John Viley & Sons, New Jersey 2008.
18. Januszewski J.: Satellite navigation systems integrity today and in the future. Monograph “Advances in Transport Systems Telematics”, Edited by Jerzy Mikulski, Wydawnictwa Komunikacji i Łączności, Warszawa 2009, 123−132.
19. www.ec.europe.eu
20. Kaplan E.D., Hegarty C.J.: Understanding GPS Principles and Applications. Artech House, Boston/London 2006.
21. Januszewski J.: How the ionosphere affects positioning solution using terrestrial and satellite navigation systems. Communication in Computer and Information Science, Telematics in the Transport Environments 329, 2012, 249−257.
22. Januszewski J.: The problem of compatibility and interoperability of satellite navigation systems in computation of user’s position. pp. Artificial Satellites, Journal of Planetary Geodesy 3, Vol. 46, 2011, 92–103.
23. www.ehow.com

Other

24. Januszewski J.: Comparison of Geometry of Galileo and GPS in maritime and urban restricted area. Annual of Navigation 6, 2003, 37–48.