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Satellite navigation systems in coastal navigation

Nawigacyjne systemy satelitarne w żegludze przybrzeżnej

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Key words: GPS, DGPS, GLONASS, Galileo, geodetic datum, integrity information

Abstract

Satellite Navigation Systems (SNSs), the GPS system in particular, were available to civilian users from the beginning. The first community interested was the maritime one, for both professional and recreational purposes. Marine navigation distinguishes between five major phases, among those the port approach and operation in restricted waters and the marine navigation in the port. SNSs, today the GPS system and its differential mode DGPS, and Satellite Based Augmentation Systems (SBAS) as EGNOS and WAAS, provide a wide range of applications in both these phases, e.g. coupling SNS receivers with dedicated sensors installed on the ship's bridge, e.g. AIS, aid in the berthing and docking of large vessels, by means of the position and the heading reference systems. In maritime restricted area, the SNS position accuracy can be decreased when the masking elevation angle causing by the obstacles is for the user on the ship greater than masking angle of observer's receiver. This diminution depends on among other things the ship course, observer's latitude, the height of the obstacle, the distance between the observer and the obstacle, here coast side.

Additionally, the problem of availability of the integrity information to users and performances, and future use of the GLONASS system after modernization, Galileo and Compass systems actually under construction, new SBASs, the next DGPS and DGLONASS reference stations, and Eurofix with differential corrections to GPS including integrity messages in coastal navigation are described in the paper.

Słowa kluczowe: GPS, DGPS, GLONASS, Galileo, układ odniesienia, informacja o integralności

Abstrakt

Dla użytkowników cywilnych nawigacyjne systemy satelitarne (NSS), w szczególności system GPS, były dostępne już od momentu ich wprowadzenia. Pierwszą społecznością zainteresowaną tymi systemami było środowisko morskie wykorzystujące je zarówno do celów zawodowych, jak i rekreacyjnych. W nawigacji morskiej wyróżnia się pięć faz żeglugi, w tym nawigację na podejściach do portów i operacje na wodach ograniczonych oraz nawigację portową. NSS, obecnie GPS i jego odmiana różnicowa oraz satelitarne systemy wspomagające (SBAS), takie jak EGNOS i WAAS, wykorzystując swoje odbiorniki zintegrowane z innymi urządzeniami mostka nawigacyjnego (np. AIS), zapewniają informację o pozycji i kierunku ruchu statku, dzięki czemu mogą być przydatne, np. podczas wprowadzania do portów wielkich statków i w ich cumowaniu. W morskich rejonach ograniczonych dokładność pozycji użytkownika określonej za pomocą NSS może się zmniejszyć, gdy przeszkoda powoduje, że wysokość satelity jest dla użytkownika znajdującego się na statku większa niż dolna graniczna wysokość topocentryczna odbiornika tegoż użytkownika. Zmniejszenie to zależy między innymi od kursu statku, szerokości geograficznej użytkownika, wysokości przeszkody, odległości statku od tej przeszkody, tudzież wybrzeża.

W artykule opisano też problem dostępności dla użytkownika informacji o integralności oraz możliwości przyszłego wykorzystania w nawigacji przybrzeżnej systemu GLONASS po zakończeniu modernizacji, budowanych obecnie systemów Galileo i Compass, nowych systemów SBAS, kolejnych stacji referencyjnych odmiany różnicowej systemów GPS i GLONASS oraz systemu Eurofix z poprawkami różnicowymi GPS.

Introduction

Global aspect of the ship's position must be fixed by two completely independent, reliable methods, so called primary and back up. The information about ship's position in all phases of navigation is obtained generally from specialized electronic position–fixing systems, in particular, satellite navigation systems – SNSs, Satellite Based Augmentation Systems (SBASs) terrestrial radio-navigation systems (Loran C, local systems etc.). SNS, the GPS system in particular, has become a mainstay of trasportation systems worlwide, providing navigation for maritime operations. That's why equipped with GPS receivers ship's officers can acccurately locate where they are and easily navigate to where they want to go [1].

As in the paper one phase of navigation, coastal navigation, is taken into account only the questions can be put:

- why, when and which SNSs and which SBASs are used by navigator to determine own position?
- when differential mode of SNS can be or/and must be used?
- which information useful for ship's officer can be provided by SNS receiver?
- which is the influence of performance parameters of SNS receivers on determined position?
- which is integrity information provided by SNSs amd SBASs?

Navigation phases, positions accuracy requirements

Marine navigation distinguishes between five major phases:

- ocean navigation;
- coastal navigation;
- port approach and operation in restricted waters;
- marine navigation in a port;
- navigation in inland waterways.

An uninterrupted information about the ship's position is one of the most important elements of the safety of navigation in the sea transport in restricted and coastal areas, recommended by International Maritime Organization – IMO [2]. The accuracy requirements (horizontal accuracy with confidence level 95%) under three resolutions in different phases of the voyage are presented below in the table 1. In mentioned IMO resolutions a relationship between the accuracy to be expected by the user, the accuracy of the system fixes and maximum time interval between the system fixes also can be found.

In IMO Resolution A.953 (23), adopted in December 2003, it can find the information – where a radionavigation system if used to assist in the navigation of ships in those harbour entrances, harbour approaches and coastal waters with a high volume of traffic and/or significant degree of risk, the system, including any augmentation, should provide positional information with an error not greater than 10 m with probability of 95%. In ocean waters SNSs should provide positional information with an error not greater than 100 m with a probability of 95%. In coastal navigation user's position must be known with the accuracy depending on local circumstances.

Table 1. The horizontal accuracy requirements (with confidence level 95%) in different phases of the voyage [2]
Tabela 1. Wymagania dokładnościowe pozycji horyzontalnej w różnych fazach żeglugi (prawdopodobieństwo 95%) [2]

Phase of the voyage	IMO Resolution A.529 (13)	IMO Resolution A.815 (19)	IMO Resolution A.953 (23)
oceanic navigation	4% of the distance from the nearest danger with a maximum of 4 Nm	1–4 Nm	< 100 m
coastal navigation		≤ 2 Nm	< 10 m
harbour entrances and approaches and waters in which the freedom to manoeuvre is limited	depends on local circumstances	depends on local circumstances	

The accuracy of the position solution determined by SNS is ultimately expressed as the product of a geometry factor and a pseudo-range error factor. Geometry factor can be expressed by the dilution of precision (DOP) coefficient, in case of maritime navigation Horizontal Dilution Of Precision (HDOP) coefficient.

HDOP coefficient values are greater in maritime restricted area (the observer on the ship) than in open area for all SNSs. This increasing depends on the height of the coast, the distance between the observer and the coast, the ship course and the ship antenna height. The coast can decrease the number of satellite visible by the observer and at the same time SNS position accuracy if the masking angle (α) causing by this coast is greater than masking elevation angle H_{min} used in the observer's receiver. The α values for different distances from the coast for the different coast heights are presented in [3]. In these calculations it was considered the observer's antenna height above sea level $H_{ant} = 20$ m.

Finally it can say that in maritime restricted area the influence of coasts on SNS position accuracy is very small, it depends on the ship course, observer's latitude and the coast side parameters. This influence in case of two or more SNSs integrated receivers is less than in case of one SNS receiver considerably.

Satellite navigation systems in 2012

Nowadays, information about ship's position is obtained generally from global satellite navigation systems (SNS) as the GPS and the GLONASS, and satellite based augmentation system (SBAS) as EGNOS (Europe), WAAS (USA) and MSAS (Japan). The last years gave a rise to many important changes in the operational status and practical exploitation of all these systems.

Satellite navigation users in Europe today have no alternative other than to take their positions from US GPS or Russian GLONASS satellites. That's why for Europe and for China also the conclusion was to build own global SNS – Galileo system for civil and Compass system for military and civil users respectively.

In coastal navigation apart from Open Service (OS) and Safety of Life (SoL) service (p. 4), the Galileo Search and Rescue service (SAR) will be very useful for ship's officers. The SAR "repeater" of some Galileo satellites can detect alert messages sent by COSPAS-SARSAT beacons in the 406–406.1 MHz. This information is transmitted to terrestrial COSPAS-SARSAT stations through the use of a specific L6 downlink 1.544–1.545 GHz. The Galileo satellites concerned send a feedback message to the initial sender of alert message in order to tell him the message is being processed [4, 5].

Supporters of the COSPAS-SARSAT system are preparing to demonstrate and evaluate a new capability called MEOSAR (Medium Earth Orbit Search and Rescue satellites). This new system will consist of SAR transponders aboard Galileo constellation, Russian GLONASS satellites block K, the U.S. GPS satellites. MEOSAR assets will report signals from COSPAS-SARSAT search and rescue beacons in the 406.0–406.1 MHz band. MEOSAR satellites will be able to provide near-instantaneous detection, identification, and location determination of 406 MHz beacons.

New SBASs, as GAGAN (GPS and Geo Augmented Navigation) in India and SDCM (System for Differential Correction and Monitoring) in Russia, will permit to use in the next regions in the world a suite of geostationary satellites and networks of ground relay stations.

New regional SNSs as IRNSS (Indian Regional Navigation Satellite System) in India and QZSS (Quasi-Zenith Satellite System), developed in Japan, will provide a regional satellite navigation service, in Asia and Oceania.

Next DGPS and DGLONASS reference stations, and Eurofix stations with differential corrections to GPS including integrity messages will be initiated. As the range of all these new stations is limited they will be very useful in coastal navigation, in particular.

The performances parameters of GPS and GLONASS systems, differences mode of these systems, Galileo system and three SBAS – EGNOS, WAAS and MSAS are presented in the table 2 [6, 7, 8, 9, 10, 11].

Table 2. Satellite Navigation Syatems and Satellite Based Augmentation Systems, performance parameters, March 2012 [6–11]
Tabela 2. Parametry nawigacyjnych systemów satelitarnych i satelitarnych systemów wspomagających, marzec 2012 [6–11]

Parameter \ System	GPS	DGPS DGLONASS	GLONASS	SBAS	Galileo
Spatial segment, satellites	31 satellites, all operational	–	31 satellites, 24 operational, 7 with different status	EGNOS – 3 WAAS – 3 MSAS – 2	2 test 2 IOV
Ground-control segment, operational monitoring stations	6 Air Force and 11 NGA	279 DGPS, 2 DGPS and DGLO reference stations	12	EGNOS – 38 WAAS – 38 MSAS – 6	several in testing phase
Operational status	FOC	all 281 stations operational	FOC	EGNOS – FOC WAAS – FOC MSAS – FOC	IOC – 2014 FOC – 2020
horizontal position accuracy 95% [m]	5–10	1–5	5–10	1–3	4–15
Integrity	non	yes (used satellites)	non	yes (system)	yes (system)
Receiver on the ship's board	one, two or more SNS receivers with/without DGPS and/or with/without one, two or three SBAS, receivers				non

FOC – Full Operational Capability, IOC – Initial Operational Capability.

Differential mode of Satellite Navigation Systems

At present, a single-frequency SPS GPS stand-alone receiver (without any corrections) can often attain better than 10 m, 95% positioning and 20-ns, 95% timing accuracy worldwide. There are many applications, however, that demand levels of accuracy, integrity, availability, and continuity beyond even what a PPS GPS receiver can deliver. For such applications, augmentation is required, e.g. differential GPS, abbreviated by DGPS, real-time positioning technique where two or more receivers are used. The same mode exists for GLONASS system – DGLONASS. DGPS and DGLONASS are intended among other things for coastal navigation and precise positioning in restricted waters by using pseudo-range corrections (PRC) broadcasting received by radio from the shore based reference stations in RTCM SC–104 protocol [Hofmann, Kaplan Urząd Morski]. Maritime DGPS has been demonstrated to provide horizontal positioning accuracy of 1–3 meters at a distance of 100 km, or more, from a reference station.

The number of beacons (stations) transmitting DGPS corrections has been increased in 10 last years considerably (Table 3). In 2002 there were 162 stations in the world with status operational, 62 with status on trial, 20 planned, in 2006 these numbers were 235, 57 and 11 respectively. At present 281 operational stations are localized in 37 countries, the greatest numbers of stations are in USA (38), Japan (27), China (21) and India (19). In Poland there are two stations, Dziwnów and Rozewie. Since few years there are two operational stations, both in Ukraine (Yenikal'skiy Lt and Zmeiniy Lt), transmitting DGLONASS corrections (in RTCM protocol 6 message types, numbers 31–36) also. At present in Russia 4 DGPS/DGLONASS stations (1 Baltic Sea, 3 Black Sea) have the status on trial, next 12 (4 Arctic Coast, 8 Pacific Coast) are planned.

Table 3. The numbers of beacons transmitting DGPS corrections in the period 2002–2011 [12, 13]

Tabela 3. Liczba stacji transmitujących poprawki odmiany różnicowej DGPS w latach 2002–2011 [12, 13]

Year (volume)	Number of stations			
	Operational	On trial	Planned	Total
2002 (vol. 8)	162	62	20	244
2003 (vol. 2)	189	84	15	288
2006 (vol. 2)	235	57	11	303
2009 (vol. 2)	256	45	22	323
2010 (vol. 2)	260	49	18	327
2011 (vol. 2)	281	*	*	*

[*] since edition 2010/2011 volume 2 of ALRS lists of known operational stations only.

In each station the information about Pseudo Range Corrections (PRC) are transmitted in type 1 or type 9 message. Additionally the part of the stations (92) transmits type 5 message with GPS Constellation Health. This message type will notify the user equipment suite that a satellite, that is deemed unhealthy by its current navigation message, is usable for DGPS navigation [12].

For each station one of details of service is information about integrity monitoring. It can distinct three cases: station with this option, station without this option, no information. In the first case it means that the station has the 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, (Pseudo Range Correction), indicated in Type 1 or Type 9 message.

Both, the total number of stations with status operational and the number of the stations with integrity monitoring have been increased in 10 last years considerably. In 2010 there were 202 stations (77.7 % of operational stations), in 2011 already 232 (82.6 %). The greatest numbers of the stations with this option are in Japan (27), USA (25), China (21) and India (18). In four countries all stations are without integrity monitoring – Spain (18), Brazil (11), Sri Lanka (3) and Lithuania (1), in four countries only some stations are without this option – USA (13), Malaysia (4), Canada (1) and India (1).

The next detail of station service, very important for all navigators, is an approximate indication of the range (in nautical miles) within which transmitted by given station DGPS corrections may be received. The range of the majority of stations is from interval 80–200 *n* miles, the greatest has Kokole Point in USA – 300 and Horta in Portugal – 294, the smallest Kau Yi Chau in China – 54 and in Reedy Point in USA – 60. In some countries the range depends on the station, its location, in particular, e.g. in USA, in other countries the range is the same for all stations, e.g. 27 stations in Japan – 108, 19 in India and 18 in Spain – 100. Both polish stations have range 80 *n* miles.

In coastal navigation, if the ship is in the range of DGPS reference station with integrity monitoring and on the ship's bridge there is DGPS receiver, position determined with the use of PRC corrections received from this station means that this position is reliable and satellites used in calculations are health.

Many nations use DGPS for operations such as buoy positioning, sweeping, and dredging. This enhancement improves harbor navigation [1].

Satellite Navigation Systems and Terrestrial Radionavigation Systems, integration

Loran (LOng RAnge Navigation) C is a terrestrial navigation system using low frequency signals. Currently (2012) the Loran C chains in operation are in Europe, Saudi Arabia and Pacific Ocean with 4 (6731 Lessay chain, 7001 Bø, 7499 Sylt, 9007 Ejde), 1 (8830 North) and 6 (6780 South China, 8390 East China, 7430 North China, 9930 Korean, 7950 Russian, 5980 Russian-American) chains respectively [12].

Eurofix is an integrated radio-navigation and communication system that uses Loran signals as the carrier (100 kHz). This is a method by which differential pseudo range corrections (PRC) to GPS, including integrity messages and short message service, are transmitted within the Loran C signals. Currently, Eurofix is employed at Anthorn (UK) station, which is secondary station Y in Lessay chain, rate 6731 and Sylt (Germany) station, both Master in Sylt chain, rate 7499 and secondary Z in Lessay chain. As Loran C stations are upgraded to broadcast low-speed data over ranges of up to 1000 km, Eurofix can be used in coastal navigation [12, 14].

The General Lighthouse Authorities (GLASs) will commence transmissions of an enhanced (eLoran) service from mentioned above Anthorn station. This service will incorporate Eurofix DGPS and DGLONASS transmissions also, and the facility to transmit both differential Loran correction messages and UTC (Universal Time Coordinated) [14].

In last several years appeared on the market many SNS (GPS, GLONASS, Galileo) and SBAS (EGNOS, WAAS, MSAS, GAGAN) integrated receivers, e.g. Javad Triumph-1-G3T (GPS, Galileo, GLONASS, WAAS, EGNOS) and Leica Geosystems GX1230 + GNSS (GPS, GLONASS, Galileo, Compass, WAAS, EGNOS, MSAS, GAGAN).

Satellite navigation systems receivers on the ship's board

Satellite Navigation Systems (SNSs), the GPS system in particular, were available to civilian users from the beginning. The first community interested was the maritime one, for both professional and recreational purposes. Very soon after the military availability of Transit (1964) the U.S. administration made this system available for civilian use (1967), and particularly to commercial maritime vessels [4, 5, 15].

Currently, on each ship the navigator can obtain own position by means: one, two or three SNSs receivers with or without GPS in differential mode, and/or with or without one, two or three SBASs. On some ships, V.L.C.C. or big passenger in particular, there are even four SNSs receivers.

Typical maritime applications include rescue and replenishment of off-shore platforms, cruising positioning dynamic positioning, digging waterways, or positioning and monitoring off-shore platforms. Other applications, directly on the ship's bridge, consist in coupling GNSS receivers with dedicated sensors as radar, ARPA, echo-sounders, fish-finders, plotter, chart-plotter, autopilot, and so on. Next two, very important applications, are the systems, which use GPS and/or DGPS for positioning information, Electronic Chart Display and Information System (ECDIS) and Automatic Identification System (AIS).

The ship's officers can also adjust the SNS true bearing to the magnetic compass bearing. The averaging function can be used to add SNS sensor signals several times and get their average. This can stabilize the measured position (latitude and longitude), speed and course data.

GPS and GLONASS are global system both, it means that the user's position can be obtained at any moment and in any point on the Earth. However, GPS gaps have been reported in the seven following areas in the world [12]:

- Bahrain, approaches to Mīnā Salmān;
- Croatia, entrance to Rijeka;
- France, approaches to Saint Malo and Golf of Lions;
- Italy, Golf of Genoa and Bay of Naples;
- United States, Chesapeake Bay.

Navigation information and alarms

Currently, there is just SNS receiver on the ship's bridge which provides navigation information as follows: BRG – bearing, RNG – range, RL – Rhumb Line, GC – Great Circle, CMG – Course Made Good, VMG – Velocity Made Good, ETA – Estimated Time of Arrival, TTG – Time To Go, TTTG – Total Time To Go, DTG – Distance To Go, TDTG – Total Distance To Go, XTE – Cross Track Error, DFT – Drift, Next waypoint, Waypoint info, Route info, CDI – Course Deviation Indicator, ROT – Rate of Turn. Additionally, some professional SNS receivers provide specialized information as follows: depth, wind, tide, tidal, current, port services, Sun almanac, Moon phases, fish, fuel or batteries.

In coastal navigation, the ship's officers can apply the different alarms and alerts accessible in the almost all SNS receivers: ANW – Anchor Watch Alarm, XTE – Cross Track Error Alarm, ARV –Arrival Alarm, SPD – Speed Alarm, WPT – Water Temperature Alarm, DPT Depth Alarm, time alarm, position no update, autopilot enable data, SOG low.

Additionally, the ship's officers can adjust the SNS true bearing to the magnetic compass bearing. The averaging function can be used to add SNS sensor signals several times and get their average. This can stabilize the measured position (latitude and longitude), speed and course data.

Geodetic datum

Horizontal position accuracy depends among other things on performance SNS receiver parameters. One of the most important parameters on which the user has a full or partial influence is geodetic datum. As GPS position must be plotted on the paper chart or introduced to electronic chart, for all users the knowledge of geodetic datum on which this chart was published is critical. The most frequently used charts, in particular in Europe, are published by United Kingdom Hydrographic Office. On bridge navigation 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) to which GPS system is referred. It means that, in those cases, position obtained from GPS receivers will not be directly compatible with the chart and must be used without adjustment because the differences may be significant to navigation. That's why since 1982 the UKHO has been adding "Satellite-Derived Positions" notes to indicate the shift that needs to be applied to WGS-84 datum positions before plotting them on the chart [4, 5, 12, 15].

As majority of the charts are referred to local or regional geodetic datum position referred to different datums can differ by several hundred meters or even more, e.g. position of South Foreland Lt in United Kingdom referred to ED-50 datum differs by 133 meters and 161 meters from position referred to WGS-84 datum and OSGB-36 datum respectively, position referred to WGS-84 differs by 11 meters from WGS-72 [12].

Actually, in each SNS receiver are available two global datums, WGS-84 and WGS-72, and *n* local datums. This number *n* depends on, first of all, the receiver's type and kind and size of area in which the user relocates with this receiver. That's why in some receivers there are several datums only, in other several dozen, in professional units a few hundred. The 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.

Since 2006 the most frequently used datums of charts published by UKHO are WGS-84 and ETRS (European Terrestrial Reference System), in 2010 it was adequately 36.1% and 18.3%. In this year the total number of charts published by UKHO was greater than 8,000, the number of used datums was 67 [1, 16].

Integrity information of satellite and based augmentation systems

Integrity can be defined as a reliability indicator of the quality of positioning, user's position obtained from satellite navigation systems (SNS) also.

Today, integrity is not available within all actual SNS (GPS and GLONASS), GPS is planning to implement it within the third generation of this system, the GPS III, GLONASS with new block K, in the case of Galileo system integrity will be assured by one from services, Safety of Life (SoL). Other solutions, such as integration of SNS and inertial navigation systems, can be taken into account also [17].

The generation GPS III can be considered the future of worldwide navigation service. GPS III will ensure also significant increase in integrity (crucial for anticipated civil aviation uses, also important for military use and some navigation applications) by performing outage monitoring, detection, validation, alerting, and the initiation of corrective action. This will be obtained through a worldwide network that will continuously monitor the state signal in space, providing a timely alert to users in case of unacceptable degradation of the signal quality. GPS III increased integrity will be expressed among other things by planned interfaces between GPS and augmentations (architectural changes) and potential for meeting broad array of civil and military needs via GPS alone.

Galileo system will provide the capability to detect satellite or system malfunctions and broadcast real-time integrity information. This system will assure 5 services, and among them Safety of Life (SoL) providing integrity messages, incorporated into the navigation data messages of Open Service (OS) signals. The purpose of the integrity mechanism for Galileo is to ensure that each individual user is provided with signals which are safe for its intended operation and is warned in due time if this condition cannot be met at one point in time.

In Galileo system, it is very important to identify the different categories of error sources and to explain how each of these error components can be addressed by the overall integrity scheme. There are three main categories of error sources: errors attributable to the Galileo signal penetration, errors due to the signal propagation and errors due to the user receiver [4, 11, 17].

The SoL service will use the E5b (1207.14 MHz) band, composed of an in phase signal incorporating navigation data and an in quadrature phase pilot signals, respectively 3 and 4, and L1 (1575.45 MHz) composed of navigation data and pilot signals, respectively 9 and 10. The SoL frequencies are identical to the ones allocated to the Open Service, but Galileo will provide specific integrity features together with back-up service provision in case of poor conditions (e.g. in case a frequency no longer operates) [17].

QZSS system is designed to provide integrity information and position service in urban canyons and mountainous environments in Japan in particular.

Satellite Based Augmentation System (SBAS) has 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. An 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 or receiver errors on the ground. SBAS is a system that provides differential GPS corrections and integrity data using geostationary satellites as the communications path. The SBAS message consists of 64 types, the 9 types are relevant to integrity equation. A unique feature of all SBASs is that they provide DGPS data, using a signal broadcast directly at the GPS L1 (1575.42 MHz) frequency, that can be used for ranging. Therefore, SBAS integrity service should protect the user from both [18]:

– failures of GPS / GLONASS / GEO satellites (drifting or biased pseudo ranges) by detecting and excluding faulty satellites through the measurements of GPS signals with the network of reference ground stations;
– transmission of erroneous or inaccurate differential corrections. These erroneous corrections may in turn be induced from undetected failures in the ground segment and processing of reference data corrupted by the noise induced by the measurement and algorithmic process.

At present, both WAAS satellites, Galaxy XV and AnikF1R, contain an L1 and L5 GPS payload. This means they will be usable with L5 GPS signals when this third civil frequency and receivers (L1 & L5) become available [8, 9].

Conclusions

In coastal navigation SNSs allow access to fast and accurate position, course, and speed information, saving navigators time and fuel through more efficient traffic routing.

As the position accuracy increases with the number of satellites visible by the observer in coastal navigation the ship's position must be obtained with the use of SNSs integrated receivers, today GPS and GLONASS systems, in the future Galileo system also.

DGPS user can remember always that this system is functioning only if GPS system is functioning and the number of satellites visible at the same time by the reference station and user is sufficient for position fix.

As the total range of near 300 operational reference DGPS stations covers the majority of coasts, the ship in coastal navigation must be equipped with at least one DGPS receiver.

In coastal navigation, harbour entrances and approaches to the ports the position on many occasions can be obtained by DGPS. If DGPS has limited range, the ship's position should be obtained by other available methods.

Today integrity, but incomplete only, is available within SBASs and DGPS reference stations with integrity monitoring, in the future integrity will be assured by the third generation of GPS system, GLONASS satellites block K and Galileo service SoL.

GPS system increases safety and security for vessels using the AIS.

Maritime users are strongly encouraged to use terrestrial radionavigation systems, Loran C system in particular, as a navigational input system to back-up the widespread use of GPS system. These two systems are highly dissimilar in operational control and signal propagation characteristics, that's why there is not much risk that both systems will fail simultaneously.

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