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Applications of global navigation satellite systems in maritime navigation

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Abstract

Currently (April 2016) uninterrupted information about a ship's position can be obtained from specialized electronic position-fixing systems, in particular, Satellite Navigation Systems (SNSs) such as GPS and GLONASS and Satellite Based Augmentation Systems (SBASs) such as EGNOS or WAAS. The generic name given to all the above mentioned systems is Global Navigation Satellite Systems (GNSS). Many models, designed for the ship's bridge and provided by about a dozen manufacturers, are available on the world market. In Europe, one of the most comprehensive sources of knowledge on the global GNSS market is a report published, on average, every 15 months by the European GNSS Agency GSA. Another receiver survey is published each year in the January number of the magazine "GPS World". The detailed analysis of market report and receiver survey, possible use of EGNOS and Galileo in the maritime market, and different maritime applications of GNSS equipment are described in this paper.

Introduction

Uninterrupted information about a ship's position is one of the most important elements in the safety of navigation for sea transport in restricted and coastal areas, recommended by the International Maritime Organization – IMO. Currently (April 2016) information about the user's position is generally obtained from specialized electronic position – fixing systems. In particular, satellite navigation systems (SNS) such as the American GPS and Russian GLONASS systems; Satellite Based Augmentation Systems (SBAS), such as EGNOS in Europe, WAAS in USA and Canada, MSAS in Japan and GAGAN in India are employed (Januszewski, 2012; 2016; Betz, 2016; Glonass-IAC, 2016; GPS.GOV, 2016). All these systems are fully operational, next to SNS and Galileo in Europe, BeiDou in China, one SBAS and SDCM in Russia. Two regional navigation satellite systems (RNSS) – QZSS (Quasi Zenith Satellite System) in Japan and IRNSS (Indian Regional Navigation Satellite System) are also under construction. The generic name given to all these systems is GNSS – Global Navigation Satellite System (BeiDou, 2016; Inside GNSS, 2016; GPS World, 2016).

At the time of writing (April 2016) more than 5 billion different GNSS devices are used around the globe. By 2023, this number is forecasted to increase to over 9 bln: more than one device per person. The primary region of global market is, and will be, the Asia-Pacific area, with a number of devices greater than EU and North America combined. The number of devices employed in EU28 and Non-EU28 European countries, in 2016, is about one billion (GNSS, 2015).

Maritime segment in GNSS Market Report

In Europe, one of the most comprehensive sources of knowledge and information on the dynamic, global GNSS market is a report published on average every 15 months by the European Global Navigation Satellite System Agency (GSA). In the first issue (October 2010) the number of GNSS market

Table 1. GNSS Market Report, cumulative core revenue (in %) in different market segments in different periods (GNSS, 2010; 2012; 2013; 2015)

Segment	Number of issue, month and year, number of pages			
	1, October 2010, 34	2, May 2012, 48	3, October 2013, 72	4, March 2015, 81
	Period			
	2010−2020	2010−2020	2013−2022	2013−2022
Location Based Service	42.8	43.7	47.0	53.2
Road	56.4	54.0	46.2	38.0
Surveying	–	0.6	4.1	4.5
Aviation	0.2	0.5	1.0	1.1
Maritime	–	0.1	0.3	1.1
Agriculture	0.6	1.0	1.4	1.9
Rail	–	–	0.1	0.2
Timing Synchronization	–	–	–	0.1

segments was equal to 4 (Location Based Service, Road, Aviation and Agriculture). In the latest (issue 4, March 2015) this number had increased to 8 (with the addition of Surveying, Maritime, Rail and Time Synchronization). The changes in the cumulative core revenue in each segment during the last years are presented in the Table 1.

Since the beginning of the reported period, the segment with the biggest revenue has been LBS (Location Based Service). Additionally, its value increases each year and in last issue it accounted for more than 50% of the cumulative revenue. The first mention about the application of these systems in the maritime segment appears in issue 2 (May 2012) when it accounted for only 0.1% of total core. This value increased in the last issue to 1.1%.

The market size of core revenues refers only to the value of GNSS receivers and chipsets in different devices, whereas enabled revenues include the full retail price of devices, smartphones in particular. The values of these two revenues, in Euros (EUR), were about 75 bln and 250 bln, respectively, in 2015. As both market sizes increase by few percentage points annually, we can expect that by 2023 these values will be about 110 bln and 300 bln, respectively.

Shipments of GNSS devices in Europe will more than double within the next 20 years, growing from 208 mln units in 2013 to 427 mln in 2023. Revenues will follow, increasing from 11 bln EUR in 2013 to 20 bln EUR in 2023. European companies account for one quarter of the global GNSS market and are the global leader (72%) in system integration in rail application as well as having a strong position in the maritime (47%) and road (29%) sectors. The group of companies classified into systems integrators comprises integrating GNSS capabilities into larger products, such as vehicles and consumer electronics, as well as dedicated (e.g. portable) GNSS devices.

In the maritime segment, GNSS is employed to satisfy the demand for navigation (in open areas at sea or in specific situations, such as harbor entrances and approaches) and positioning (including, among others, vessels monitoring, traffic management, locator beacons for distress situations, etc.) of vessels and crews by different stakeholders. That is why according to the distinction provided by IMO Resolution A.951(22) GNSS applications can be split into navigation and positioning:

- navigation
  - sea; SOLAS vessels: all passenger ships and cargo ships larger than 500 gross tons are regulated by and rely heavily on GNSS navigation; Non-SOLAS vessels: GNSS systems for maritime navigation are widespread across commercial and recreational vessels, both overseas and in high traffic areas;
  - inland waterways (IWW) as rivers, canals, lakes and estuaries: GNSS is also used to ensure safe navigation;
- positioning
  - traffic management and surveillance: these activities are supported by GNSS–based systems including AIS (Automatic Identification System) and LRIT (Long-Range Identification and Tracking);
  - search and rescue, different types of devices as EPIRBs (Emergency Position Indicating Radio Beacons), PLB (Personal Location Beacons), and AIS-SART (Search and Rescue Transmitter) can make use of GNSS;
  - fishing vessel control: GNSS positioning enables Vessel Monitoring Systems to check the position of fishing vessels;
  - port operations: Transit progress, docking and loading–unloading operations are monitored through GNSS–based technologies;

– marine engineering: GNSS is used to support marine construction activities.

The global number of vessels and ports in 2015 is shown in the Table 2. The recreational and merchant fleets are the most and least numerous, respectively, with about 29 mln and 81 thousand vessels each.

Table 2. Global number of vessels and ports in 2015 (GNSS, 2015)

Vessels				Ports	
Merchant	fishing	recrea-tional	inland waterways	sea port	recreational marinas
81,500	2.7 mln	29.2 mln	529,000	8,289	23,280 (20 countries)

Currently (2016) European GNSS (EGNSS) consists of two systems – EGNOS and Galileo. The possible uses of these systems in the maritime and other market segments for different applications are presented in the Table 3.

GNSS receivers on ships

In the case of maritime transport, almost all ships are equipped with one GPS/DGPS receiver at least. More frequently two receivers are present (either both of the same models or two units provided by different manufacturers), and sometimes three or four (special ships) devices are employed. The need to use the second SNS exists mainly in restricted areas where the position fix using one SNS only is impossible. On the ship, the user can determine its own position from other sources, e.g. the radar. That's why at sea GNSS receivers (two or more SNSs) are still very rare (Januszewski, 2014).

The capability (in percentage) of GPS receivers integrated with at least one of the three SNS (GLONASS, Galileo and BeiDou) and/or at least one SBAS was shown for the first time in 2013, in issue 3 of GNSS Market Report. No information was available about manufacturers. In the last issue (No. 4), this survey contained information about the 31 manufacturers of more than 300 different GNSS receivers currently available on the market. All these GNSS receivers, chipsets and modules will be from now on called GNSS receivers (GNSS, 2013; 2015).

Another very well-known, and certainly also very comprehensive, receiver survey database for GPS and GNSS equipment is published annually in the January issue of the magazine "GPS World" (GPS World, 2016). In this survey we can find detailed information, i.e. 19 performance parameters, about several hundred receivers provided by several dozen manufacturers. In the number published in January 2016 the information was provided for 45 manufactures and more than 438 receivers. This receiver survey, based on performance parameter user environment and applications, distinguishes between 15 different types of users, one of which is marine (M). This type only was taken into account in the present paper. The total number of manufacturers and receivers designed for marine users in both surveys, GNSS Market Report and "GPS World", are very similar, equal to 31 and 37, and 301 and 308, respectively.

Fifteen manufacturers (Furuno, Hemisphere GNSS, Japan Radio Co, Ltd, John Deere, Leica Geosystems AG, NavCom Technology, Inc., Nottingham Scientific Ltd, NovAtel, Rockwell Collins, Septentrio, SkyTraq Technology, Thales-Avionic Division, Topcon, Trimble and u-blox) are mentioned in the last survey of GNSS Market Report (issue 4) as well as in magazine "GPS World". At least one of the GNSS receivers produced by these manufacturers is designed for the maritime segment, with the only exception of John Deere.

The percentage of GNSS integrated receivers (GPS system and/or SBAS or other SNS) in use in the different market segments in different years, reported in the two surveys, is presented in the Table 4. GNSS Market Report (issue 3, 2013) analysis was based on GPS World Survey 2013.

In the case of the maritime segment, the percentage use documented in the GNSS market report for the year 2015 is, for all three SNSs, greater than

Table 3. Possible use of European systems, EGNOS and Galileo, in maritime and other market segments for different applications (EGNOS, 2016; GNSS, 2015)

Applications	Market segments, maritime and	EGNOS	Galileo
Mass Market Consumer	LBS, road, aviation, rail	accuracy, especially in remote areas	availability, better resistance to multipath, accuracy, time to first fix
Liability-critical	LBS, road	integrity, accuracy	authentication, availability, accuracy, continuity
Safety-critical	LBS, road, aviation, rail	integrity, accuracy, compliance with safety requirements and standards	integrity, accuracy, compliance with safety requirements and standards, dedicated SAR service with return link

Table 4. Capability of GNSS integrated receivers (in percentage) according to GNSS Market Report (in all market segments and maritime segment) in different years and GPS World receiver survey (marine user) in 2016 (GNSS, 2013; 2015; GPS World, 2016)

GPS system and	GNSS Market Report				GPS World (marine user) 2016
	all market segments		maritime segment		
	2013	2015	2013	2015	
SBAS	74	62	89	77	91
GLONASS	48	55	46	68	77
Galileo	34	36	20	53	60
BeiDou	21	25	10	34	52
Number of the manufacturers	–	31	–		37
Number of GNSS receivers	–	300	–		308

the corresponding value for 2013 and, in comparison with all other market segments, lower in 2013 and higher in 2015. In the "GPS World" survey, the percentage of GNSS integrated receivers, relative to both SBASs and all SNSs, is greater than the value that appears in the GNSS Market Report for both all segments and the maritime segment only.

The surveys in GNSS Market Report and GPS World differ because the first takes into account four global SNSs, and in some cases SBAS only, while the second also accounts for two RNSS, QZSS and IRNSS.

Both in GNSS Market Report and "GPS World" Receiver Survey the analysis assesses the capabilities of receivers currently available on the market. That is why it is impossible to compare the distributions in separate years: each year different group of manufacturers are used in analysis.

The distribution of GNSS receivers (GPS only and multi-constellation), depending on the number of global SNS, in all 8 segments and in the maritime segment only, documented in the GNSS Market Report (issue 4) is presented in the Table 5. We can say that:

- distribution for all segments and maritime only differ; the percentage is highest in the case of the GPS-only and GNSS receivers of all four global SNSs respectively;
- the percentage for GNSS receivers of two SNSs is the biggest for GPS and GLONASS combination, both for all 8 segments and for maritime only.

In the survey of GNSS unit shipments by application we can distinguish 11 different types of application: Search & Rescue (PLB), Search & Rescue (EPIRB), Traffic Management, Homeland Security, Inland Waterway info, Ports, Marine Engineering, Fishing Vessels, Inland Waterway Navigation, Merchant Navigation and Recreational Navigation. The 4 types with the biggest number of the units are, and will be, Recreational Navigation, PLB and EPIRB, and Merchant Navigation. Considering the geographical distribution of GNSS devices and revenues we can distinguish 6 regions: North America, EU28, Asia-Pacific, Non-EU28 Europe, Middle East + Africa, and South America + Caribbean. The regions with the biggest installed GNSS devices for maritime applications are the first three. North America is expected to remain the most important region, although Asia-Pacific is growing at a faster pace (GNSS, 2015).

Table 5. Distribution of GNSS receivers (in percentage) depending on the number of global satellite navigation systems in GNSS Market Report in all 8 segments and maritime segment only (GNSS, 2015)

Number of the systems	System	Per cent	
		all 8 segments	maritime segment
1	GPS only	41	24.5
2	GPS + GLONASS	22	22.0
	GPS + Galileo	4	5.0
	GPS + BeiDou	1	1.5
3	GPS + GLONASS + Galileo	8	12.5
	GPS + GLONASS + BeiDou	2	–
	GPS + Galileo + BeiDou	1	–
4	GPS + GLONASS + Galileo + BeiDou	21	34.5
	Total (%)	100	100

GNSS Applications

The first applications planned for GNSS use were clearly military, and more precisely concerned the ability to provide a good departure location for intercontinental missiles launched at sea. Very soon after the military availability (1964) of the first SNS Transit (1967) the U.S. administration made the system available for civilian use also, and particularly for commercial maritime vessels. The main advantages of having an automatic positioning device are to

allow optimized routes over the oceans and also for increased security when facing bad weather.

GPS system has been available for civil and military use for more than two decades. Full Operational Capability of this system was declared in July 17, 1995 but in the early 90s GPS receivers could be already used in many different applications. That period of time has witnessed the creation of numerous new GPS applications. Because it provides high-accuracy positioning in a cost-effective manner, GPS has found its way into many industrial applications, e.g. marine applications, replacing conventional methods in most cases.

While not the largest market segment, marine navigation was the first to embrace satellite navigation. Today the market is maturing. Along with radios, AIS and radar, a GNSS receiver (in the most cases GPS receiver with or without DGPS or SBAS) is a piece of standard equipment on any ship or boat operating far from shore (Kaplan & Hegarty).

Typical maritime applications include rescue and replenishment of off-shore platforms, cruising positioning, digging waterways, or positioning and monitoring of off-shore platforms. Other typical applications consist in coupling GNSS receivers with dedicated sensors such as radar, ARPA, echo-sounder, fish-finders, and log. At sea, the receivers are usually quite crude as there is no possibility to implement techniques such as map matching, as one might be situated anywhere (Samama, 2008). A GNSS receiver can aid in the berthing and docking of large vessels, by means of position, attitude, and heading reference systems. These installations use multiple antennas aboard the vessel to determine an accurate representation of the ship's orientation. Combined with appropriate reference cartography, this can be an immense aid in the handling of large vessels in close quarters (Kaplan & Hegarty, 2006).

Marine seismic surveying is similar in principle to land seismic surveying. That is, a low-frequency acoustic energy is sent into the subsurface rock layers and is reflected back to the surface to reveal information about the composition of subsurface rocks. To obtain meaningful results, the position of the energy source and of the devices, called hydrophones, used for detecting reflected energy must be known with sufficient accuracy. This can be easily achieved, at lower costs, with GPS systems (El-Rabbany, 2002).

With the aim of differentiating and quantifying marine navigation safety requirements in the United States, the Federal Radionavigation Plan defined marine navigation in terms of phases (Federal Radionavigation Plan, 2014). The four phases defined in this Plan are ocean, coastal, harbor/harbor approach (HHA), and inland water: each phase is characterized by a remarkably different set of performance requirements based on safety and environmental concerns and aimed at minimizing marine collisions, ramming, and grounding. The GNSS GPS system, in particular, is able to satisfy many of the ocean and coastal phase performance requirements. In exploiting GNSS, currently using GPS and DGPS, for the marine environment, particular attention has to be given to vessel footprint steering performance and the interplay between sensor and ship models. Other related functions, such as hazard warning, risk assessment, and on-line dynamics modelling, are also important elements (Prasad & Ruggieri, 2005).

According to (Hofmann-Wellenhof, Lichtenegger & Wasle, 2008) maritime navigation distinguishes between five major phases: ocean navigation, costal navigation, port approach and operation in restricted waters, marine navigation in a port, and navigation in inland waterways. Satellite navigation provides a wide range of applications in the maritime domain. The position, velocity, and attitude determination capability of GNSS is used, e.g., in conjunction with river information service (RIS) to increase the situational awareness at inland waterways.

Maritime navigation is also one of the envisaged applications of the Galileo system, which is currently under construction. Open ocean and inland waterways are the most widely used modes for transporting goods worldwide, one of the strategic aims of the Galileo based transport network. Additionally, the high accuracy and integrity, certified services, and high availability brought by Galileo will be applied to leisure boats, commercial vessels, and all ships falling under the safety of life at sea convention in every phase of maritime navigation and in all weather conditions (Prasad & Ruggieri, 2005).

Conclusions

- GNSS navigation is being used in many different application areas, from purely commercial to highly scientific. In between, there are many professional domains that have found a great interest in using GNSS.
- Multi-constellation GNSS receivers became widely available on the world market, maritime market also.
- In the past few years, the GLONASS system has been the second system of choice after the GPS system.

- Detailed distribution of multi-constellation GNSS receivers consisting of a GPS receiver and one, two, three or four receivers of other systems showed that in each case the greatest percentage is when one of these systems is SBAS. This percentage will grow further with the expansion of SBAS coverage, particularly with new stations in the southern hemisphere.
- Galileo and BeiDou, two global satellite navigation systems under construction, are already present in several dozen per cent of multi-constellation receivers' models, well ahead of their full operational capability.

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