J. Ind. Geophys. Union (April 2015)
v.19, no.2, pp:210-214

Navigational Electronics Present Status, Future Demands and Strategies to Enhance Quality

A.D.Sarma
Dept.of ECE, CBIT, Hyderabad,
Former Director, Research and Training Unit for Navigational Electronics, Osmania University, Hyderabad
ad_sarma@yahoo.com

ABSTRACT
This paper briefly discusses history of navigation followed by operating principles of various satellite based navigations systems. The limitations as well as performance enhancement techniques are mentioned. The present status of satellite based navigation systems is discussed. The importance of latest techniques including indoor navigation and source localization are highlighted. The major future demands and strategies to enhance quality are given.

INTRODUCTION

Navigation is the art of directing a vehicle such as an aircraft or a person from one point to another point. In early days navigation was accomplished based on the movement of stars and the sun. As time progressed various instruments like the compass, the clock, the theodolite, the chronometer etc. came to the aid of the navigator. The radio navigation, which makes use of electromagnetic waves in fixing the position of an aircraft has an accuracy far superior compared to the earlier navigational methods such as Navigation by pilotage, celestial navigation, Navigation by dead reckoning etc.(Nagaraja,1982). Instrument Landing System (ILS) and Microwave Landing System (MLS) are some of many such terrestrial based radio navigation systems and more susceptible to errors such as interference, noise and multipath.

History changed on October 4, 1957, when the Soviet Union successfully launched the world's first artificial satellite Sputnik I. Since then satellite based Communication and Navigation fields have advanced leaps and bounds. The first satellite based navigation system 'Transit' proved the concept of position fixing using satellite signals. Navigation has become part and parcel of everyday life. An advanced and powerful Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) became operational in 1990s (Parkinson, 1996; Kaplan, 1996). The other satellite constellations, which are either under development or semi operational stage are Beidou -2 / COMPASS of China and Galileo of European Space Agency (Cao and Luo,2008; Bian et.al.,2005; Prasad and Ruggieri,2005; ESA Report,2005). These two constellations are designed for Global coverage. All these constellations are universally known as Global Navigation Satellite Systems (GNSS). GNSS refers to the world wide positioning, navigation and time determination capability available from one or more satellite constellations along with regional systems. India is developing its own Regional Navigation Satellite System (RNSS), known as Indian Regional Navigation Satellite System (IRNSS). Already 3 satellites are launched and have been giving 2D fix. This will cover Indian land mass and about 1500Kms from the mainland (Rao et.al., 2011). In contrast to other systems, it works on L5 and S-band signals. The use of L band and to some extent S-band gives acceptable received signal power with reasonable satellite transmit power levels, compared to C band and less ionospheric delay and fluctuation in delay, compared to UHF. The robustness to GNSS and RNSS can be partially attributed to the implementation of spread spectrum technology. The most important features are summarized in Table 1(Parkinson, 1996; Pratap Mishra and Pe Enge,2011; Hoffman et.al.,1992; Leick,2004).

Some of the prominent advantages of the GNSS / RNSS are: (Guochang Xu,2007; Pratap Mishra and Per Enge,2011)

- Land based system problems like ground reflections, electromagnetic interference, reflections from physical systems are mostly avoided since they are space constellation.
- Intentional interference like jamming and unintentional interference will not affect easily as spread spectrum techniques are used in it.
- System accuracy can be improved to the order of centimeters using differential techniques.

As these GNSS and RNSS systems suffer from several errors, they cannot be used for strategic applications and Precision approach of aircraft. To overcome these problems, augmentations to these systems are necessary. The purpose of the augmentation systems is to improve the positional accuracy by transmitting corrections and / or ranging signals and other parameters such as health parameters integrity messages etc. There are two important categories of augmentation systems that are either developed or being developed by various countries around the world. The first

Table 1. Salient features of GNSS and RNSS

Item	**GPS** (USA)	**GLONASS** (Russia)	**Galileo** (European Union)	**Beidou** (China)	**IRNSS** (India)
No. of SVs (Status as on Jan 2015)	30	24	4	15	3
Altitude	20,200 km.	19,100 km	23,222 km.	36,000 km 21,500 km	36,000 km
No. of orbits	6	3	3	7	3
Orbital period	11 hrs. 58 min	11hrs. 15min	14 hrs. 24min	24 / 12hrs.	24 hrs
Modulation	BPSK	BPSK	BPSK, QPSK BOC	QPSK	BPSK BOC
Operating Frequencies (MHz)	L1 = 1575.42 L2 = 1227.6 for all the satellites	L1=1602 – 1615.5 L2 =1246 – 1256.5 Each satellite has different freq.	E1 = 1587 –1591 E2 =1559 – 1563 E5 = 1164 –1214 E6 = 1260 –1300	B1=1559.052-1591.788 B2=1166.22-1217.37 B3=1250-1286.423	L5=1176.45 C= 6700-6725 S=2492.028
Services offered / Applications	Civilian and Military	Safety-of-life Search and rescue service.	Open Service. Search and rescue service.	Open service Authorized service	Open service Restricted service

Table 2. Salient features of SBAS

S.No	SBAS and Country	No. of satellites	Typical accuracy (95%) (m)	Operational status
1	WAAS (USA)	5	Hor: 0.9; Vert:1.3	Operational
2	EGNOS(European Union)	3	Hor: ~ 1 ; Vert:~2	Operational
3	MSAS (Japan)	2	1.5-2.0 (Hor. and Vert.)	Operational
4	GAGAN (India)	2	Hor:1.5; Vert:2.5	Operational

category is Space Based Augmentation System (SBAS). Wide Area Augmentation System (WAAS) of USA, European Geostationary Navigation Overlay Service (EGNOS) of the European Space Agency, the European Commission and EUROCONTROL, the Multi-functional Satellite Augmentation System (MSAS) of Japan and GPS aided Geo Augmented Navigation (GAGAN) system of India come under this category and provide seamless air navigation service across their respective regional boundaries. India would become the fourth country in the world to adopt this system. The salient features of these SBAS are presented in Table 2 (Parkinson, 1996; Pratap Mishra and Per Enge, 2011).

Though SBAS provides a coverage area of over thousands of miles, it suffers from less accuracy. As India comes under equatorial and low latitude regions,where ionospheric behavior is dominated by intense irregularities and large horizontal gradients associated with the F- region equatorial anomaly, extra precautions are necessary to compensate for errors. SBAS is not expected to perform efficiently in such Indian conditions. The SBAS is performing to the expected performance levels during en route of the aircraft and other such applications. But, during take-off and landing it is satisfying only near CAT-I requirements. The SBAS systems could not satisfy the Required Navigation Performance (RNP) Parameter specifications completely for CAT-1. The limitations of SBAS include inability to meet civil aviation precision approach requirements of Category II and III, limited operational area and usage of expensive certified aircraft receivers. All these limitations can be trounced by use of GBAS, especially during takeoff and landing operations of aircraft.

The use of Ground Based Augmentation System (GBAS) facilitates precision approaches (Cat-II and Cat-III) of aircraft. The Local Area Augmentation System (LAAS) of USA is one such system that is developed recently. This is expected to satisfy all precision approach category requirements of aircraft. To appreciate the use of GBAS for achieving the ultimate positional accuracy, and its applications in several other areas including mining, its

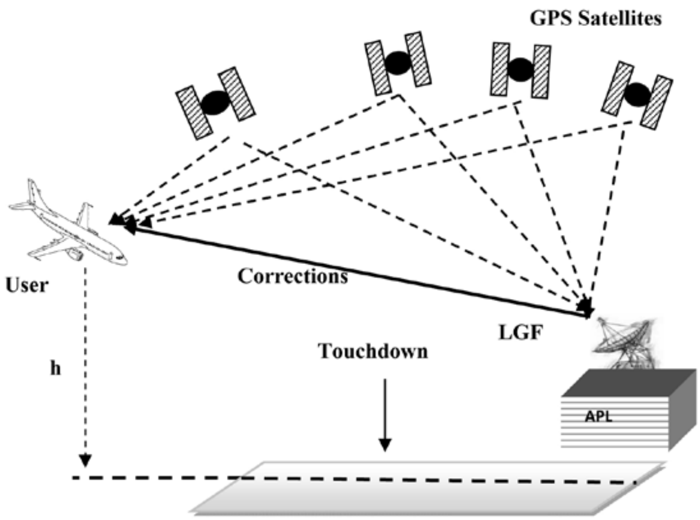

Figure 1. Architecture of Local Area Augmentation System (LAAS)

basic principle of operation is briefly described here (Per Enge,1999, RTCA-DO 245A,2004).

LAAS developed by Federal Aviation Administration (FAA) of USA, is a DGPS based augmentation to GPS. LAAS is expected to provide high accuracy, reliability and safety required for low visibility conditions and meets the RNP for all three categories of precision approaches. LAAS Ground Facility (LGF) consists of multiple reference receivers at precisely surveyed locations and a VHF radio data transmitter and one or more pseudolites to increase availability (Fig.1). In LAAS, the differential corrections, integrity information and additional ranging signal will be made available to users through a LAAS Ground Facility (LGF). The ground station makes the differential corrections and then broadcasts these on VHF frequencies along with an integrity message to aircrafts within a radius of 20 to 30 nautical miles from the airport in LAAS message format. A receiver on an aircraft uses this information to correct GPS signals (RTCA-DO 246D, 2008). In contrast to WAAS, which makes multiple vector corrections such as ephemeris, clock and ionospheric to each satellite, LAAS makes a single scalar range correction for each satellite. LAAS with its inherent superior accuracy assumes a key role in advanced terminal area operations such as precision departure, curved approaches as well as airport surface surveillance and guidance. When an individual ILS is required for each runway end, a single LAAS can provide coverage for every runway end on the airport and can be extended to provide coverage for nearby airports also.

GPS Modernization: This program aims to provide signal redundancy and improve the positional accuracy, signal availability and the system integrity. Modernization is being done in two stages (GPS II and GPS III). The new GPS signals properties include faster codes, longer codes, forward error correction, and data-free signal components. These properties bring immediate improvements to signal acquisition and tracking. This would be especially useful for low signal to noise ratio environments. GPS III will ensure integrity by performing outage monitoring, detection, validation, alerting and the initiation of corrective action. With modernization GPS will transmit as many as 8 signals (Pratap Mishra and Per Enge,2011, Leick,2004).

GNSS APPLICATIONS: It is not an exaggeration to say it is nearly impossible to find an area where GNSS has no application. To name a few, communications, transport sector, medical, agriculture etc. Due to tremendous advancements in the GNSS technology, several demands (some critical and some not so critical) are emerging. Smaller size and reduced cost of the GNSS receiver enables it to be a part of 3G Communications onwards. By keeping the GNSS at 'Fixed" stations and operate continuously one can determine their positions each day and monitor their motions relative to a global coordinate system. In campaign mode, on well surveyed locations, temporary GNSS sites can be established on the Earth and the motion of these sites can be studied. Even though, submarines while navigating underwater use non-GNSS systems, for updating their position and maintain accuracy, they periodically use GNSS signals.

LIMITATIONS OF GNSS: Even though, GNSS based systems have several advantages over conventional navigation systems and are robust, they cannot be used for indoor applications due to non-availability of line of sight signals. The performance of GNSS systems can still be affected by jamming and spoofing. Spoofing refers to the process of replicating the GPS code so that the user computes incorrect position solutions (Parkinson, 1996). By spoofing the GNSS system, any person can maneuver the GPS equipped user and destroy the very purpose of GNSS. For example, in defense the missile will hit the wrong target; it can make electric power units to be tripped due to loss of synchronization.

FUTURE DEMANDS:

To counter spoofing, anti-spoofing techniques such as encryption are to be implemented. In some circumstances, GNSS signals may not be available, either due to jamming, spoofing or due to environmental conditions. In such circumstances Navigation via Signals of Opportunity (NAVSOP) are to be used for intelligence navigation. (http://www.modularmining.com/gps/glossary.htm). Aviation needs a multi-constellation GNSS for better performance and more robustness against vulnerabilities. Gradual reliance on multi-constellation GNSS for Communication, Navigation and Surveillance applications for all phases of flight enables future Air Traffic Management (ATM) more effective.

Availability and processing of data in real time is a challenge. Main challenge is how to achieve position accuracy, portability, and low power consumption at affordable price. The ultimate aim is to develop reliable and efficient Green Navigation systems to meet these emerging challenges.

SIGNIFICANCE OF NAVSOP: To counter the limitations of GNSS and improve navigation availability, this technique uses the same wireless technologies as mobile phones, TVs, radios and Wi-Fi. As this utilizes wider range of signals, it offers greater resistance. This technology is likely to influence future navigation applications both in civilian and military domains. The conventional terrestrial based navigation and satellite based navigation techniques are normally limited to outdoor environments. Thus there is a clear need for developing effective navigation technologies for indoor applications including in mines, exploration areas where line of sight of radio signals is not guaranteed. Under such conditions, NAVSOP techniques can be implemented. Indoor localization has been actively researched recently due to security and safety as well as service matters.

LOCALIZATION TECHNIQUES: Like satellite based navigation, localization techniques are finding innumerable applications. The prominent methods include, TOA, TDOA and Received Signal Strength (RSS) measurements. Wireless sensor network localization is one such method and created lot of enthusiasm among the researchers and academics. This interest is expected to grow further with the proliferation of wireless sensor network applications (Mao, Fidan and Anderson, 2007).

INTERNATIONAL STATUS OF STATE OF THE ART NAVIGATIONAL RESEARCH: Several research institutes and universities around the world have been working actively in this challenging field. Their research is periodically presented / published in peer reviewed conferences and Journals. To know the latest developments in this area, including basic science, engineering and applications one may refer the latest Proceedings of Institute of Navigation GNSS conference held in USA every year. Acquisition and sharing of GNSS data such as ionospheric data would help for the advancement of GNSS technology. "Electronic Navigation Research Institute (ENRI) is responsible for research and development in the field of electronic navigation in Japan. Ionospheric delay and scintillation of GNSS signals can result in the ranging/ positioning errors. In the magnetic low latitude region, where the ionospheric variations are intense, appropriate characterization of the ionosphere is very important. ENRI is working on ionospheric data collection, analysis, and sharing in collaboration with research organizations in Japan and overseas as well as ICAO to facilitate GNSS implementation for aviation in the low magnetic latitude region." (http://www.enri.go.jp/eng/index_e.htm). One more area which GPS has totally revolutionized throughout the world is seismic research. In 1987, the U.S. Geological Survey (USGS) began using GPS to gather precise position data on the ground in several earthquake-prone areas in California. The first major test of GPS as a seismic tool occurred on Oct. 17, 1989, when the Loma Prieta earthquake struck San Francisco. Even though the strain gauges, trenching and other approaches provide useful information on crustal motion, only GPS provided scientists with precise measurements of both large- and small-scale displacements, thus GPS proved its worth. (John Stenmark,2014) http://www.earthmagazine.org/article/precise-fault-how-gps-revolutionized-seismic-research.

Based on GPS data, Bevis et.al. (1992) presented a novel approach for remote sensing of water vapor. They reported that data from ground-based GPS networks could be analyzed in concert with observations of GPS satellite occultations by GPS receivers in low Earth orbit to characterize the atmosphere at planetary scale. The measurements are expected to be useful in operational weather forecasting and in fundamental research into atmospheric storm systems, the hydrologic cycle, atmospheric chemistry, and global climate change. Appropriately designed dense GPS networks are useful to sense the vertical distribution of water vapor in their immediate vicinity. Significant information on how outer space can be explored for the benefit of the humanity, including navigational aspects can be accessed from 'United Nations Committee on the Peaceful Uses of Outer Space' reports.

CONCLUSIONS

Historical background is necessary to get motivation and inspiration to do research in the area of navigational electronics. The topics introduced in this paper together with the references are expected to be helpful in understanding basic concepts and to know the latest advancements. Now the research in multidisciplinary areas such as GNSS and signal processing aspects have become order of the day and influencing and commanding both the technological and societal aspects.

REFERENCES

Bian, S., Jihang Jin, and Zhaobao Fang, Fall 2005. "The Beidou Satellite Positioning System and Its Positioning Accuracy," Navigation: Journal of the Institute of Navigation, v.52, no. 3,

Bevis Michael, Steven Businger, Thomas A. Herring, Christian Rocken, Richard A. Anthes, and Randolph H. Ware, 1992 "GPS meteorology: Remote sensing of atmospheric water vapor using the global positioning system", Journal of Geophysical Research, v.97, Issue D14, pp: 15787–15801.

Cao, C., and M. Luo, 2008. "COMPASS Satellite Navigation System Development," Proc. Stanford's 2008 PNT Challenges and Opportunities Symposium, Stanford, California, November, pp:5–6.

ESA report of 2005 at http://www.esa.int/esaNA/GGG0H750NDC_galileo_0.html.

EVP Europe report of 1999 at http://www.esa.int/esaNA/GGGMX650NDC_galileo.

Guochang Xu, "GPS: Theory, Algorithms and Applications",2nd Ed.2007, ISBN 978-3-540-72715-6,Springer.

Hofmann-Wellenhof, B., Lichtenegger, H. and Collins, J., 1992 "Global Positioning System: Theory and Practice", 4th edition, Springer-Verlog, Berlin Heidelberg New York, pp:389,.

Kaplan,E.D., 1996. "Understanding GPS: Principles and Applications", Artech House.

Leick, A., 2004 "GPS Satellite Surveying", 3rd Ed., ISBN: 978-0-471-05930-1, John Wiley and Sons Publications,.

Misra Pratap and Per Enge, 2011 "Global Positioning System: Signals, Measurements, and Performance", Revised Second Ed.2011, ISBN 0-9709544-1-7, Ganga-Jamuna Press.

Nagaraja N.S., 1982. "Elements of Electronic Navigation", Tata McGraw–Hill,

Parkinson, B. W., 1996. "GPS Theory and Applications", Volume I, American Institute of Aeronautics and Astronautics, Inc, Washington, pp:81-114,

Per. Enge, 1999." Local area augmentation of GPS for the precision approach of aircraft", Proceedings of the IEEE, v.87(1) pp:111–132.

Ramjee Prasad and Marina Ruggieri, 2005. "Applied Satellite Navigation Using GPS, Galileo and Augmentation Systems", Archtech House Publishers,

Rao,V.G, G. Lachapelle, and S.B. VijayKumar, 2011 "Analysis of IRNSS Over Indian Subcontinent", Proc. of the 2011 International Technical Meeting of The Institute of Navigation, San Diego, CA, pp:1150-1162.

RTCA DO-245A, 2004. " Minimum Aviation System Performance Standards for LAAS", 9 December,2004.

RTCA DO-246D, 2008 "GNSS Based Precision Approach LAAS Signal-in-Space Interface Control Document (ICD)" , 16 December 2008.

Mao,G., Fidan ,B., Anderson.B.D.O, 2007 " Wireless sensor network localization techniques", Computer Networks v.51 pp:2529–2553,Elsiever.

Related Websites

i. ftp://tycho.usno.navy.mil/pub/gps/gpsb2.txt.
ii. http//:sidt.gpsworld.com
iii. http://isro.gov.in
iv. http://sc.gpsworld.com/gpssc/Survey+&+Construction+News/ION-GNSS-Market-to- Grow-to-6B-to-8B-by-2012/ArticleStandard/Article/detail/551703
v. http://www.beidou.gov.cn/
vi. http://www.glonass-ianc.rsa.ru/pls/htmldb/f?p=202:20:14637162736231801312::NO
vii. www.isro.org/pressrelease/Jul04_2006
viii. http://www.datacollection.eu/contents/articles/en/20120228/galileo_will_boost_economy

Prof. A.D. Sarma obtained Ph.D. in Electronic and Electrical Engineering from London University(UK) in 1986. Between 1977 and 1982, he was associated with DEAL (Dehradun), Electrical Eng. Dept. of IIT, New Delhi, and DLRL, Hyderabad. Between 1986 and 1991 he was associated with the Telecommunications Div. of Electrical Eng., Dept. of Eindhoven University of Technology, The Netherlands and Wave Propagation laboratory of NOAA, Boulder (USA). Between 2000 and 2013 he was Director for Research and Training Unit for Navigational Electronics, Osmania University, Hyderabad. Presently, he is working as a senior professor at Dept.of ECE, CBIT, Hyderabad. He has about 220 publications to his credit both in national and international journals, Conferences, Symposia etc. Under his guidance 17 students obtained Ph.D.

He successfully completed 19 nationally important projects and organized 22 training programs and short courses including five SERC schools on GPS sponsored by DST, New Delhi. He is a member of several prestigious committees including, DRDO, ISRO, MIT, and has given more than 60 invited talks/lectures at prestigious organisations. Recently he is awarded IETE Flt.Lt. Tanmaya Singh Dandass Memorial Award (2013) in recognition of outstanding contributions in atmospheric time delays for improving the positional accuracy of GPS and providing training in the area of navigational electronics. His interests include GPS, GPS augmentation systems, Atmospheric effects, mobile and green communications, high frequency antenna analysis and microwave and millimeter wave systems. He is editorial board member of Indian Journal of Radio and Space Physics (CSIR) and guest editor for a special issue. He is a fellow of IETE, IE, IGU and member of AGU (USA) and Senior member of IEEE.