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REVIEW ARTICLE

Overview of the development of global navigation satellite system

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ABSTRACT

Global navigation satellite system and its application fields are constantly expanding and deepening. This paper mainly introduces the current situation of global satellite navigation system and its application technology, development trend and application prospect. At the same time, this paper makes a comprehensive comparison of these navigation systems, analyzes the opportunities and challenges faced by China's BeiDou satellite navigation system in the global context, and puts forward some suggestions for future work.

Keywords: GNSS; GNSS Positioning Technology; GNSS-R Technology; GNSS Occultation Technology; Integrated Navi-Gation Technology; Multi Frequency and Multi System Joint Positioning Technology

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1. Introduction

Global navigation satellite system (GNSS) is a space-based radio navigation and positioning system that can provide users with all-weather three-dimensional coordinates, speed and time information at any place on the earth's surface or near earth space[1]. At present, satellite navigation and positioning technology has basically replaced ground-based radio navigation. Traditional geodesy and astrometry navigation and positioning technology, and promote the new development of Geodesy and navigation and positioning field. Today, the GNSS system is not only the infrastructure of national security and economy[2], but also an important symbol of the status of a modern power and the comprehensive national strength of a country. Because it is in politics, economics, military and other aspects are of great significance. Major military powers and economies in the world are competing to develop independent satellite navigation systems. On April 14th, 2007, China successfully launched the first BeiDou satellite, marking that the fourth GNSS system in the world has entered a substantive operation stage[3], and it is estimated that the U.S. GPS will be launched by 2020. Four GNSS systems, including Russia's GLONASS, EU Galileo and China's BeiDou satellite navigation system, will be completed or modernized. In addition to the above four global systems, it also includes regional systems and enhanced systems, including QZSS in Japan and IRNSS in India, and WASS in the United States. MSAS in Japan. EGNOS in the European Union. GAGAN in India and NIGCOMSAT-1 in Nigeria.

In the next few years, the satellite navigation system will enter a new stage[4,5]. Users will face the situation that nearly 100 navigation satellites of four global systems coexist and are compatible with each other. Abundant navigation information can improve the usability of satellite navigation users, accuracy, completeness and reliability, but at the same time, we have to face the competition of frequency resources, satellite navigation market competition, time and frequency dominance competition, compatibility and interoperability debate and many other issues. Therefore, on the basis of introducing the current situation and development of GNSS system, this paper makes a comprehensive comparison, and analyzes the application and development of navigation system, as well as the opportunities and challenges faced by BeiDou satellite navigation system in China.

2. Development status of satellite navigation system

2.1 GPS

GPS is a radio navigation and positioning system developed on the basis of the U.S. navy navigation satellite system[1,6]. It has omnipotence, global, all-weather, continuous and real-time navigation. Positioning and timing functions can provide users with precise three-dimensional coordinates, speed and time. Today, there are 31 GPS satellites in orbit, including 10 GPS-2A satellites, 12 GPS-2R satellites, and 9 modernized GPS-2R-M and GPS-2F satellites with M-code signals. According to the GPS modernization plan, the United States promoted the upgrading process of GPS in 2011. Gps-2F satellite is the last model of the transition from the second generation GPS to the third generation GPS, which will further enable GPS to provide higher positioning accuracy.

GPS modernization process includes space segment. The goal of the modernization and upgrading of the ground segment and user segment is to greatly alleviate the vulnerability of the current GPS and provide global users with high anti-interference. High positioning accuracy and safe and reliable service. At present, the research and development of the third generation GPS is progressing smoothly. According to the plan, the first GPS-3 satellite will be launched in 2014, and the whole GPS-3 constellation plan will be completed in nearly 20 years, so as to replace the current GPS-2. The third generation GPS will choose a new optimal design scheme, abandon the current layout and structure of the 6-orbit 24 satellite constellation, and plan to use 33 GPS-3 satellites to build a new GPS hybrid constellation combining high elliptical orbit (HEO) and geostationary orbit (GEO). In addition, a new pseudo noise code L1C code is added to the first GPS navigation and positioning signal, which will be other civil signals (L1C). L2C and L5) and the generation of new M-code signals, so that the navigation information is more complete, and the accuracy and effectiveness are improved.

2.2 GLONASS

GLONASS is the second generation military satellite navigation system independently developed and controlled by the former Soviet Defense Ministry[1], which is the second global satellite navigation system after GPS. The project has been in operation since 1976, and the whole system was completed and put into operation in 1995. With the disintegration of the Soviet Union, the GLONASS system was unsustainable. By April 2002, there were only eight satellites left to operate. From August 2001, Russia began to plan to recover and carry out the modernization of GLONASS after economic recovery. After 10 years of paralysis, the GLONASS navigation constellation finally resumed the operation of the whole system at the end of 2011.

Russia will continue to launch six satellites in 2012. It plans to increase the number of constellation satellites to 30 in the next few years, and make its positioning accuracy reach 3m in 2015, which is equivalent to the positioning accuracy of current GPS, so as to achieve compatibility and interoperability with GPS/Galileo on L1 frequency.

2.3 GALILEO

Galileo satellite navigation system (GALILEO) is a global satellite navigation and positioning system developed and established by the European Union[1]. The plan was announced by the European Commission in February 1999 and is jointly responsible with ESA. The system consists of 30 satellites, including 27 working satellites and 3 backup satellites. The satellite has an orbital height of 23,616 km and is located in three orbital planes with an inclination of 56°. In October, 2012, the second batch of two satellites of GALILEO global satellite navigation system were successfully launched. The four official Galileo satellites in space can form a network and initially realize the function of precise positioning on the ground. GALILEO system is the world's first civil based global navigation satellite positioning system. After it is put into operation, users around the world will use multi-standard receivers to obtain more signals from navigation and positioning satellites, which will virtually greatly improve the accuracy of navigation and positioning.

The implementation of GALILEO plan is divided into five stages, GSTB-V_1 stage and GSTB-V_2 stage have been completed. Since October 21, 2011, the program has entered the on-orbit verification phase (OVP). The task of this phase is to verify the feasibility of GALILEO by launching four in orbit verification satellites and testing the satellite and ground control system. As of October 12, 2012, four OVP satellites have been in orbit. According to the plan, GALILEO constellation will have 18 satellites by 2015, and 30 satellite constellations will be completed by 2020. After putting into use, it will be compatible and interoperable with GPS on L1 and L5 frequency points.

2.4 BeiDou satellite navigation system (BDS)

BeiDou Navigation Satellite System (BDS) is independently developed by China. An independent global satellite navigation system. The system is divided into two generations, namely BeiDou generation I and BeiDou generation II[7].

China decided to build the BeiDou System in the 1980s. In 2003, the BeiDou satellite navigation verification system was completed. The system consists of four geostationary satellites. The ground control part and the user terminal are composed of three parts. The double star positioning system formed by the BeiDou generation can provide active positioning services within China and around the Taiwan Strait. In order to further improve the capability of BeiDou satellite navigation system, the construction of BeiDou second generation system is currently under way. The BeiDou generation II system consists of five synchronous earth satellites and 30 medium orbit satellites, of which the medium orbit satellites are distributed on three orbital planes with an inclination of 55°, and the orbital radius is 21,500 km. Following the launch of a BeiDou geosynchronous satellite and a medium orbit satellite in February and April 2007, the BeiDou second generation system entered the construction period. So far, 16 BeiDou navigation satellites have been successfully launched, and a regional passive satellite navigation system covering China and the Asia Pacific region has been initially built. It is planned to launch 35 BeiDou navigation satellites to realize a global passive satellite navigation system, and this huge constellation is planned to be built by 2020. The BeiDou II system has many similarities with the U.S. GPS in terms of navigation mode and coverage, but retains the two-way position report of BeiDou I. Short message communication function, which is also an advantage of BeiDou in competition with other GNSS systems.

3 Future development of satellite navigation system

3.1 Development trend

At present, the global navigation satellite system is undergoing unprecedented changes: from a single GPS era to a new era of GNSS with multi satellite coexistence and compatibility, which makes the satellite navigation system globalized and multi-mode; from satellite navigation applications as the main body to positioning navigation. The new stage of time service and the integration of information carriers such as mobile communication and Internet makes information fusion and integration. At present, the expansion of GNSS application technology mainly includes:

3.1.1 GNSS positioning technology

Navigation and positioning technology is developing from two countries to many countries. In the future, satellite navigation and positioning systems will face the coexistence of multiple systems, which will promote the development of navigation technology; the mutual compatibility of national satellite navigation systems in the civil field will become the general trend of international development; the integration of navigation, communication and geographic information system. Mutual penetration will become the mainstream of future applications. The satellite navigation and positioning technology will be continuously improved and perfected, and the accuracy will be improved. The coverage area is expanded to long service life. Anti-interference. The development direction of anti-strike ability and improving autonomous operation ability; receivers are developing towards miniaturization and intelligence. Satellite navigation will become the third largest information industry affecting human society after mobile phones and the Internet. The new development of GNSS positioning technology is mainly reflected in two aspects: precise point positioning (PPP) and network RTK Technology:

In terms of PPP, the research focus has shifted from the real solution of non-difference ambiguity to the integer fixed solution of non-difference ambiguity. In 2007, the document[8] used the inter satellite single difference method to estimate the uncorrected phase delay (UPD) of the inter satellite single difference at the satellite end using the observation data of about 180 GPS tracking stations around the world. Users can use this set of estimated UPD products to realize the integer fixed solution of the ambiguity of the inter satellite single difference through post-processing. Different from the fixed method of single difference ambiguity between satellites, the document[9] proposes to use the observation data of several GPS stations and networks, re-estimate the "integer satellite clock" by introducing the reference clock, and publish it to the user. Using its improved satellite clock difference, after initialization of about 30 min and 90 min in static and dynamic modes, the fixed non difference integer ambiguity can be obtained. Collins, Lahaye, Hrous, *et al.*[10] proposed a decoupled clock model. In this model, the GPS satellite clock difference corresponding to the pseudo range is determined by the pseudo range, and the GPS satellite clock difference corresponding to the carrier phase is determined by the carrier phase. The carrier phase ambiguity is no longer affected by the pseudo range hardware delay, so that the non-difference ambiguity has the integer characteristic again. The experimental results show that the non-differential integer ambiguity can be successfully solved after about 30 minutes of initialization.

In terms of Network RTK technology, network RTK based on double difference mode has been relatively mature, and many engineering applied network RTK systems have been established at home and abroad. At present, many scholars are carrying out research on network RTK technology based on non-differential mode, and have achieved phased results. In the future, China can establish a nationwide network of continuously operating reference stations, and form a system for the reception and management of navigation data, data processing, integration of various types of navigation data, and the distribution of navigation information. Realize high-precision, three-dimensional, real-time dynamic navigation from meter level to millimeter level, as well as fast static or precise single-point positioning services for aviation, railway, highway, shipping, water transportation, urban transportation, surveying and mapping and other users.

3.1.2 GNSS-R technology

GNSS-R technology is a method to obtain target information by using GNSS reflected signal. As a new remote sensing method, GNSS-R technology has received extensive attention. Scholars have used GNSS-R technology to measure sea level height, soil moisture, snow thickness, etc. Major countries such as the United States and Europe have invested a lot of manpower. The material and financial resources are studied, and the foundation is carried out. Airborne and spaceborne observation experiments have laid a foundation for further research and application in the future. GNSS-R in theory. Technology and data inversion will be improved. There will be more and more receiving stations, and the data obtained will be more and more dense.

3.1.3 GNSS occultation technology

GNSS radio occultation observation technology is to retrieve atmospheric parameters by placing

GNSS receivers on LEO satellites to receive atmospheric refraction signals generated by occultation events. This technology gets rid of the shortcomings of traditional detection methods, and can stably measure the global distribution of atmospheric parameters and ionospheric electron density from the ground to 800 km altitude for a long time, with all-weather, high-precision, high vertical resolution, long term stability, global coverage and other characteristics[11]. The emergence of GNSS occultation technology is a revolutionary change in the history of space exploration. Using Occultation Technology to obtain atmospheric parameters will be one of the most conventional detection technologies in the 21st century. The future occultation observation system will change from a single low orbit satellite to multiple low orbit satellites, from only GPS satellites to multiple GNSS satellites, and obtain more atmospheric occultation observation data. More evenly distributed. The detection range of occultation atmosphere is deeper into the ground, and the detection accuracy is higher. Occultation observation technology will focus on spaceborne occultation. Airborne occultation and mountain-based occultation are the auxiliary directions. The implementation and completion of the occultation plan requires broader international cooperation.

3.1.4 Integrated navigation technology

The form of integrated navigation system will be more diversified, integrated and intelligent, INS/GPS combination will still be the first choice for integrated navigation system; ground-based radio navigation technology is still used as an effective backup and supplement for satellite navigation services; terrain-aided navigation technology continues to improve performance, and develop new terrain matching methods and expand the scope of application; and sonar navigation, underwater electric field navigation, geomagnetic and electromagnetic navigation, and gravity and gravity gradient navigation technologies will also continue to improve accuracy. With the continuous improvement of navigation technology, its application will be more extensive.

3.1.5 Multi frequency and multi system joint positioning technology

Under complex observation conditions, the traditional single system dual frequency navigation and positioning often faces the problems of insufficient visible satellites, poor positioning accuracy and reliability. The application of multi frequency observations and the implementation of multi system joint positioning will provide users with more alternative combined observations, increase the number of visible satellites, enhance the geometric strength of satellites, reduce or eliminate the systematic errors caused by single system navigation and positioning, so as to improve the positioning accuracy and reliability. With GPS. With the advancement of the modernization process of GLONASS and the development of GALILEO and China’s BeiDou satellite navigation system, the joint positioning mode of multi frequency and multi system will gradually become the mainstream navigation and positioning mode. The development of satellite navigation systems in various countries will pay more and more attention to the compatibility and interoperability between systems. Unification of spatiotemporal benchmarks among multiple systems. The fusion of multi system data and the integrity monitoring of multi system have become the key technologies that need to be studied and solved. Multi frequency and multi system joint positioning will provide users with more stable and reliable positioning results, so as to expand the application of satellite navigation and positioning technology in various fields.

3.2 Application prospect

At present, the application of GNSS has penetrated into all fields of economy and society, which can be said to be pervasive. Now some people even say that the application of GNSS is only limited by people’s imagination. It can be seen that the application prospect of GNSS is extremely broad. The following is just a few applications as examples.

3.2.1 Surveying and mapping application

GNSS is widely used in high-precision geodetic surveying, control surveying, cadastral surveying and engineering surveying. At present, the application of GNSS in the field of geodesy has been extended to geophysics, geodynamics, etc. In addition to the observation of crustal motion, with the continuous increase of GNSS continuous observation stations, the observation phenomenon will be more abundant. High-precision GNSS technology will become an important means of monitoring volcanic earthquakes, tectonic earthquakes, and global plate movements.

3.2.2 Transportation application

In terms of land transportation, GNSS technology is used to track, dispatch and manage vehicles, and vehicles are allocated reasonably to respond to user requests at the fastest speed, reducing energy consumption and saving transportation costs; in terms of water transportation, it realizes ocean navigation of ships; realize aircraft navigation and guide the aircraft to enter and leave the airport safely. In the future, a digital information transportation platform will be established in the city, and the on-board equipment will be accurately positioned through GNSS, combined with electronic maps and real-time traffic. According to the traffic conditions, the optimal path is automatically matched, and the autonomous navigation of the vehicle is finally realized.

3.2.3 Public safety applications

GNSS responds efficiently to emergencies such as fires, natural disasters, traffic accidents, and crime scenes to minimize losses. With the help of GNSS, rescuers can carry out effective search and rescue of missing persons in harsh environments. Vehicles equipped with GNSS devices can locate and alarm in time in case of danger, so that they can be rescued more quickly and in time.

3.2.4 GNSS-R application

The application of GNSS-R mainly focuses on ocean remote sensing. Soil moisture monitoring[12]. Snow thickness measurement[13] and vegetation change inversion. In terms of ocean remote sensing, the average height of the sea surface can be calculated by using the GNSS sea surface reflection signal, sea surface wind field, wave height, important ocean information such as sea surface salinity; using GNSS-R remote sensing to calculate soil moisture content can be used to prevent drought and flood disasters; the application of GNSS-R in glaciers and snow can promote the understanding of the internal structure of snow, and further deepen the understanding of the continental boundary, especially the Antarctic continent; GNSS-R can also be used to monitor the change of surface vegetation, which is of great significance in preventing land desertification and reflecting the characteristics of climate change.

3.2.5 GNSS occultation application

The application of GNSS occultation inversion technology is embodied in numerical weather prediction, climate analysis and ionospheric monitoring. Using GNSS occultation observation data, atmospheric parameters can be continuously monitored in a wide range (up to hundreds of kilometers), so as to analyze and predict precipitation for meteorological departments. Typhoon and other severe convective weather provide important reference data. The assimilation of occultation observation data can also be used to test and improve the numerical weather prediction model. GNSS occultation observation data has the characteristics of being unaffected by weather, no calibration, and stable data, so it can also be used for climate analysis and research. In addition, global ionospheric electron density distribution data can be obtained by using occultation observation technology, which can be applied to ionospheric analysis and research, such as detecting ionospheric anomalies during earthquakes or solar storms. The development of GNSS radio occultation observation technology will also promote space environment monitoring, data assimilation, development of research on space weather effects and climate change[14].

4. Opportunities and challenges faced by BeiDou satellite navigation system

At present, the BeiDou satellite navigation system has officially provided independent regional services of satellite positioning and navigation timing in China and surrounding areas, marking the successful completion of the second step of the BeiDou “three-step” strategy. The application of BeiDou satellite navigation system has been involved in transportation, fisheries, hydrology, meteorological, forestry, signal communication, electricity. In many industries such as rescue, China's BeiDou satellite navigation system is now moving towards the "third step" and the goal of forming a global coverage capacity by 2020. Therefore, the development and application of BeiDou satellite navigation system in China will not only face many opportunities, but also meet some challenges. Based on the existing data, a preliminary comprehensive analysis is made here.

4.1 Opportunities

Satellite navigation is a high-tech industry worthy of the name, with high growth. High efficiency is characterized by small investment. Typical of large output; the satellite navigation industry will soon enter a stage of rapid development.

At present, international cooperation has become a hot trend in the development of GNSS. BeiDou satellite navigation system is facing a good opportunity for rapid development. Of course, at the same time, we should see that GNSS international cooperation is not only a kind of communication and coordination, but also a kind of game and competition. Among the opportunities, the most urgent thing for BeiDou satellite navigation system is to ensure that GNSS is compatible, interoperable and exchangeable in technology, which is not only the need of international cooperation, but also the urgent need of China's industrial and market development.

4.2 Challenges

4.2.1 Market issues

Due to the late start of BeiDou satellite navigation system, the international and domestic satellite navigation market has been basically occupied by GPS and GLONASS, so it is very difficult to occupy a place; at the same time, it is relatively difficult to import many advanced equipment related to satellites.

4.2.2 Policy issues

Both GPS in the United States and GLONASS in Russia have relatively complete and transparent policies and use specifications. As a major national infrastructure, BeiDou satellite navigation system has issued a clear development strategy, but there is no sound satellite navigation application policy and standard. The BeiDou satellite navigation policy is not perfect, the transparency is not enough, and the system status is not obvious enough, so it is difficult to win the trust of users. At the same time, the relevant management policies for the construction and application of BeiDou satellite navigation system are not clear enough, which will affect the expansion of users.

4.2.3 Conceptual issues

At present, the market share of BeiDou satellite navigation system is not high, the concept of active service of receiver manufacturers and management departments is still weak, and the promotion of products. The initiative of maintenance and service needs to be strengthened.

4.2.4 Technical issues

BeiDou satellite navigation system is facing strong technical competition. The performance and stability of satellite system need to be improved, and the receiver technology, atomic clock technology. There is a lot of room for the development of signal modulation and acquisition technology, and the related coordinate system and time system still have room for improvement; at the same time, there are relatively few BeiDou ground tracking stations, and the geometric structure is not reasonable; the data service center is almost blank, and the corresponding service products are not rich enough.

5 Conclusion

Nowadays, with the rapid development of GNSS, satellite navigation technology is entering a critical period of rapid development. The establishment and development of independent BeiDou satellite navigation system is the need of China's national defense security and military modernization, but also an urgent need to promote the development of domestic satellite application technology and promote economic construction. The fierce competition of GNSS in many countries in the world will inevitably lead to its more comprehensive functions, wider coverage, more reliable stability, better completeness and deeper application. There is still a certain gap between China's existing technological level and the world's leading-edge key technologies, which still needs continuous efforts and improvement. At present, the development of GNSS is both an opportunity and a challenge for China. Therefore, we must seize this opportunity to further improve and perfect the existing satellite navigation system and technology, so as to speed up the pace of GNSS, especially the BeiDou satellite navigation system with Chinese characteristics, towards application.

Conflict of interest

The authors declare that they have no conflict of interest.

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