Beidou Navigation Satellite System Development, Application, and Prospects

Sian Lu[1, *], Siying Pan[2] and Haotong Zheng[3]

[1] School of Shanghai International High School of Britain, Shanghai China

[2] School of Wuhan Optics Valley Foreign Languages School, Wuhan, China

[3] Fuzhou No.8 Middle School, Fujian, China

*Corresponding author: lusian070416@icloud.co

Abstract. The Beidou Navigation Satellite System (BDS), also known as Beidou, is an independently developed global satellite navigation system by China, and it is the third mature satellite navigation system following GPS and GLONASS. BDS, along with GPS, GLONASS, and GALILEO, is recognized by the United Nations Committee on Global Navigation Satellite Systems as a supplier. Comprising of space, ground, and user segments, the Beidou system provides all-weather, all-time, high-precision positioning, navigation, and timing services to users worldwide, with unique short message communication capabilities. After years of development, Beidou has become a significant new type of infrastructure providing global users with all-weather, all-time, high-precision positioning, navigation, and timing services. This paper explores the development, application, and prospects of the Beidou navigation system. The aim is to investigate the positioning accuracy of BDS by reviewing relevant literature, starting with understanding its benefits when applied to satellite navigation systems (such as accurate error estimation and real-time estimation of the receiver's position and velocity). The paper then mentions applications related to accuracy, such as emergencies in tunnels, lunar probe applications, and low-altitude air traffic. Finally, it discusses the prospects and innovations in the direction of BDS. The research method involves querying recent literature on the topic from CNKI for research and comparison. The conclusion is that BDS achieves high-precision satellite navigation positioning through. Based on the accuracy of BDS, it can be inferred that in the future, it will be used in conjunction with 5G technology in daily life.

Keywords: BDS; Satellite Signal; GPS; 5G.

1. Introduction

This paper primarily conducts a series of studies on the development, application, and prospects of the Beidou Satellite System (BDS) by searching for various relevant progress. The main issue encountered during the research process was selecting which positioning system to combine with 5G [1,2]. After conducting related investigations, it was shown that GPS has lower accuracy compared to BDS, and BDS has advantages in terms of coverage, completeness, and specificity. Therefore, chose to focus our research on BDS. Subsequently, some examples of applications that primarily leverage the accuracy of BDS, such as its use in tunnel emergency positioning, lunar exploration vehicles, and low-altitude aerial vehicles. These applications once again demonstrate the advantages of BDS, such as high positioning accuracy and fast reception speed. By combining these characteristics, concluded that BDS can be used in conjunction with 5G. They complement each other; the shortcomings of BDS, such as local positioning blind spots caused by regional obstructions, can be addressed by the dense deployment of 5G base stations. Moreover, 5G technology can be applied in various daily scenarios, and when combined with BDS, it can provide users with more precise location accuracy and more accurate timing. The combination of 5G and BDS multiplies the advantages of both systems, offering more precise and intelligent services. In conclusion, in the future, 5G is very likely to be combined with BDS. By leveraging coverage advantages and high positioning accuracy, a high-precision positioning network that covers both outdoor and indoor scenarios can be established, providing more accurate data and a broader coverage range.

2. Advantages of BDS

Beidou BDS has a stronger advantage in accuracy over GPS. The BDS system has a global precision of meters, while GPS typically provides an accuracy of 3 to 5 meters [3]. This means that in applications requiring high precision, such as aerospace and precision agriculture, BDS is more favoured. Secondly, BDS has advantages in service coverage and integrity [4]. The BDS system is composed of a global 5-satellite regional navigation system and a global satellite-based augmentation system, providing all-weather, all-time, high-precision navigation and positioning services to global users. It also includes asymmetric spread spectrum technology, which is more conducive to weak signal reception and has broader coverage than GPS. Lastly, BDS applications in public safety and public services are more comprehensive [5]. For example, BDS supports short message communication and satellite communication functions, which are significant in public safety rescue and disaster warning. BDS also has more active detection and auxiliary search capabilities, providing more timely and precise positioning services to users. Overall, BDS has undeniable advantages over GPS in terms of accuracy, coverage, integrity, and specialization. Of course, GPS also has its strengths, such as leading in global application and advanced technology research. This information should help you better understand the differences and advantages between BDS and GPS systems.

3. Applications of BDS

3.1. in Positioning Accuracy

Since the launch of the Beidou system, it has been widely applied in aviation, lunar probes, transportation, tunnel emergencies, agriculture and fisheries, hydrological monitoring, meteorological reporting, communication systems, power dispatching, disaster relief, public safety, and other fields, integrating into the national core infrastructure and generating significant economic and social benefits.

3.2. Application in Tunnel Emergency Situations

To address the issue of ineffective positioning of personnel and equipment in tunnel emergencies and to improve emergency response efficiency, an analysis of the characteristics of emergency events in highway tunnels, positioning requirements, and the features of positioning technologies is conducted. Based on actual engineering project design, a Beidou-based tunnel emergency positioning system is proposed [6]. Combining Beidou beacons, Beidou emergency terminals, and various communication methods, data integration is achieved on the Beidou emergency resource monitoring system platform, and a unified platform information release and reception is carried out through the multimedia dispatch platform. The system provides fast, accurate, and effective positioning data for on-site rescue personnel and command personnel. Tests show that the positioning system has an average initial positioning time of 60.33 seconds, with a positioning accuracy of $\leq$0.6 meters, and an average data transmission time of 0.19 seconds, meeting the needs of tunnel emergency rescue.

3.3. Application in Lunar Probes for Satellite Navigation and Positioning Problems：

Of lunar probes in lunar orbit, based on the research of high-orbit spacecraft satellite navigation positioning, a multi-GNSS joint positioning method is used for simulation [7]. The availability of the main lobe and side lobe of the antenna radiation under the weak signal capture threshold of 15dBHz is analysed, and the precision factor values under various system combinations are analysed [8]. Simulation results show that when the main lobe and side lobe signals received from the satellite antenna are above the threshold, the three or four systems of global navigation satellite systems can meet real-time positioning conditions; when the side lobe loss is not compensated, the received signal-to-noise ratio is below the threshold, and any combination cannot complete positioning. The analysis of the precision factor of each system combination shows that the geometric precision factor of single or dual system combinations changes dramatically, and the geometric precision factor of the four-

system combination decreases by 16.93% compared to the three-system combination; among the three-system combinations, the combination of the US GPS, China's Beidou Satellite Navigation System, and Europe's Galileo Satellite Navigation System has the most stable geometric precision factor value, making it the best choice. Theoretical analysis and simulation results provide references for the research of lunar probe positioning technology and the design of multi-system receivers on board.

3.4. Application in Low-Altitude Airspace for Aircraft

In response to the current ADS-B transmitter's positioning information mainly derived from GPS and the limited transmission range of its transmission link, a study on ADS-B surveillance technology based on "Beidou" is conducted [9]. Based on an in-depth study of the ADS-B message protocol, "Beidou" communication is used as a supplement to the ADS-B transmission link and seamless navigation surveillance technology for general aviation aircraft is studied. A multi-network integrated onboard surveillance terminal system based on "Beidou" positioning sources is designed. Using the Ruixiang electric aircraft RX1E and the built surveillance centre system, the ADS-B and "Beidou" transmission of the onboard terminal are tested and verified. The experimental results show that the data transmission link has achieved wide-area surveillance of low-altitude general aviation aircraft, and the flight status information sent by the onboard terminal has enabled the surveillance centre to perceive the online situation of low-altitude general aviation aircraft. The research results provide technical references for ensuring the safety of China's general aviation aircraft operations and improving the informatization level of low-altitude airspace management.

4. Prospects of BDS Positioning Accuracy Combination with 5G

Although the high-precision positioning capability constructed by the Beidou satellite navigation system and ground-based augmentation systems can cover a wide area, there are still local positioning blind spots due to local occlusions (such as under overpasses, and shaded roads). At the same time, densely deployed 5G base stations can effectively cover these shaded outdoor areas to supplement Beidou's outdoor blind spots and can fully cover indoor areas where Beidou signals cannot reach. Therefore, the integration of 5G and Beidou in positioning services is timely and complementary [10].

5G technology can be applied to smart homes, smart buildings, smart cities, 3D video, cloud work, cloud entertainment, remote medical services, virtual reality, augmented reality, and communication between intelligent industrial robots. By sending differential signals through satellite augmentation systems such as the Beidou navigation satellite system ground-based augmentation service (BDGBAS) and continuously operating reference stations (CORS), users can obtain position information at the position, decimeter, centimetre, or even millimetre level, as well as nanosecond-level timing. The integration of 5G and Beidou can multiply the advantages of both systems, providing various smart services for people.

5. Conclusion

In summary, the BeiDou Navigation Satellite System (BDS) has established itself as a critical technology for high-precision navigation and positioning, with wide-ranging applications such as autonomous driving, precision agriculture, and disaster management. By enabling real-time state estimation and utilizing covariance matrices to assess accuracy, BDS delivers positioning capabilities that meet the demands of increasingly complex and dynamic environments. Despite its remarkable achievements, BDS faces challenges such as signal interference in urban areas and coverage limitations in obstructed or indoor scenarios, which must be addressed to fully unlock its potential.

The future development of BDS lies in its integration with emerging technologies, particularly 5G networks. Leveraging the low latency, extensive coverage, and high bandwidth of 5G can overcome existing limitations, such as blind spots in high-precision positioning services, and create a seamless

network capable of covering outdoor and indoor scenarios alike. This synergy can deliver positioning accuracy at the metre, decimetre, centimetre, or even millimetre level, unlocking new possibilities for applications in smart cities, industrial automation, and augmented reality.

Future research must focus on innovative approaches to integrate BDS with 5G and other global navigation satellite systems (GNSS) to enhance interoperability and performance. Additionally, addressing the challenges of signal robustness, data security, and privacy will be crucial to ensure reliability and public trust in these technologies. Through continuous innovation and collaboration, BDS can achieve its vision of providing ubiquitous, high-precision positioning services and cement its role as a cornerstone of the global navigation ecosystem. This development will not only strengthen BDS's competitiveness but also contribute to the broader goal of creating smarter, safer, and more connected societies.

Authors Contribution

All the authors contributed equally, and their names were listed in alphabetical order.

References

[1] Wymeersch, H., Seco-Granados, G., Destino, G., Dardari, D., & Tufvesson, F. 5G MMWave positioning for vehicular networks. IEEE Wireless Communications, 2017, 24(6), 80–86.

[2] Del Peral-Rosado, J. A., Raulefs, R., Lopez-Salcedo, J. A., & Seco-Granados, G. Survey of Cellular mobile radio Localization methods: From 1G to 5G. IEEE Communications Surveys & Tutorials, 2017, 20(2), 1124–1148.

[3] Ma, X., Yu, K., He, X., Montillet, J., & Li, Q. Positioning performance comparison between GPS and BDS with data recorded at four MGEX stations. IEEE Access,2020, 8, 147422–147438.

[4] Liu, C., Cao, Y., Zhang, G., Gao, W., Chen, Y., Lu, J., Liu, C., Zhao, H., & Li, F. Design and performance analysis of BDS-3 Integrity Concept. Remote Sensing,2021, 13(15), 2860.

[5] RXiaodong, W., Xun, W., Hongyang, L., & Jing, L. Study on application status and standard system of BDS in transportation. IEEE.2017.

[6] Cheng, W., Shan, K., Liu, G., & Yang, X. Public Security command and warfare system based on Bei-Dou positioning service. IOP Conference Series Materials Science and Engineering, 2019,612(3), 032089.

[7] Wu, Z., Ni, S., Xiao, W., Li, Z., & Liu, H.Study on the Feasibility and Performance Evaluation of High-Orbit Spacecraft Orbit Determination Based on GNSS/SLR/VLBI. Remote Sensing, 2024,16(22), 4214.

[8] Rezaei, M. J., Abedi, M., & Mosavi, M. R. (2016). New GPS anti-jamming system based on multiple short-time Fourier transform. IET Radar Sonar & Navigation, 10(4), 807–815.

[9] Yang, H., Li, H., & Shen, X. S. Secure Automatic Dependent Surveillance-Broadcast Systems. In Wireless networks. 2022.

[10] Li, G., Yu, X., & Lu, W. Space-Earth integrated high-precision positioning system based on 5G and Beidou navigation satellite system. 2022 7th Asia Conference on Power and Electrical Engineering (ACPEE), 2022,649–653.