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Development Status and Future Prospect of Space-Based Information Systems in China

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Abstract: As an important means of obtaining information resources, space-based information systems, which serve national defense and economic construction, are developing in the direction of integration, dynamicity, real-time, and intelligence. Based on the long-term progress of China's aerospace sector, this paper presents a detailed review and summarizes the development status of international space-based information systems by literature research and expert consultation, as well as an analysis of the development of Chinese policies, industries, equipment, and technology in this field. In addition, the future development trend of space-based information systems is summarized. This paper focuses on examining the shortcomings of domestic space-based information systems, involving institutional mechanisms, policy guarantees, technical capabilities, and industrial development. The research suggests that we must improve the institutional mechanism to coordinate the space-based information system resources, consummate laws and regulations to guide the development of this industry, stress technical innovations, and establish development concepts to build space-based information systems for real-time service.

Keywords: space-based information system; real-time service; institutional mechanisms; technical innovation; policy guarantee

1 Introduction

The space-based information system is a satellite application system that realizes real-time observation of natural landscapes and human activity on the earth's surface using remote sensing, navigation, positioning, and communication, among other technical means. The current hotspot of construction is the space-based information system with real-time service. It comprises hundreds of low-orbit satellites with remote sensing, navigation, and communication functions that cooperate with high-resolution remote sensing satellites and new-generation satellite navigation systems. Moreover, this system can integrate with satellite communication networks, terrestrial internet, and mobile networks to achieve global high-temporal-resolution data collection, high-precision real-time navigation and positioning, and broadband mobile communications [1].

The space-based information system can effectively serve the needs of economic construction, national defense construction, and people's livelihood. It is a core element that reflects national scientific strength and is currently the most radiant, driven high-tech field and strategic emerging industry. The research, construction, utilization, and promotion of the development of space-based information systems are important factors for the future advancement

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of the top countries of aerospace manufacturing. For example, the space-based real-time information system can effectively meet national strategic needs, comprehensively improve national space competitiveness, and nurture new driving forces for economic growth.

The research on space-based information system in domestic and foreign literature mainly focuses on the following aspects [2–9]: the construction of space-based information systems in China and abroad, the integrated management and control system of space-based information systems, the application of space-based information systems in combat command and control, the troubleshooting of the space-based information system, and the construction of the service system of the space-based information system in military-civilian integration and other aspects. However, macro-level analyses of the development situation and problems of space-based information systems are yet to be performed. Therefore, this paper systematically establishes the development status and trends of space-based information systems in China and abroad, analyzes the problems existing in this field in China, and then demonstrates and proposes the conception of building a space-based information system for real-time service in China, with a view to providing reference for the space system development strategy.

2 Development status of space-based information systems in China and abroad

2.1 Research abroad

With its unique information commanding height, the space-based information system has a wide range of applications in combat command, deep space detection, and navigation measurement and control, among others, and has become an important means to promote the extension of national strategic interests from traditional categories to marine, space, and electromagnetic space. The United States, the European Union, Russia, Japan, India, and other major foreign aerospace countries are vigorously developing integrated space-based information systems. They have successively conducted concept research, system design, and technical verification, and promoted innovation-driven development from national strategies, operating mechanisms, business models, and other aspects.

2.1.1 Formulating development approaches and promoting the development of space-based information systems through national strategies

Major countries in aerospace attach great importance to the development of space-based information systems, and promote the construction and development of space-based information systems through national strategies. According to “National Security Presidential Directive 39,” the United States formulates policies to expand its technological leadership in space-based information system applications and services through the development and deployment of global practical and effective space-based information systems, and maintains the leading position in the global aerospace field. To enhance the competitiveness of the space sector, the European Union has successively promoted and implemented space-based network plans, such as the *Space Strategy for Europe* and the *2018 EDA Capability Development Plan*, and determined a course of action, including “focus on the development of space-based information and communication services.”

Russia stated in *Russia's Space Development Strategy Before 2030 and Beyond (Draft)* [10] that the development of space technology is a national strategic goal and a space equipment system should be established that can meet international competition needs in both quantity and quality. Taking the *Basic Law on Space* as an opportunity, Japan has accelerated the advancement of research projects in space science, manned space activities, space-based solar power generation, and small experimental satellites to gradually improve the construction of space-based information systems.

2.1.2 Optimizing institutional mechanisms and coordinating overall national sector management and industrial development

In the field of space-based information systems, the major aerospace countries have adopted a highly centralized management model of the government to control the construction of the system and coordinate various types of information resources. According to the characteristics of satellites, application requirements, and division of labor, a relatively complete classification of satellite application systems has been established. For example, *U.S. Space-Based Positioning, Navigation, and Timing Policy* is the basis for the overall strategic decision-making in the United States. The National Space-Based PNT Committee is responsible for comprehensive coordination and management. Additionally, the United States Department of Defense coordinates defense surveillance and decision-making. The commercialization of information system products and services is specifically undertaken by aerospace companies, such as Lockheed Martin.

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2.1.3 Improving technical capabilities and maintaining the advancement and stability of space-based information systems

Major countries in aerospace continue to use scientific and technological innovations to optimize space-based information systems, so that the stability and service capabilities of the system are continuously improved: (1) New satellites have been developed with improved and perfected constellation functions. For example, Russia has strengthened the modernization and satellite supplementation of the GLONASS satellite navigation system. (2) Research on alternative technologies has been strengthened. The LEO satellite enhancement system has become a development trend (Table 1), and it is regarded as the advancement of space-based information systems. (3) Space technology cooperation between countries has been strengthened, making up for the shortcomings of a single system, and promoting the stability of system services. For example, since 2004, the three major satellite navigation systems GPS, GLONASS, and GALILEO have been cooperating in terms of interoperability and compatibility. (4) Integration has been strengthened with new technologies; coordinated observation, new system communication, on-orbit real-time processing, space-based information fusion processing, security protection, and other emerging technologies have been applied and integrated, which has significantly improved the application and service capabilities of space-based information systems.

Table 1. Representative LEO satellite constellation plans.

System	Number of satellites (unit)	Orbit altitude (km)	Networking year	Business	Research facility
Iridium	66	780	1998	Voice	Motorola
Global star	48	1400	2000	Voice	Global star
One Web	900	1200	2019	Broadband	One Web
V-band	2956	1000-1200	2016	Broadband	Boeing
Star link	4425	1100-1325	2020	Broadband	SpaceX
Planet-Dove	188	420	2017	Remote sensing	Planet
Sky Sat	21	600	2017	Video	Planet
Black Sky	60	—	2019	Video	BlackSky Global

2.1.4 Innovating the industrial model to ensure different requirements of military, civilian, and commercial sectors

Major countries in aerospace meet the various requirements of the military, civilian, and commercial sectors through the application and innovation of space-based information systems, the market services and industrial development of which mainly take the following forms: (1) Open service: providing users with free space-time reference services such as positioning, navigation, and timing. (2) Commercial services: the application of space-based information systems combined with various industry technologies, such as location-based business services, satisfying the business needs of ground transportation, air transportation, and maritime supervision. (3) Social security services: coordinating the application of multiple satellite navigation systems to improve the stability of traditional services and create new application models, showing prospect in ship navigation, locomotive operations, traffic navigation, and robot applications. (4) Public control services: the space-based information system provides accurate emergency services for the government with a proprietary frequency band.

2.2 Research in China

After over 60 years of development, the space-based information system of China has completed the “from nothing to existence, from existence to excellence” leap owing to the following reasons: (1) The development and application technology of sub-meter high-resolution remote-sensing satellites in China has matured; (2) The BeiDou satellite navigation system will form a global service capability in 2020, and significant progress will be made in low-orbit satellite-based navigation-enhancement technology; (3) A technological breakthrough was achieved in the development of low-orbit smart communication satellites, and the development momentum of low-orbit satellite communication networks is stable; (4) China has formed a relatively complete satellite research and application technology system, and has the basic conditions for the construction, demonstration application, and industrialization of space-based information systems for real-time service.

2.2.1 Improvement of comprehensive satellite capabilities of China and formation of a sound satellite system

As of October 2019, China had a total of 323 satellites in orbit, only subordinate to the United States [11]. China has established a relatively complete satellite research, development, operation, and application system, including

commercial aerospace. Furthermore, China has formed a satellite system that includes communication satellites, remote-sensing satellites, and navigation satellites, and a number of spectra. China has initially established a relatively complete application system in various industries, covering the departments of national security and national economy. The space-based information system in line with national conditions has emerged.

2.2.2 Policies issued by China to guide the development of the space-based information industry

Recently, China has issued several policies, such as the *National Medium and Long-Term Development Plan for Civil Space Infrastructure (2015–2025)* and *Guidance on Accelerating the Construction and Application of the "Belt and Road" Space Information Corridor*, that have guided the development direction and implementation path of the space-based information system to serve the economic and social development from the national top-level strategy. These policies are conducive to comprehensively promoting not only the healthy and rapid development of space-based information systems, but also the scale, business, and industrialization of space resources.

2.2.3 Rapid growth period and good development prospect of the space-based information industry of China

According to the analysis of China's satellite application market, the current output value of the market is mainly concentrated in the midstream of the industrial chain represented by vehicle, handheld, command, and other terminal equipment (approximately 60%). The downstream applications (~30%) represented by special needs and personalized services, and the upstream (~10%) of the industrial chain such as chips, boards, and antennas make up relatively small sectors, indicating that the satellite industry remains in the initial stage of development and there is still room for future development of the satellite application market. With the development of industrial markets, mass markets, special markets, and smart cities, the space-based information industry represented by satellite services is expected to continue to expand its scope of applications; in particular, the downstream application market will develop rapidly.

By 2025 [12–14], the downstream service market will reach 50%, the proportion of midstream industries such as system integration and terminals will fall to 40%, while the data, chip market, and other upstream industries will account for around 10%. According to the current development plan and the overall development of the satellite industry, the space-based information market of China is expected to reach 736.5 billion yuan in 2025, of which the navigation, communication, and remote-sensing satellite markets can make profits of 630 billion yuan, 95 billion yuan, and 11.5 billion yuan, respectively (Fig. 1).

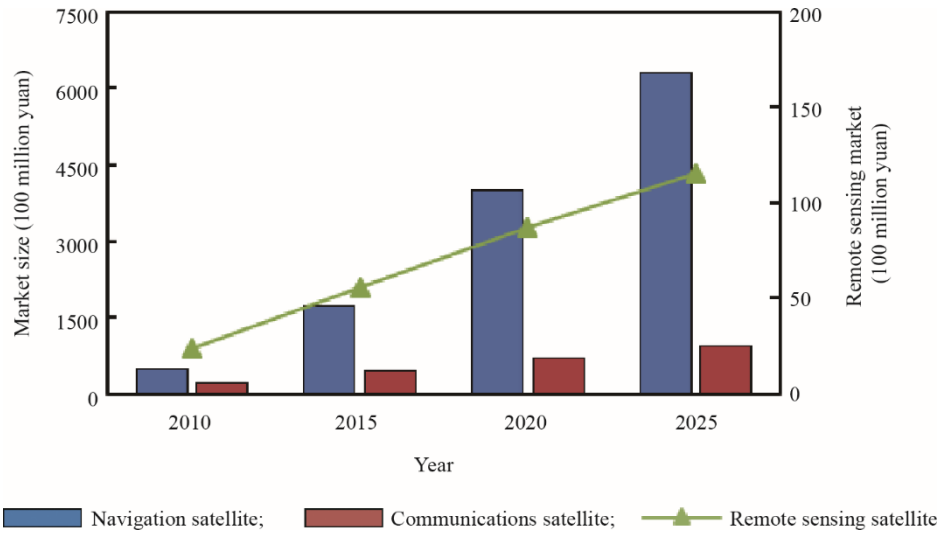

Fig. 1. Development of China's satellite navigation, communication, and remote-sensing satellite markets (2010–2025).

2.2.4 Rapid development of satellite technology of China and important breakthroughs of some key technologies

The high-resolution ground observation, enhanced low-orbit satellite navigation, and low-orbit satellite communications of China have developed rapidly and made important breakthroughs, including the following: (1) With the promotion of major national science and technology projects, the research and application technology of high-resolution remote-sensing satellites have matured, large-scale commercial applications of which have been launched. (2) The BeiDou navigation satellite system has global service capabilities initially, and the low-orbit satellite-based navigation enhancement technology has made expected progress. Further, the navigation accuracy,

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completeness, and real-time performance have greatly improved. (3) Satellite application practices such as Lujia-1A show that low-orbit satellites can enhance the performance of the BeiDou navigation satellite system by improving the real-time positioning accuracy from 5–10 m to the sub-meter level. (4) The construction of a low-orbit communication satellite system in China is prospering. China Aerospace Science and Technology Corporation and China Aerospace Science and Industry Corporation have begun construction of the "Hongyan" and "Hongyun" satellite constellations, which realize broadband data transmission based on inter-satellite links to provide data transmission channel for space-based information, as well as provide a platform for navigation enhancement payloads.

3 Development trend analysis of space-based information systems

With the development of technology and the advance of demand, the global space-based information system exhibits the following development trends: (1) The space-based information system is developing in the direction of a group network, and multiple types, multiple functions, and a large number of satellites are networked to realize functional reconstruction and innovation; (2) The satellite coordination in the system develops from static to dynamic, which has a stereo-reconfigurable dynamic topology structure to significantly improve the stability of the system; (3) Integration of advanced ground network technology and application of the integrated routing, service, and control technologies of satellite and earth integration on each satellite node to support the system's real-time and intelligent services; (4) Aim at the requirements of military applications, focusing on the coordinated development of the core network functions of core node satellites and the multifunctional integration of tactical small satellites.

In contrast, the space-based information system of China is based on national conditions and independent research and development, and has the following characteristics: (1) Consideration of the comprehensive capabilities of space-based information systems, and improvement of the technical level of large-capacity with high-rate transmission, system intelligent scheduling, comprehensive management and control between systems, and information service assurance; (2) Focus on breakthroughs in core key technologies, such as satellite laser communications, space IPv6, inter-satellite links, and satellite constellation technologies; (3) Satellite application technologies of remote sensing, navigation, and communication tend to converge; thus, the space-based information function of real-time intelligent network integration emerges(Fig. 2); (4) The rapid development of information technology has caused the deep integration of space-based information and ground information integration technology, which has expanded the breadth and depth of the space-based information industry.

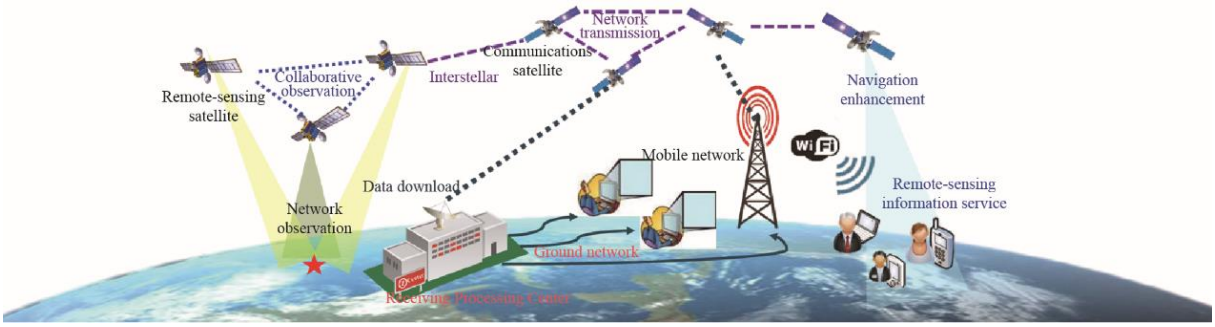

Fig. 2. Schematic of real-time intelligent service mode of space-based information system.

4 Problems in the development of China's space-based information system

Presently, China is in a critical period of marching from a major player in space to a major power in space. However, compared with developed countries, the level and capabilities of China's applied satellites remain far behind. Some problems exist in the development of the satellite application industry, as described below.

4.1 Insufficient overall coordination in terms of systems and mechanisms

The existing communication, navigation, and remote-sensing satellite systems comprise their own systems, resulting in system isolation, information separation, and service lag. On the one hand, there is a lack of coordination in satellite data sharing and application development, as well as information security. On the other hand, the satellite communication network of departments and industries cannot realize the unified allocation of resources and the coordination between systems. Moreover, the waste of resources coexisting with scarcity is prominent.

4.2 Incomplete laws and regulations in terms of policy guarantees

The field of space-based information systems has not yet established a comprehensive system of laws and regulations or industrial policies. In particular, the commercial standards of communication, navigation, and remote-sensing satellite systems are still not complete. An organic and unified standard system has not been formed; thus, the development of space-based information industries is limited.

4.3 Innovation needs cannot be met in terms of technological capabilities

At present, the existing space-based information technology in China cannot provide information quickly, accurately, flexibly, and intelligently on a global scale. On the one hand, the construction of space-based information systems involves aerospace, information, surveying and mapping, communication, artificial intelligence, and other fields, which covers many disciplines, and has a complicated technical system that is difficult to tackle. On the other hand, the development of space-based information technology in China is restricted by some satellite core components, chips, and data processing software, among other factors. Therefore, it is urgent to conduct collaborative innovation research in related disciplines such as information science, aerospace science, earth science, and artificial intelligence.

4.4 Industrial development remains at an early stage

The scale and level of China's space-based information industry are still in the primary stage of development. The satellite application level is low, the market size is small, and the application mode is single. In addition, China's space-based information industry has shown a transition from high-tech private networks to Internet publicity. However, not only the consumption concepts and supporting policies, but also industry standards and capital operations still require further improvement and development.

5 Suggestions

5.1 Improve systems and mechanisms to coordinate space-based information system resources

The integration of celestial bodies should be coordinated to connect the constructions of satellite and ground application systems closely, which may effectively improve the overall satellite application benefits. First, the planning and construction should be coordinated, the current status of concentrating on space more than ground should be changed to promote the coordinated development between satellite applications and space systems, so that the timeliness of product quality and services can be improved. Second, the management mechanism should be innovated to improve the operational capacity building of the satellite system for integrated observation, satellite-earth integrated dispatching, and data resource sharing. In addition, the large-scale engineering and automation of industrial development should be highlighted, and the comprehensive benefits of satellite application should be fully released. Third, the sharing mechanism of satellite applications should be innovated, any obstacles that restrict satellite data sharing and application development must be removed, and the resource utilization efficiency should be improved. Fourth, the business connectivity and the technology integration between departments and industries need strengthening, satellite resources should be uniformly deployed in various departments and industries, and the resource utilization efficiency must be improved.

5.2 Complete laws and regulations to guide the development of space-based information system industry

To comprehensively promote the development of the scale, business, and industrialization of space resources, policies and measures to ensure the development of space information infrastructure should be formulated to create a sustainable and healthy environment for the development of space-based information system industry. In addition, it is suggested that the current laws and regulations should be adjusted and optimized according to the industrial application. It is also necessary to improve regulation standards and industry access systems, set up fair competition provisions, and gradually establish improved system interconnection standards and sharing mechanisms.

5.3 Highlight technological innovation to tackle difficulties in the construction of space-based information systems

A space-based information system for real-time service should be built to meet major strategic needs, such as real-time tracking of global moving targets and real-time monitoring of fixed targets. There is an urgent need to cooperate with all parties to focus on conducting the joint research and development of the three major systems of space-based information regarding intelligent acquisition platform and load, sky-ground integrated information processing, and intelligent application. In addition, the seven key technologies of low-orbit satellite-based navigation enhancement, space-to-ground integrated network communication, multi-source imaging data on-orbit processing,

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space-based information intelligent services, space-based resource scheduling and network security, multi-load integration and integration platform, and space-time-ground integration should also be progressed.

5.4 Innovate the development concept to build a space-based information system for real-time service

To face the increasing market demand, it is suggested to accurately grasp the development trend of global space-based information system and technology, as well as conduct the construction and organization of related systems in China. By integrating the existing communication, navigation, and remote-sensing satellite systems, terrestrial Internet, mobile networks, and other resources, China's space-based information system for real-time service should be constructed to realize integrated real-time services of navigation, positioning, timing, remote sensing, and communication. Given the current international situation and domestic needs, building an independent space-based information system for real-time service in China can not only occupy the strategic commanding heights of the emerging field of space-based information services, but is also an important measure to promote the development of the national digital economy.

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