Comparison of Distributed Space Metrology Data Information Transmission Technology for Space Solar Power Station

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Abstract

The space solar power station will be assembled in the space environment, with the basic units (referred to as cells) of the assemblage being stitched together to form a monolithic structure with a huge area. The multi-parameter metrological data and control information distributed in the cell will converge together to become a massive data and information flow. How to realize the space metrology data transmission between each cell and the control center of the power station will become a technical problem that must be resolved in the space solar power station. Starting from the current spacecraft data information wired and wireless transmission technology, comparing the traditional wired transmission, electromagnetic wave wireless transmission, and other data communication technologies, this paper analyses the advantages and disadvantages of various technologies, clarifiesthe necessity ofthe research and development of space solar power station new information transmission technology, and puts forward a distributed data transmission technology based on guided wave principle in the combined spacecraft structure, which uses cell structure as the transmission medium carrier. While taking into account the advantages of wireless information transmission, such as working without wiring and avoiding single-point failure, this technology also has the advantages of good compatibility, strong resistance to electromagnetic interference, high reliability, and so on, compared with the electromagnetic wave transmission technology, which can effectively meet the needs of in-orbit modular assembly, operation, and maintenance of space solar power station, and provide strong support for accurate data transmission for the space metrology technology.

1. Introduction

In 2014, China first proposed the concept of "space metrology", which means a technology and management action to assure unified system of unit and an accurate and reliable measured value in space work which out of earth[1]. The development goal of space metrology is to achieve in-orbit traceability of various types of measurement data and to ensure the accuracy, reliability, and unity of measurement units. For this reason, space metrology has become a standard feature of long-life, large-size spacecraft, and all measurements need to take into account the attributes of space metrology, that is, how to ensure that metrology is carried out in-orbit while verifying that they are accurate, stable and reliable. Data is the basis for supporting space metrology, and space metrology is inseparable from data acquisition and data transmission.

As a renewable energy system concept, Space Solar Power Station (SSPS) has become an important policy option for major space powers to cope with the challenge of net emissions due to its advantages of high energy flow density, continuous stability, not being affected by day and night climate, cleanliness and pollution-free[2].

To solve the different technical difficulties, a variety of SSPS concepts have been proposed, and the common feature of each program is that it needs to be transported by cell and assembled into a huge scale, and its in-orbit life needs to reach at least several decades to ensure economic feasibility. Real-time dynamic monitoring of the operating status of the solar power station, and the cell's real-time measurement data, such as voltage, current, vibration, deformation, and other multi-parameter data timely transfer to the power station control center, to synchronize with the digital twin is crucial. Taking into account the tens of thousands of cell bases, as well as the status data and control feedback that each cell needs to submit and receive, the realization of the SSPS space metrology task will produce an unusually large amount of data in the system. How to realize the orderly and accurate transmission of massive spatial metrology data will become a technical problem that must solve.

This paper bases on the research needs of distribution information transmission technology of the SSPS, introduces and compares the traditional wired transmission based on bus network and electromagnetic wave wireless transmission technology of spacecraft. At the same time, it puts forward a guidedwave information transmission technology based on vibration wave transmission of solid structure, which is a new mechanism for transmitting data and can overcome the technical problems of information interaction in the combined structure, and provides a new idea for the assembly, operation, and maintenance in-orbit.

2. Wired data transmission technology based on bus networks

Nowadays, internal data transmission in spacecraft is mainly achieved by wired data buses, such as MIL-STD-1553B, RS-485, CAN, Ethernet, etc., with twisted pairs, coaxial cables, optical fibers, etc., as the transmission channel. Their common advantages are transmission safety, reliability, and strong anti-interference capability. however, this perforated alignment also brings many practical in-orbit problems, such as greatly reducing the strength and integrity of the thin-walled metal structure, and increasing the risk of fatigue cracks in the structure due to the local stress concentration at the perforation. On the other hand, unlike traditional spacecraft, the area and scale of the SSPS are huge, which makes the influence of network wiring on the overall layout of the spacecraft larger, especially the weight of cables caused by the increase in network scale, which is not conducive to the implementation of modular and lightweight assembly of the SSPS.

During the in-orbit operation of a large structural assemblage such as theSSPS, operations such as maintenance, dismantling, and replacement of independent cell elements need to ensure that they do not interrupt the normal operation of other modules, let alone cause an overall shutdown. These problems brought about by perforating and wiring, such as the inflexibility of communication link switching, restrictions of the transmission path, and difficulty in avoiding single-point failure, lead to the inability of wired information transmission to independently support the mission requirements of long-term in-orbit operation and maintenance of such large spacecraft structures as theSSPS. Therefore, there is an urgent need to explore and develop a suitable wireless data transmission method for the SSPS.

3. Electromagnetic wavebased wireless data transmission technology

Along with the continuous breakthroughs in the global aerospace industry, the development of wireless network technology will provide significant support for spacecraft multi-parameter metrology control and data management, internal real-time data communication, and other applications. Compared with the traditional wired communication bus, the advantages of wireless network transmission are reflected in the following: ①The design of the wireless node is flexible and simple, so it can save a large number of connecting cables, which is conducive to reducing the weight and transport costs; ②The wireless transmission technology is easy to be assembled and replaced in the space environment. It has the ability toself-organization and self-repairing, so as to avoid single-point failure; ③Compared with wired technology, wireless transmission technology is fast, flexible, and easy to expand the network, which can effectively adapt to the space environment for emergency treatment, module assembly, structure expansion and additional functional requirements.

For the research of wireless data transmission technology of spacecraft, the current mainstream research direction is to directly promote the application to the space field by using the existing commercial standards of electromagnetic waves on the ground, such as Bluetooth (IEEE 802.15.1), WiFi (IEEE 802.11), ZigBee (IEEE 802.15.4) and other protocols, or to develop new spacecraft electromagnetic wave communication protocols after splitting and combining. Another research direction is to develop a special wireless transmission mode for spacecraft according to the characteristics of the space environment. The current research on wireless communication technology within large space composite structures is still in the exploratory stage. On the one hand, the lack of research carriers can not carry out targeted research. On the other hand, there has not been a unified wireless transmission network rule standard.

Table 1. Comparison of three electromagnetic wave transmission technologies.

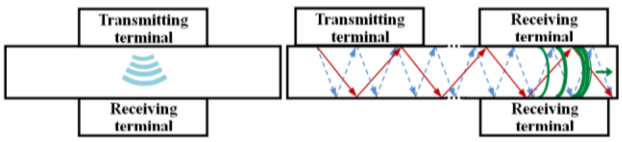
Transmission technology	Bluetooth	WiFi	ZigBee
Distance	Short	Far	Far
Rate	Fast	Fastest	Slow
Consumption	Low	High	Lowest
Security	High	Low	High
Stability	Strong	Poor	Strongest
Maximum number of nodes	8	2007	65000
Connection ability	Weak	Mid	Strong

Each of the three electromagnetic wave technologies mentioned above has its advantages and disadvantages, as shown in **Table 1**. For different application backgrounds, the correct application of electromagnetic wave technology can also meet the functional requirements of diverse fields. Giving full play to the characteristics of electromagnetic waves, studying the fusionmethods of various types of electromagnetic wave wireless networks, making up for the shortcomings of various technologies, and improving the comprehensive performance of the whole network an idea for the application and research of electromagnetic wave transmission technology in large-scale spatial structure combinations such as the SSPS.However, for the time being, various electromagnetic wave wireless networks have not yet been able to achieve mature information interaction between them, and there is a certain amount of interference between them, which has a serious impact on the performance of the system. For example, in the world's only publicly available frequency band ISM 2.4GHz, Bluetooth has 79 channels, ZigBee has 16, and WiFi has 11, once in the transmission process of any two technologies working channel overlap may produce interference.

All of the above types of wireless transmission methods based on electromagnetic waves inevitably have the risk of multi-path and multi-source interferences, which causes the signal transmission to be affected by the scattered transmission paths in the structure. On the other hand, based on the GEO orbital space environment in which the SSPS operates, this kind of electromagnetic wave data is susceptible to space ray and high-power microwave interference, and with the accumulation of time, the probability and degree of irradiation interference will continue to increase, which makes it difficult to meet the long-life design expectations and requirements of spacecraft with large-volume structure like the SSPS. The dispersive propagation characteristics of electromagnetic waves can also result in the leakage of important data and information to the space environment outside the structure and contamination of the electromagnetic spectrum environment.

4. Solid-state guided wavebased wireless data transmission technology

According to the advantages and disadvantages of the above types of transmission technology, it is not difficult to recognize that, for the structural and functional characteristics of the SSPS, the development of an emerging transmission technology is very necessary, and it often depends on the breakthroughs of various types of basic research. Take optical coupling transmission technology as an example. Since optical coupling devices are sensitive to the space environment[3], their maintain ability is limited during the operation of spacecraft in orbit. This program is still depending on a breakthrough in the study of the performance degradation and damage mechanism of the optical coupling technology in thespace radiation environment.



(a) body wave **(b) guided wave**

Figure 1. Comparison of ultrasonic body wave and ultrasonic guided wave transmission modes

Ultrasonic waves can be divided into body waves and guided waves according to whether they receive boundary limitation when propagating in a solid[4]. Body wave technology that is not affected by boundary coupling has limitations in solving data transmission problems. Body wave transmission requires the transducer to be strictly aligned on both sides of the metal wall, and is not suitable for carriers with strict space constraints such as SSPS. In addition, the body wave mode can only achieve point-to-point transmission, which can not meet the data transmission requirements of a large number of distributed sensors, as shown in **Figure 1**.

This paper proposes a combined spacecraft structural distribution data transmission technology based on solid ultrasonic guided wave principle with the cellular structure as the transmission medium carrier, which can take into account the advantages of wireless data transmission technology such as no need for perforating or wiring and avoidance of single-point failure. At the same time, it also possesses the advantages of good compatibility, good anti-electromagnetic interference ability, and high reliability that are not possessed by the electromagnetic wave transmission technology, which can effectively meet the needs of in-orbit modular assembly, operation, and maintenance of SSPS, and provide a new program of data transmission for the multi-parameter metrology and data management technology in large structural assemblies.

From the application point of view, this technology can simplify the layout and design of spacecraft structures, without the need for complicated large-area and long-distance wiring. It is not burdensome or detrimental to the structure because it only requires the installation of microtransducers at the corresponding points. By designing the location distribution of each node in SSPS and using grid network design, we can study the dynamic link and path search protocol of guided wave transmission links. The adjacent nodes transmit the data generated during the structure operation and the processing results to the superior system employing relay transparent transmission. In this way, the self-organization management of the data path can be realized in the large structure, and the nautical data distributed in the square kilometer space has the bi-directional addressing function of data and instructions. At the same time, the information transmission network system is redundant and robust, which can meet the modular technical design requirements of SSPS, and realize the rapid assembly, testing, and replacement of spacecraft equipment, as shown in **Figure 2**. Even if the local cell transmission is hindered, the transmission task can be realized through other paths in time, without affecting the normal work of other cells and the overall system.

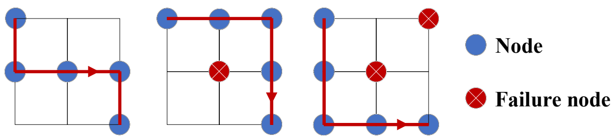


Figure 2. Solid guided wave node multipath selection relay transparent transmission mode.

In the future, this technology can be studied in collaboration with the design of truss structures. With voltage, current, strain, vibration, temperature, debris impact, space electric/magnetic field, light angle, light intensity, and other parameters of the sensor miniaturization, low power consumption, and integrated design, through reasonable distribution and assembly, further design of “intelligent truss” and “intelligent cell”. This kind of intelligent module has the functions of lightweight support structure, state parameter detection, high-quality transmission of data information, redundancy and replacement, etc., and can provide real-time in-orbit health monitoring, fault diagnosis, and digital twin services for SSPS. Take "intelligent cell" as an example, its integrated design should include hardware composed of CPU, four groups of ultrasonic guided wave transducer and pickup transducer distributed in the four corners of the cell, interface sensor, each weight parameter measurement sensor, each control device components, and other devices. The hardware composition of the cell module is shown in **Figure 3**.

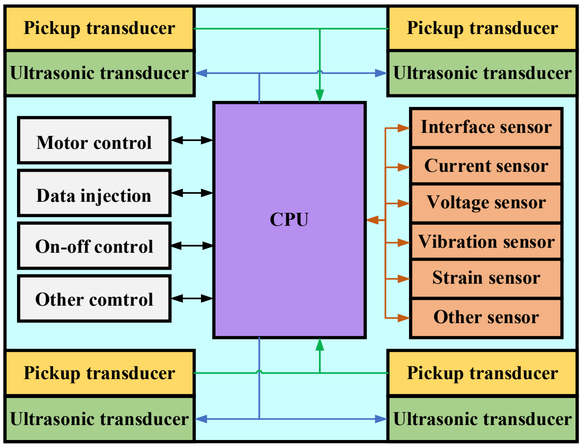


Figure 3. The structure cell module hardware composition diagram.

5. Conclusion and Outlook

Data are the most important space metrology resource. At the same time, space metrology and intelligence requirements are driving the generation of increasingly large amounts of data distributed over large structures, including state data, space environmental data, and directional control parameters distributed to detail. However, managing the data is the most expensive task. The variety of parameters, the density of measurement points, data transfer, and storage all take up a huge amount of hardware resources. Future intelligent giant spacecraft are data-dependent and need to use metrology data to generate accurate feedback and decisions. The quality and quantity of measurement data and control parameters, as well as the corresponding problems of accuracy and timeliness of data transmission are constraining the development of space metrology.

The wired data transmission technology based on bus networks and the wireless data transmission technology based on electromagnetic waves have a more mature research basis and wider application on the ground, but each technology has more or less limitations, and it is difficult to independently realize the data transmission task of the whole station. SSPS data transmission technology based on solid structure waveguide mechanism expands a new way of data transmission for large structure spacecraft, which has advantages that cannot be taken into account by both wired data transmission and electromagnetic wave data transmission. While solving the key problems of this technology and achieving in-orbit application, it is of great significance to the design of the SSPS parameter information transmission technology program by taking advantage of the advantages of this technology program and designing a unified heterogeneous integrated network with other wired and electromagnetic wave technologies through cross-combination.

However, due to the high complexity of the signal characteristics of the guided wave, there will be a nonlinear dispersion phenomenon in the propagation process, and the complex boundary conditions will cause multipath reflection, it is extremely difficult to establish an accurate analytical model. Therefore, the current research on medium and long-range ultrasonic guided wave data transmission technology still needs a key breakthrough, and the research on trans-connected interface transmission of guided waves in large assemblies such as the SSPS will become a new important scientific issue. Based on the existing research foundation, four key technologies need to be researched at a later stage: guided wave transmitter-receiver electromechanical coupling model and special transducer research for the space solar power station; Guided wave coupling transmission and enhancement mechanism research across the connection interface; Data transmission grid planning technology between structural cell elements; And strong perturbation-resistant guided wave high-speed information modulation and demodulation strategy research.

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