Engineering 7 (2021) 1047–1050

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Views & Comments

Future Research Trend for Improving Large Reflector Antenna Service Performance

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A large reflector antenna is one of the key components of a deep space telemetry track and command (TT&C) network, which is of great importance for human space activities, such as satellite communication, spaceflight, and deep space exploration [1]. The main feature of this antenna type is its large aperture and often it requires strict surface accuracy to ensure high gain and high pointing performance [2,3]. There are two kinds of reflector antennas: non-fully movable antenna and fully steerable antenna. The Five-hundred-meter Aperture Spherical Radio Telescope in China is one representative non-fully movable antenna with a super large aperture and low operation frequency. The fully steerable reflector antennas worldwide can be further divided into four categories according to their aperture diameters and highest operation frequencies, as shown in Fig. 1. Most of the antennas in Fig. 1 can be found in Ref. [4] and the details are not presented here. Category 1 includes the traditional reflectors with large apertures and low operation frequencies. Category 2 includes large antennas with actuators on their reflectors to adjust the surface, and normally, the operation frequency is much higher than that of Category 1 antennas, which have nonadjustable reflectors. For example, the 100 m Green Bank Telescope (GBT) in America has 2004 panels supported by 2209 actuators. Category 3 includes submillimeter-wave antennas with higher surface accuracy but a smaller aperture. For example, the surface accuracy of the 12 m radio telescope for the Atacama Large Millimeter Array (ALMA) are 0.01 mm. The submillimeter-wave antennas with large aperture and high surface accuracy (Category 4) are still in their conceptual stage [5] because the service performance of submillimeter-wave antennas with a large aperture is more sensitive to their working environment.

One important reason high antenna service performance is challenging to achieve is the harsh environmental requirement; in particular, some suitable sites are located in areas such as the Gobi Desert [3]. Therefore, in addition to gravity, other external loads are inevitable, such as wind, temperature, inertia, and vibration shocks, that significantly reduce the antenna service performance. In engineering, if the temperature gradient is large or the wind is strong, only low-frequency observations can be carried out, which seriously prevents the task of high-frequency observations. Consequently, future research should focus on improving antenna service performance to ensure that large antennas can reach further distances with higher resolution and higher robustness. Additionally, the high-frequency observation task should be effectively guaranteed. In addition, nine corresponding key research directions have been identified and are summarized in Fig. 2. The details are presented as follows.

(1) **Electromechanical coupling**. Environmental factors can impact the antenna performance by affecting its mechanical parts, and simultaneously, there is a relationship of mutual influence and mutual restriction between the electromagnetic performance and antenna structure. Therefore, the realization of high antenna performance depends on the combination of multiple disciplines. Currently, the electromechanical coupling relationship between the structural displacement field and its electromagnetic field has been proposed [6]. In the future, the coupling relationships among the external environment, electromagnetic performance, and antenna structure should be further explored to provide theoretical support for integrated multidisciplinary multifield design and service performance improvement.

(2) **Condition monitoring**. High-precision and large-scale transmission components are key for transmitting the large reflector antenna movement accurately. However, surface wear becomes inevitable due to the low-speed and heavy-load conditions and the harsh environment, which deteriorates the transmission accuracy, causing pointing errors. At the same time, service performance is also dependent on the robust ability of the structure to resist environmental disturbance. Therefore, we should further pursue the following two research directions:

- Study the transmission system wear evolution mechanism and the wheel-rail contact under dynamic loads;
- Establish a real-time monitoring system for monitoring environmental and structural conditions to provide data support for further service performance improvement.

https://doi.org/10.1016/j.eng.2021.05.005

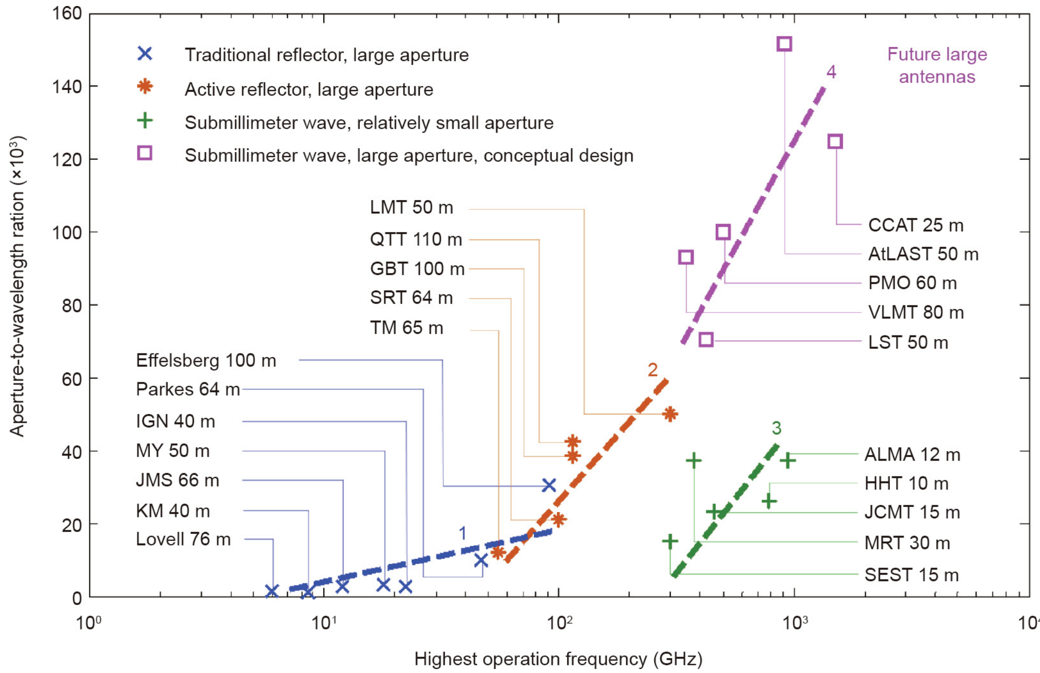

Fig. 1. Fully steerable reflector antennas with various apertures and operation frequencies. IGN: Instituto Geográfico Nacional; MY: Miyun; JMS: Jiamusi; KM: Kunming; LMT: large millimeter telescope; QTT: Qitai Telescope; GBT: Green Bank Telescope; SRT: Sardinia Radio Telescope; TM: Tianma; ALMA: Atacama Large Millimeter Array; HHT: Heinrich Hertz Telescope; JCMT: James Clerk Maxwell Telescope; MRT: millimeter radio telescope; SEST: Swedish European Southern Observatory Submillimeter Telescope; CCAT: Cornell Caltech Atacama Telescope; AtLAST: Atacama Large Aperture Submillimeter Telescope; PMO: Purple Mountain Observatory; VLMT: very large millimeter telescope; LST: large submillimeter telescope.

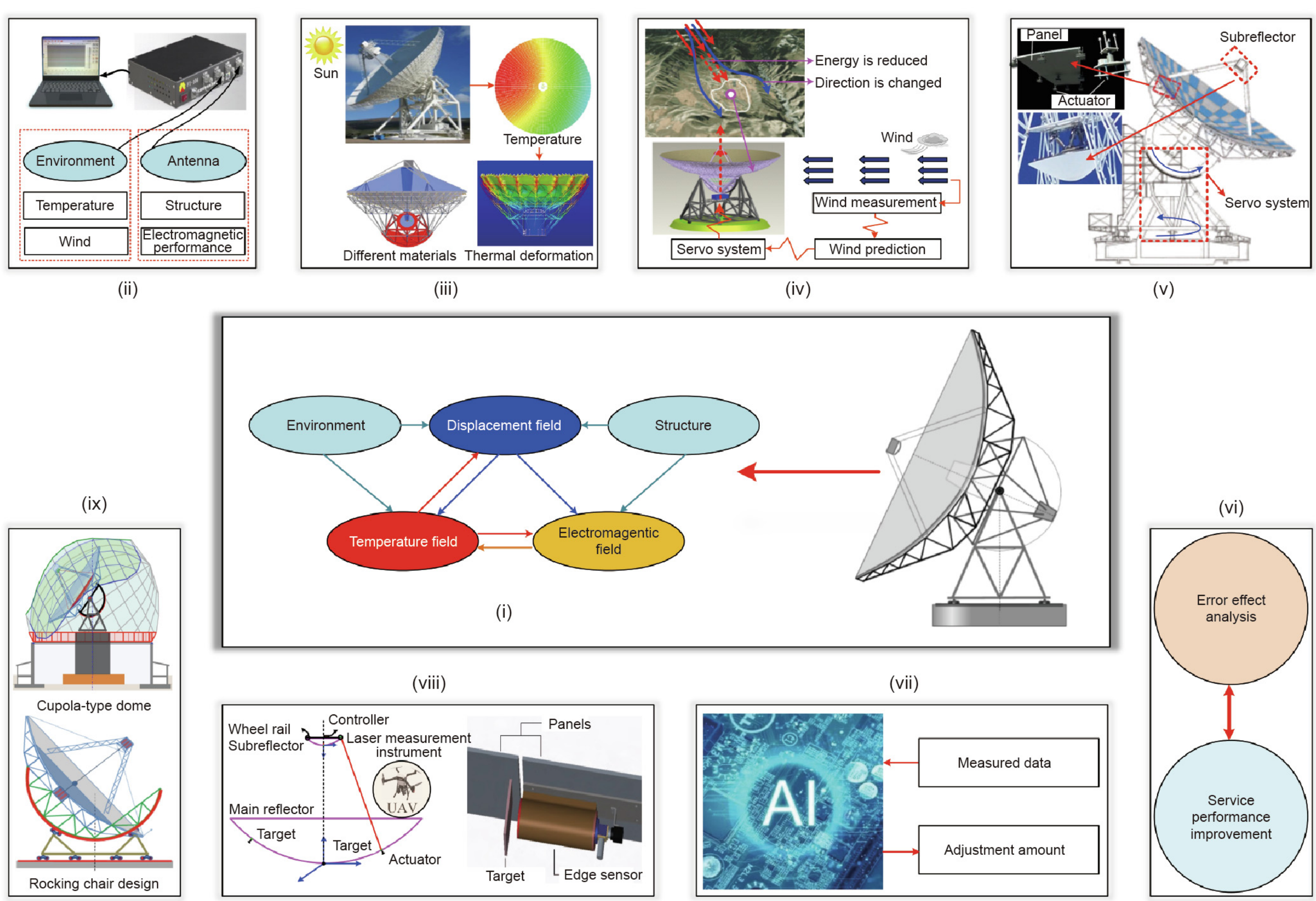

Fig. 2. Summarized key research directions. (i) Electromechanical coupling; (ii) condition monitoring; (iii) thermal deformation compensation; (iv) wind disturbance control; (v) multisystem synergy adjustment; (vi) error effect analysis; (vii) application of artificial intelligence; (viii) new measurement scheme; (ix) innovative structure design. UAV: unmanned aerial vehicle; AI: artificial intelligence.

(3) **Thermal deformation compensation**. The temperature gradient is an important factor that affects antenna service performance, and due to the inherent time-varying nature of the temperature field, compensation for temperature-related changes remains a challenging task. At present, temperature control equipment and composite materials have been adopted to reduce thermal deformation [7], but the high cost has become unacceptable. Therefore, we suggest the following two research directions:

- Study low-cost and lightweight thermal control systems and explore homologous design methods considering different materials with different thermal expansion coefficients with only the key part of the structure being made of composite material to reduce the cost [5,8];
- Research the real-time reconstruction method of the temperature field with a small number of sensors. Perhaps we can establish one simulation temperature database for special operation conditions in advance, and then, the real temperature field can be approximately obtained by correcting the corresponding simulation temperature with the measured temperature data [9].

(4) **Wind disturbance control**. Wind disturbance is another important environmental factor causing large antenna pointing errors, and it is also difficult to compensate for such errors in engineering due to the transient nature of wind gusts. Future research is suggested in the following two directions:

- Explore the method of regulating and controlling the wind field at the large antenna site [10]. One potential method is to establish a wind simulation model according to the topography of the antenna site and then optimize the windbreak belt or wind power equipment to reduce the wind energy or change the wind direction near the antenna.
- Study the control strategy for an antenna's servo system to achieve the aim of pointing stability under wind disturbance [11]. We can predict the wind field near the antenna in advance by measuring wind data at some key positions far away from the antenna and constructing a wind prediction model to provide sufficient time for the adjustment calculation and servo system response.

(5) **Multisystem synergy adjustment**. The adjustment subsystem of a large antenna generally includes the active main reflector, the subreflector Stewart platform, the servo system, and the phased array feed (PAF) excitation (only for the PAF reflector antenna). The PAF technique can greatly enlarge the field of view and improve the efficiency of sky surveys of radio telescopes, and the effect of deformation on the electromagnetic performance can be greatly reduced by adjusting the amplitude and phase of the excitation of the array elements [12]. In fact, each subsystem's influence on service performance is mutual coupling, which has not been considered so far. In the future, a model of the couplings between different subsystems should be established to form a multisystem synergy adjustment system and analyze each subsystem's ability to adjust and control the electromagnetic performance when running independently to seek one optimal scheme of the weight assignment.

(6) **Error effect analysis**. Many papers have focused on the influence of structural error on the electrical performance through the interval method or probability method [6,7,13]. However, few works in the literature have focused on error effect analysis in the service performance improvement process, such as measurement errors in condition monitoring, reconstruction errors in environment reconstruction, model errors of finite element models, and adjustment errors of different subsystems. There is an urgent need to carry out an influence analysis of various errors on the compensation effect to realize the robustness of service performance compensation.

(7) **Application of artificial intelligence**. The condition monitoring and performance improvement system accumulate a large amount of multitype data, such as wind data, temperature data, vibration data, structural strain data, and multisystem adjustment data. In the future, we should make full use of the large historical amount of data to realize intelligent adaptive control of large antennas through the application of artificial intelligence methods. The possible applications may be the intelligent prediction of temperature or wind, intelligent determination of subreflector's location and posture, intelligent calculation of each subsystem's weighted adjustment amount, and so on.

(8) **New measurement scheme**. The existing standard measurement methods, such as laser measurement, photogrammetry, and holographic measurement, have difficulty realizing real-time measurements because of the complicated and time-consuming measurement process. The measurements cannot be carried out during the observation process. Therefore, it is necessary to explore new real-time measurement schemes to satisfy the real-time requirement for improving service performance. To date, some new schemes have already emerged [14,15]. For example, the measuring instrument can be placed on the subreflector or the unmanned aerial vehicle, or edge sensors can be installed on panels to measure the tilt angle between two adjacent panels.

(9) **Innovative structure design**. The innovative structural design is a challenging task to break through the traditional design framework of the existing antenna and make it insensitive to environmental disturbance. For future large antennas with high operation frequency, performing innovative structure design is crucial. Ref. [5] reported some new structural design to reduce the effect of wind by a cupola-type dome and to reduce weight by the "rocking chair" design concept; at the same time, the antenna can be equipped with an elaborate carbon fiber backup structure complemented by a closed-loop active surface accomplished by the tilt sensing system.

With the development of large reflector antennas towards larger aperture, higher frequency, higher gain, and higher pointing precision, the room for improving its performance becomes less because of the impact on these factors by complex environmental factors. The study of this area has become an important research trend towards ensuring the excellent and robust service performance of the antennas and it is full of opportunities and challenges for relevant researchers. This paper has summarized nine key research directions on service performance improvement. We hope that readers are inspired with new thoughts for future research in this area with the presented suggestions. With the further performance of the Chang'e project, Tianwen project, and related radio astronomy projects, remote communication distance and higher navigation precision in deep space are becoming challenging. It is urgent to carry out the suggested studies to provide technical support for the improvement of antenna service performance and the construction of larger aperture and higher precision antennas, which effectively improves the performance of deep space TT&C networks to realize stronger deep space communication capability.

Acknowledgements

We thank all the relevant researchers for their work on large reflector antennas. This project was supported by the National Natural Science Foundation of China (51805399, 51975447, and 52005377), the Youth Innovation Team of Shaanxi Universities (201926), and the Fundamental Research Funds for the Central Universities (JB210404 and JB210403).

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