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Research on FAST Optimum Parabolic Surface Based on Active Reflection

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Abstract: *For the problem, to obtain the best-receiving effect of celestial electromagnetic waves reflected by the reflective surface, analyze the celestial body S directly above the reference spherical surface, to make all the reflected light reach the feed bin, according to the question given parameters, this paper establishes a space rectangular coordinate system at the center of the reference sphere and designs the parameter equation. By analyzing the relationship between the physics and geometry of the reflecting surface, the optimal paraboloid function is obtained.*

Keywords: *Fit optimization Model, Active Reflection Surface, Electromagnetic Wave Reflector*

1. Question Restatement

China Sky Eye - Five-hundred-meter Aperture Spherical Radio Telescope (FAST) is the largest single-aperture and most sensitive radio telescope in the world with independent intellectual property rights. Its completion and the opening is of great significance for my country to achieve major original breakthroughs in the frontier of science and accelerate innovation-driven development.

The problem to be solved in this paper is to determine an ideal paraboloid under the adjustment constraints of the reflective panel, and then adjust the reflective surface to a working paraboloid by adjusting the radial expansion and contraction of the actuator, so that the working paraboloid is as close as possible to the ideal paraboloid to obtain The best receiving effect of celestial electromagnetic waves after being reflected by the reflective surface.

Question 1: When the celestial object to be observed is located directly above the reference sphere, that is, $\alpha = 0°$, $\beta = 90°$, the ideal paraboloid is determined by considering the adjustment factors of the reflective panel.

2. Problem Background

The 500-meter Aperture Spherical Radio Astronomy Telescope (abbreviation: FAST) was built in the Dawotai depression of Jinke Village, Kedu Town, Pingtang County, Qiannan Buyi, and Miao Autonomous Prefecture, Guizhou Province. The Dakota site is about 85 kilometers northeast of Pingtang County. The southwest is about 45 kilometers away from Luodian County. The project covers an area of 457,100 square meters. It uses the natural karst landform of Guizhou, lays a spherical crown active reflector with a diameter of 500 meters in the pit, and uses a light cable-net mechanism to achieve high-precision positioning of the telescope receiver. These innovative ideas enable the FAST telescope to break through the 100-meter engineering limit of the telescope and create a new model of giant radio telescopes. Upon completion of construction, the FAST telescope will become the world's largest single-aperture radio telescope. The effect after its completion is shown in Figure 1: FAST Sky *Eye*.

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Figure 1: FAST Sky Eye

The active reflecting surface system of the FAST sky eye: This system is an important part of the FAST telescope, which is a spherical surface with an aperture of 500 meters, a radius of 300 meters, and active adjustable deformation. The active reflector system includes supporting ring beams and lattice columns, main cable nets, reflector units, actuator devices, ground anchor devices, and other components. Among them, the main cable net is installed on the lattice ring beam, and there are 2225 connection nodes. There are 4450 reflecting surface elements installed on these nodes. There is a pull-down cable and an actuator under each node to actuate The device is then connected to the ground anchor. Real-time 300-meter-diameter instantaneous paraboloid for astronomical observation by controlling the actuator.

3. Problem Analysis

For the topic requiring the calculation of the paraboloid, the equation of the projected paraboloid in the plane can be calculated by establishing a spatial right-angle coordinate system in the reference sphere and calculating the focal point and vertex coordinates of the paraboloid projection through geometric mathematical and physical properties. Because this observation point $\alpha = 0°$， $\beta = 90°$ is located on the axis of the constructed spatial coordinate system z, the expression of the ideal paraboloid can be calculated, and then the adjustment and structure of the reflective panel can be analyzed to better improve and optimize the obtained expansion of the desired paraboloid expression.

4. Model Assumptions

Assuming that the air does not refract the electromagnetic waves

Assume that the distance between adjacent nodes after the adjustment of the main index node is negligible

Assuming that the size of the feed cabin is negligible, it is treated as a particle

Assume that each reflective panel is smooth enough to allow specular reflection of electromagnetic waves

Assume that the light received by the observed star is parallel

5. Symbol Description

Table 1: Symbol Description

Symbol	Content
α	Azimuth
β	Elevation angle

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Symbol	Content
K	Stiffness Matrix for Cable-Net Systems
ΔS	Displacement vector of cable-net system
F	Force Vectors on Nodes of a Cable-Net System
n	The direction cosine matrix of the drag cable
K_e	Element Stiffness Matrix
M_e	Element Mass Matrix
E	Elastic modulus of the cable segment
d	A collection of cable net non-illuminated nodes
$\lvert s_i \rvert$	The absolute value of the displacement of the non-illuminated nodes of the cable net

6. Model Building and Solving

For the topic requiring the calculation of the ideal paraboloid, the equation of the projected paraboloid in the plane can be calculated by establishing a spatial right-angle coordinate system in the reference sphere and calculating the coordinates of the focal point and vertex of the paraboloid projection through geometric mathematical and physical properties. Because this observation point lies on the axis z of the spatial coordinate system constructed by $\alpha = 0°$, $\beta = 90°$, the expression of the ideal paraboloid can be calculated, and then the adjustment and structure of the reflective panel can be analyzed to improve and optimize the obtained representation of the desired paraboloid better. So we can establish the overall layout to calculate the equation of the desired paraboloid by the relationship between the reflective panel and the cable network.

6.1 Relationship between Reflection Panel and Cable Net

The reflection panel and the cable mesh are the front cable mesh structure of the radial rib cable mesh antenna reflects for supporting the metal reflector mesh of the reflector. In the microgravity environment of space, the cable unit is in a linear state under the pretension, so the antenna reflector surface is formed by a large number of small planes stitched together with the cable net nodes as the vertices. There is an unavoidable error between the rotating paraboloid surface stitched by a large number of small planes and the ideal reflecting surface, which is the principal error of the reflecting surface of the cable network, mainly determined by the cable network configuration (node topology relationship), the grid size and the cable network node position. Figure 2: FAST Reflective *panel*.

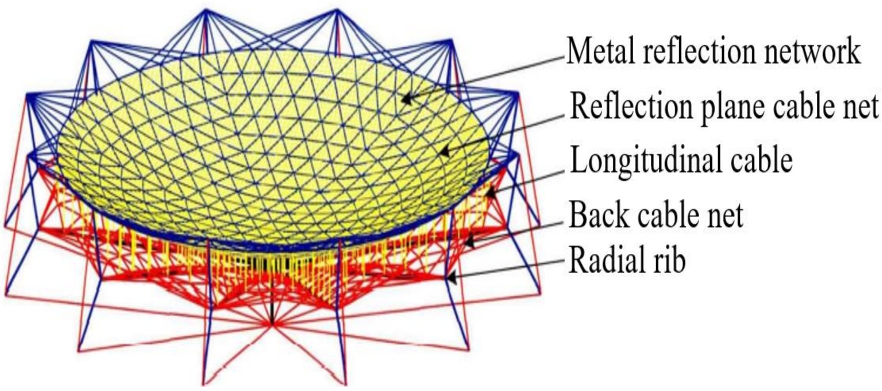

Figure 2: FAST Reflective panel

6.2 Calculation of the Ideal Paraboloid Equation

In this paper, according to the data are given in Annex 1.csv[6], the following is obtained using Matlab Figure 3: FAST Benchmark Position:

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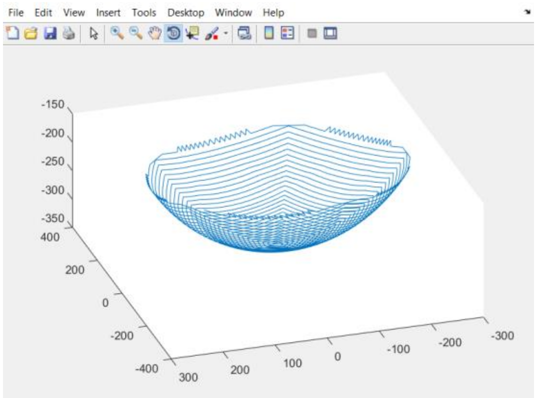

Figure 3: FAST Benchmark Position

The observed star s is located directly above the reference sphere. As shown in Figure 5, line S,C is perpendicular to the ground, and the space rectangular coordinate system $c-xy\ z$ is established with the reference sphere center C as the origin. The line where S,C is located is the z axes. In the $o-xz$ planes, the section of the ideal paraboloid is a parabola as shown in Figure 4: Ideal Parabolic Section:

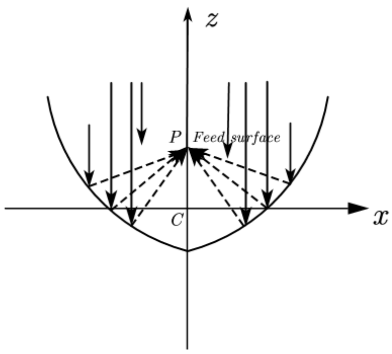

Figure 4: Ideal Parabolic Section

In a certain range, the electromagnetic wave will converge on the feed surface after being reflected by the reflective surface, so the observation effect of the feed surface on the focus P of the parabola is the best. Suppose the equation of the parabola in the $c-xz$ plane is:

$$z = 2px^2 + d \tag{1}$$

Since S is just above the reference sphere, the position of the vertex is also located on the straight line SC, as shown in the actual situation Figure 5: FAST Profile Diagram.

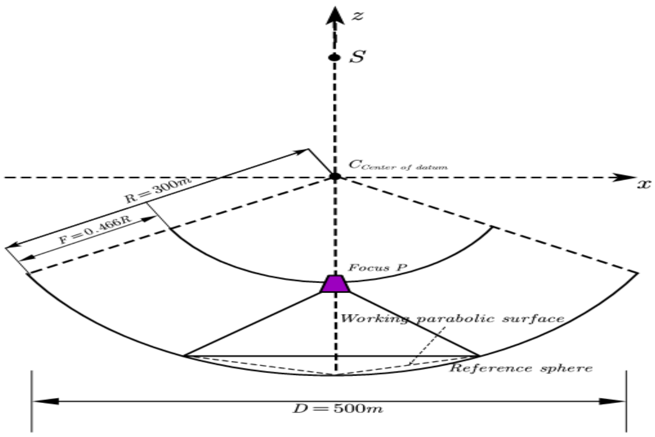

Figure 5: FAST Profile Diagram

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As shown in Figure 5: FAST Profile Diagram, if the parabola is on the reference sphere and the paraboloid is inside the reference sphere, the observation data can be obtained to the maximum limit. So the focal length is F, and $F=\frac{p}{2}$.

You can get:

$$z=4Fx^2+d \tag{2}$$

From Figure 3: FAST Benchmark Position, we can see that the geometric configuration of the reference sphere is a rotating paraboloid, and the ideal paraboloid and the reference reflecting surface are on the same rotation axis, and the ideal rotating paraboloid can be obtained by rotating the paraboloid of equation x around the z-axis.

On the $c-xy$ planes, the paraboloid of revolution is projected as a circle whose center is at the origin, and its equation is:

$$x^2+y^2=r^2 \tag{3}$$

In space geometry, the paraboloid rotating around the coordinate z-axis needs to be replaced by its x^2 to (x^2+y^2), and the vertex position is at R directly below the point C, so $d=-R$, the equation of the ideal paraboloid is obtained by substituting P = 0.466R into the equation (2) after the replacement.

$$z=\frac{(x^2+y^2)}{559.2}-300 \tag{4}$$

Then the fixed point of the reference sphere is $(0,0,-300,40)$. To compare with the original reference sphere, this paper draws the ideal paraboloid calculated by the formula (4) based on the space diagram of the original reference sphere, as shown in Figure 6: Comparison of ideal paraboloid and reference sphere:

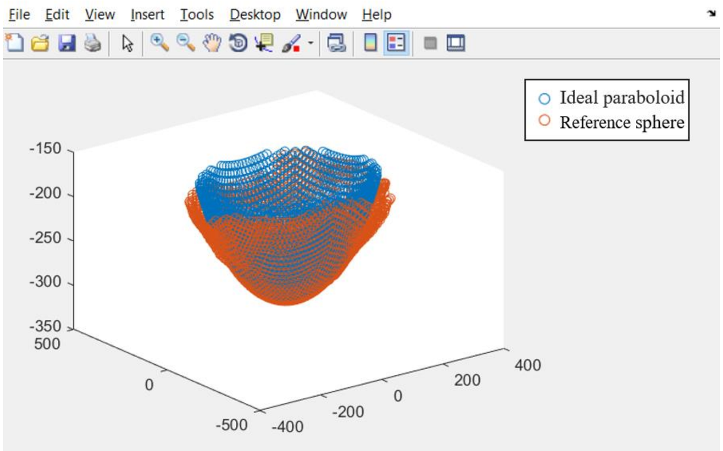

Figure 6: Comparison of ideal paraboloid and reference sphere

It can be seen from the figure that the ideal paraboloid is inside the reference sphere. When the position of the reflective layout is properly adjusted, the ideal paraboloid can be attached to obtain the best observation.

7. Model Evaluation

7.1 Advantages of the Model

Based on strict mathematical and physical concepts, the physical concepts are clear, have strong applicability and flexibility, and see the results clearly and intuitively.

The model in this paper is based on the radiation electric field theory with appropriate

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simplification and uses the idea of definite integral to solve the equivalent area of the relevant paraboloid.

7.2 Disadvantages of the Model

The small changes in the distance between neighboring nodes are ignored, which may produce some errors.

The effect of the leakage holes on the reflective panel on the reflection of electromagnetic waves is not considered.

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