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Research on Shape Adjustment of "FAST" Active Reflector

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Abstract: This paper mainly studies how to determine an ideal paraboloid when the adjustment of "fast" is constrained. In the case of vertical illumination, the operation feasible region of the main cable node is the region between two triangular reflection panels. Because the ideal paraboloid can make the parallel electromagnetic waves gather in the feed cabin and the expansion and contraction of the actuator have a range, the problem can be transformed into a single objective optimization problem for two-dimensional graphics. Combined with the parameters, geometric knowledge, light reflection principle and accessory data of the triangular element mirror, the included angle between the triangular element mirror and the horizontal line can be calculated by MATLAB, and then the relationship between the expansion amount of the actuator and the x-axis can be deduced, and finally the ideal paraboloid can be obtained.

1. Introduction

The five hundred meter aperture spherical radio telescope (fast) is a radio telescope with independent intellectual property rights in China. At present, it has the largest single aperture and the highest sensitivity in the world. Its completion and use is of great significance for China to achieve major original breakthroughs in the forefront of science and accelerate innovation driven development. Fast consists of active reflector, signal receiving system (feed cabin) and related control, measurement and support systems. The active reflector system is an adjustable sphere composed of main cable net, reflector panel, lower cable, actuator and support structure. The main cable net is composed of flexible main cables in the form of geodesic triangular grid, which is used to support the reflection panel (including back frame structure). A reflection panel is installed on each triangular grid, and the whole cable net is fixed on the surrounding support structure. Each main cable node is connected with a lower cable, and the lower end of the lower cable is connected with the actuator fixed on the ground to realize the shape control of the main cable network. There is a certain gap between the reflection panels, which can ensure that the reflection panel will not be squeezed, pulled and deformed during displacement.

2. Model establishment and solution

2.1 Problem analysis

When the observed celestial body S is located above the reference sphere, it is necessary to determine the ideal paraboloid by considering the adjustment factors of the reflection panel. When the light wave is irradiated, it is assumed that each light wave is irradiated at the center of each panel and reflected at the center of the effective area of the received signal in the feed cabin, so that the degree of each light wave reaching the unified focus through the reflecting surface is maximized. In this process, the paraboloid is processed in layers. Each layer is composed of a specific number of panels, and the reflection angle θ_i of light wave on the panel is calculated. According to the three-point coordinates of the panel given in Annex 1, combined with the angle θ_i, the vertex coordinates of the triangular panel are obtained, and then the curve is made with MATLAB. Then the paraboloid curve is an ideal paraboloid.

2.2 Problem solution

1. When "$\alpha = 0°$, $\beta = 0°$", as shown in the figure below, the area of the spherical crown can be calculated:

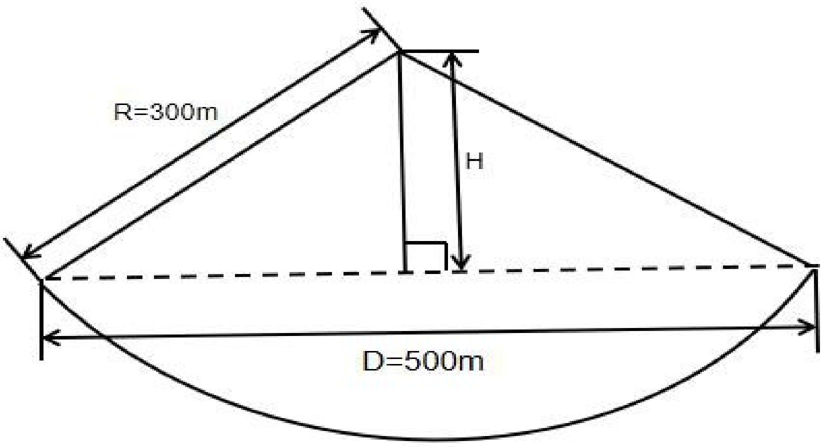

Figure 1: Spherical crown analysis diagram.

$$S_{qg} = 2\pi R(R - H) = 2\pi * 300 * (300 - \sqrt{300^2 - 250^2}) \tag{1}$$

The spherical crown area obtained is approximately equal to 252773.945 m^2.

2. Find the area of the datum sphere as follows:

$$S_{jz} = 2\pi * 300 * (300 - 150\sqrt{3}) \tag{2}$$

The area of unit panel $\frac{S_{qg}}{4300}$ is obtained through $S_{mb} = 58.785m^2$, and then the length of triangular panel is calculated by using the relevant properties of equilateral triangle, which is about 11m. At the same time, the three-dimensional diagram of reference sphere is obtained through MATLAB programming calculation:

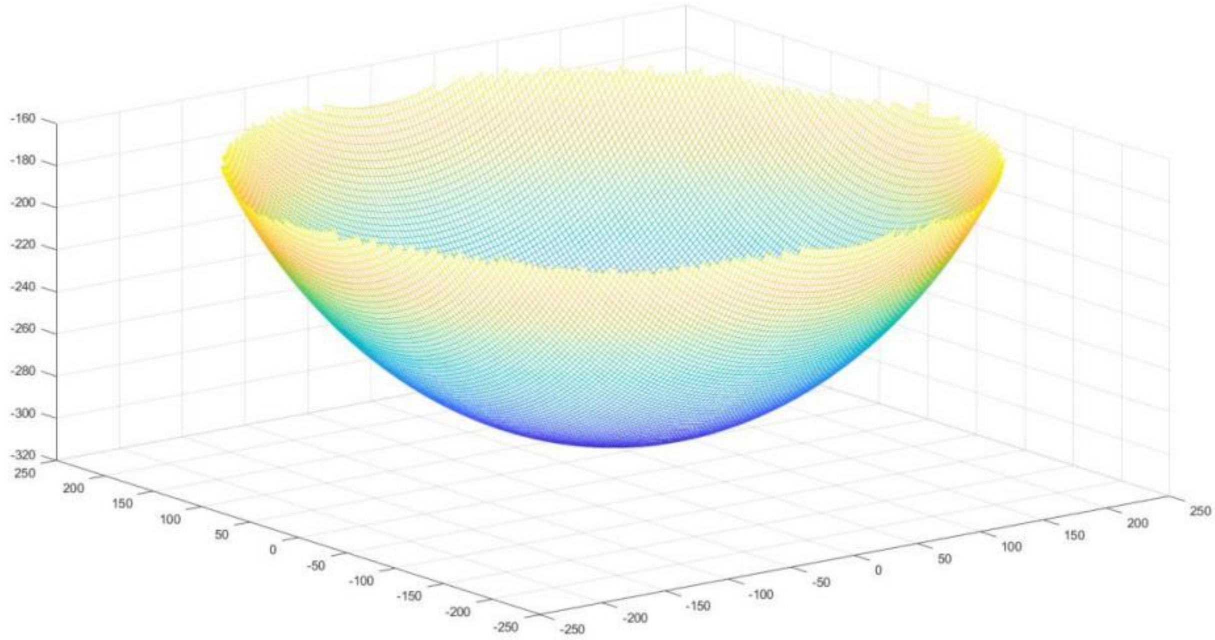

Figure 2: Three dimensional view of the reference sphere.

According to $\frac{S_{jz}}{S_{mb}}$, there are about 1288 panels in the "lighting area".

According to the layered treatment in this paper and considering the gap between adjacent panels, 1280 panels are obtained for the following calculation.

Considering the factors of adjusting the actuator in combination with the reflective surface plate, select the outermost panel in the "300m" lighting area. When a beam of light wave shines in, the effect is as shown in the figure:

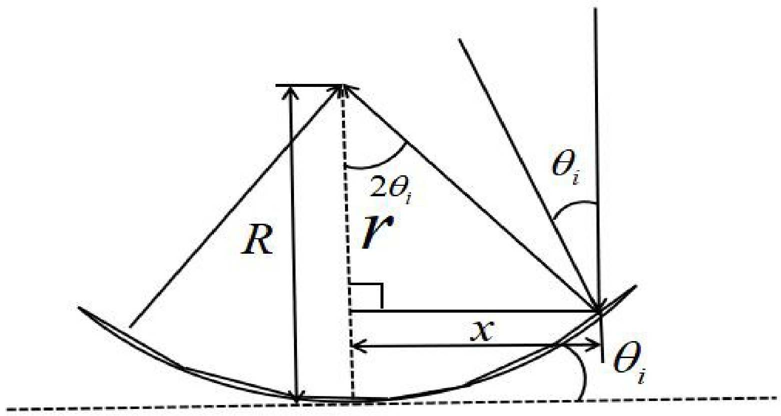

Figure 3: Brief analysis of light incident from the outermost layer.

It is easy to know that the reflection angle is equal to the depression angle of the panel relative to the horizontal line:

$$\begin{cases} r = \mathrm{R} - \mathrm{h} \\ \tan 2\theta = \dfrac{x}{r} \end{cases} \tag{3}$$

Take any sixteen groups of data and substitute them into the formula to obtain the following data:

Table 1: Experimental data.

Num	x axis	angle	z axis
1	0	0	-300.4
2	10	0.6507	-300.2202
3	20	1.3019	-299.802
4	30	1.9581	-298.265
5	40	2.6195	-296.2788
6	50	3.2901	-293.4821
7	60	3.9573	-291.633
8	70	4.6331	-289.0872
9	80	5.3184	-286.0076
10	90	6.0112	-282.265
11	100	6.6950	-280.1251
12	110	7.3972	-276.5491
13	120	8.1088	-272.6112
14	130	8.8264	-268.5466
15	140	9.5273	-265.3780
16	150	10.2494	-261.2621

The relationship between expansion amount and x-axis is shown in the following figure:

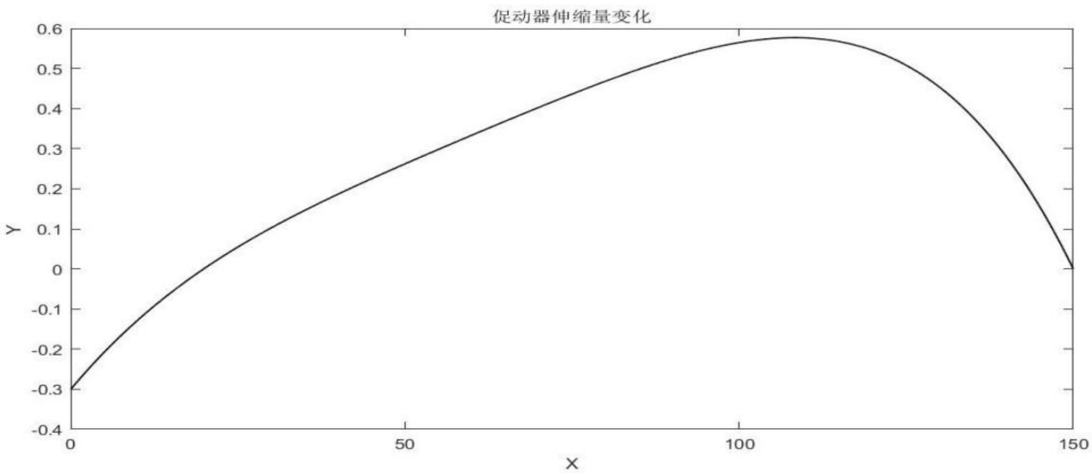

Figure 4: Brief analysis of light incident from the outermost layer.

In order to obtain the coordinates of the vertices of the triangular panel, this paper obtains the i iterative formula through calculation, as follows:

1. Select the center of the equilateral triangle (three centers in one) as the reflection point, let a_1 and a_2 be the distances from the vertex to the center and from the edge to the center respectively, and the value is obtained through the triangle related formula theorem as follows:

$$\begin{cases} a_1 = 6.3509\text{m} \\ a_2 = 3.1754m \end{cases} \tag{4}$$

2. It is known that θ_i is the incident angle and reflection angle of the ith light wave on the panel and the included angle between the panel and the ground;

3. H_{ij} is the distance between the intersection of the extension line of the j-th panel on the i-th floor and the coordinate axis Z and the feed cabin, and $H_{11} = H_{12}$ =139.955m is known;

4. l_{ij} is the distance between the extension line of the j-th reflection point of the i-th layer and the intersection of the z-axis, and is known:

$$\begin{cases} l_{11} = a_1 \\ l_{12} = a_2 \end{cases} \tag{5}$$

5. Establish the model by iterative method:

$$l_{ij} = \frac{l_{i-1,j} + h - a_{mi}}{\sin\left(\frac{\pi}{2} - \theta_{ij}\right)} + a_{ni} \tag{6}$$

Finally get:

$$\sin\theta_{ij} = \frac{l_{ij}}{2H_{ij}} \tag{7}$$

Since when $\alpha = 0°$, $\beta = 0°$, it can be regarded as a paraboloid symmetrical about YOZ, only xoz surface can be considered;

After the iterative formula of the reflection angle of incident light wave is obtained, the equations of x-axis and z-axis are obtained by Matlab:

$$Z = 0.0012x^2 + 0.097x - 300.4 \tag{8}$$

At the same time, the images produced by MATLAB are obtained:

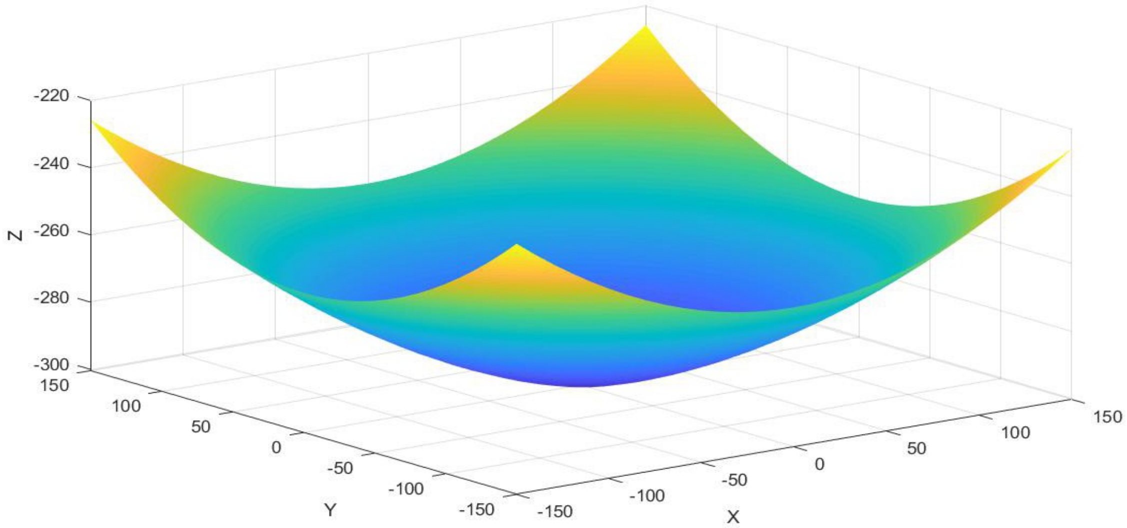

Figure 5: Brief analysis of light incident from the outermost layer.

So, when $\alpha = 0°$, $\beta = 0°$, its ideal paraboloid is:

$$z = 0.012(x^2 + y^2) + 0.097\sqrt{x^2 - y^2} - 300.4 \tag{9}$$

3. Model evaluation

A large number of image models are used, which is more intuitive. The image relationship between some variables is supplemented, which is more comprehensive.

The model has no strong universality and is only suitable for solving fast related problems.

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