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Research on shape adjustment of reflector based on optimization model

Zhang Quan

Xijing University, Xi'an, Shaanxi, 710000

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Abstract: In this paper, the spatial analytic geometry problem is transformed into a plane analytic geometry problem by analyzing the trajectory of the feed tank.Then, the objective function is established to minimize the longitudinal distance of the relevant coordinates, and the genetic optimization algorithm is used to obtain the minimum longitudinal distance of the relevant coordinates.Finally, an ideal parabolic equation with an upward opening is obtained.The slope, the coordinates of the main cable point, the space paraboloid equation and the datum sphere equation are used to analyze the variation rule of the radial distance between the ideal paraboloid and the datum sphere.Exhaustive method using violence to 886 groups of data into the model, and the corresponding coordinates in the ideal paraboloid, finally will be ideal paraboloid and benchmark of the spherical coordinates in space, the distance between two points in the formula to find the ideal paraboloid and benchmark spherical coordinates of radial distance, equal to the scale of the various actuators

1. Background

FAST[1] is currently the world's largest single-aperture and most sensitive radio telescope.The essence of FAST's work is to rely on listening, through the absorption and refraction of electromagnetic waves,so as to get a lot of astronomical knowledge. FAST is composed of active reflecting surface, signal receiving system and related control, measurement and support system.In order to obtain the best receiving effect of celestial electromagnetic wave reflected by the reflecting surface, it is necessary to study the above system [2].

2. Modeling and solving of problem 1

2.1 Model Establishment

The basic principle of a classical radio telescope is similar to that of an optical reflective telescope, in that other projected waves are reflected by a precise mirror and move in the same direction to a common focus. It's easy to focus in the same direction using a rotating paraboloid as a mirror, and a rotating paraboloid can concentrate light at a focal point, whereas a sphere concentrates light on a straight line [3]. According to the conditions for the formation of the ideal paraboloid in the problem, the reflecting panel on the reference sphere is constrained by the feed capsule, and the trajectory of the feed capsule moves on a sphere concentric with the reference sphere, so the three points of the body center of the feed capsule are collinear, so the spatial analytic geometry problem is transformed into the plane analytic geometry problem.

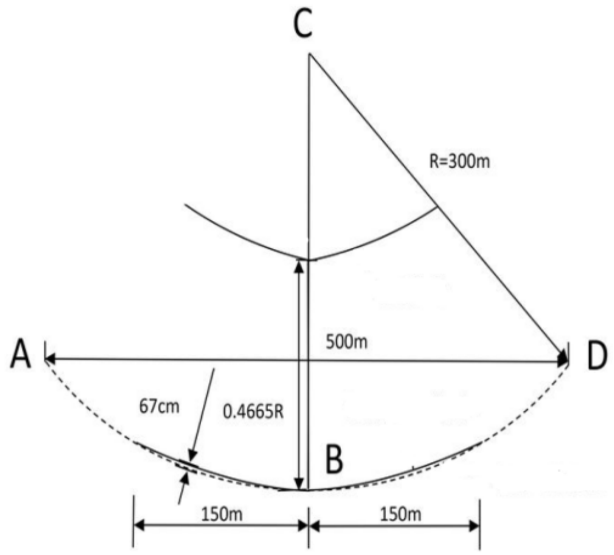

Figure 1: Geometric diagram of working surface

Firstly, the conic curve model of the plane is established.According to the known conditions given in the problem, it can be assumed as a parabola, and the equation of the parabola is set as:

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

Then, the geometric diagram of the working surface is abstracted according to the problem knowledge, as shown in the Figure.To establish the Pythagorean equation model, set the coordinates of point A (y_1, z_1), point D(y_2, z_2), point C $(0,0)$, and point B $(0, z_3)$. According to the known condition$z_2 = z_3$ in the figure, set$z_2 = z_1 = b, y_1 = -y_2$, and the equation is:

$$x^2 + y^2 - 300.0339 = 4(-b + a - 160.2)z \tag{2}$$

Finally, in order to solve the parameters set in the problem, a nonlinear programming model is established:

$$min\, f\,(x) = {x_1}^2 - 90000 + 4(-b + x_2 + 160)x_1 - 0.6 + 300.0339 \tag{3}$$

$$s.t. \begin{cases} |b| \le 300 \\ 499.4 \le x \le 500.6 \end{cases} \tag{4}$$

2.2 Model solving

Step 1: Due to the large amount of data in the question, it is suitable to apply the algorithm with global search property, and the genetic algorithm rarely has local optimization, so the genetic algorithm is used to design the number of iterations is 500, crossover rate is 0.6, mutation rate is 0.01, and the range of two independent variables is set as [499.4,500.6]and [-300,300]. Then run the program to get the results.

Step 2: Through the above solution, the optimal value is 0. At this time, the output independent variables 259.807 and 300.025 are obtained. The value obtained by running the program for many times afterwards, only the first value 259.807 fluctuates within the range of plus or minus 0.2, and it finally stabilizes at 0.

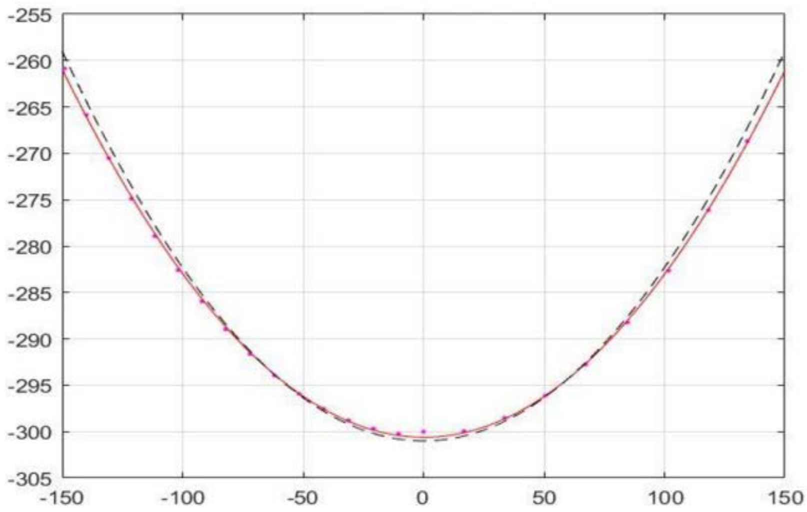

Figure 2: Ideal paraboloid and reference sphere

Step 3: Substitute the independent variable obtained in the second step into the parabola equation,and the focal length of the parabola is 0.0004469.Then substitute into the equation,and the parabola equation is $z = 0.0017878x^2 - 300.0339$.The equation of the ideal paraboloid is $z = 0.001787(x^2 + y^2) - 300.0339$.In order to make the result more intuitive,the reference sphere and the ideal working surface are fitted.From the image,it can be seen intuitively that the two images almost coincide to meet the relevant constraints.

3. Modeling and solving of problem 2

3.1 Model Establishment

In this paper,the slope,the coordinates of the main cable point,the space parabolic equation,the benchmark spherical equation and five variables are used to analyze the change rule of the radial distance of the relevant coordinates.Therefore,the function of the five variables mentioned above is:

$$y = f\left(x_i, y_i, z_i, k_i, g(x,y), h(x,y)\right) \tag{5}$$

Since slope k_i is related to x_i, y_i, z_i, the equation of slope and coordinate is established:

$$X = 300\sqrt{\frac{x_i^2}{x_i^2+y_i^2+z_i^2}} \tag{6}$$

$$Y = 300\sqrt{\frac{y_i^2}{x_i^2+y_i^2+z_i^2}} \tag{7}$$

$$Z = 300\sqrt{\frac{z_i^2}{x_i^2+y_i^2+z_i^2}} \tag{8}$$

The equation of an ideal paraboloid in space is:

$$z = -(1.09x^2 + 0.98y^2 + 300.33) \tag{9}$$

The equation of the reference sphere is:

$$x^2 + y^2 + z^2 = 300^2 \tag{10}$$

The formula for the distance between two points in space:

$$d = \sqrt{(x_i - X)^2 + (y_i - Y)^2 + (z_i - Z)^2} \tag{11}$$

The mathematical model of this problem is:

$$\begin{cases} \frac{X-x_0}{x_i} = \frac{Y-y_0}{y_i} = \frac{Z-z_0}{z_i} = k_i, \quad i = 1,2,3,\dots,n \\ k_i = 300\sqrt{\frac{1}{{x_i}^2+{y_i}^2+{z_i}^2}}, \quad i = 1,2,3,\dots,n \\ z = -(1.09x^2 + 0.98y^2 + 300.33) \end{cases} \tag{12}$$

3.2 Model solving

Step 1: Use the coordinates of the observation point and the spherical center to establish the space linear equation, and calculate the vertex coordinates of (-12.845, -23.339, -330.0339) by combining the equation of the ideal parabola with the space linear equation established with the spherical center.

Step 2: Set the upper limit of X to 162.845 and the lower limit to -137.155, the upper limit of Y to 173.335 and the lower limit to -126.661. Finally, there are 886 points that are changing.

Step 3: Using brute force method, firstly, 886 groups of data are substituted into the model, and the corresponding coordinates on the ideal paraboloid are obtained.Then, the radial distance between the coordinates of the ideal paraboloid and the reference sphere is obtained, which is equivalent to the expansion of each actuator.

4. Evaluation of Model

4.1 Advantages

The principle of the model is easy to understand and easy to use, and most of the calculation is the use of elementary mathematics language, so the stability and superiority of the model is also a bright spot, and in order to ensure the accuracy of the results with some more advanced algorithms for error analysis, to increase the operation of the model.

4.2 Disadvantages

The model is only used to measure the relevant information of a single celestial body.When facing multiple celestial bodies, the low level of algorithm results in low operability.

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