On Static Calibrating and Realtime Tracking Method for Feed Cabin of 50-m LT Model

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1. Introduction

With the development of radio astronomy, it becomes necessary to build a new-generation large radio telescope (LT), which was proposed by radio astronomers [1]. Since then, this work has been kept going forward with continuous progress and more focus. KARST Project of spherical array of Arecibo-type telescope [2] with about 30 large spherical reflectors and each antenna with the diameter of up to 300-500 m was proposed in 1995, in China [3], because there is a unique Karst formations in Guizhou Province of China [4]. So far the largest spherical antenna is the Arecibo spherical radio telescope with a diameter of 305 m, which was built in the 1970’s and located in Puerto Rico, USA. Because of the limitation of technology in the 1970s, the azimuth and pitching tracking are all implemented in the terms of mechanical methods, which not only lead to lower tracking accuracy and high cost, but also result in a very heavy line fee and back-up structure with a 1000-ton weight. In order to overcome these problems, an optomechatronics design project with integration of mechanical, electronic and optical technologies is developed [5-6], as shown in Fig. 1. In this design project, the backup structure- type of Arecibo telescope is thrown away, a light moving cabin structure driven by six cables with six big power servomechanisms, and the feed arranged on the moving platform of Stewart fine tuning platform [7-8] are adopted.

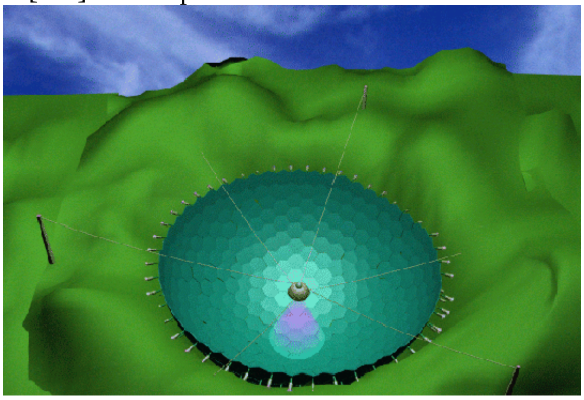

Figure 1: An Optomechatronics Design of Next Generation Radio Telescope

To ensure the illuminated part of the whole sphere being changed to a parabolic reflector, a group of servomechanisms is necessary to be controlled by a computer. A great of experiments has been developed combining the outer 50-m LT model built in Xidian University with important and useful data which has established the foundation for the more next researches. In the experiments, the given locations and positions of the cabin is the premise to make closed-loop control over the feed cabin of the radio telescope. Therefore, the related datum must be obtained by dynamic tracking of the cabin. According to the testing principles of computer stereovision and CCD image analysis, a new principle of and measuring method for dynamic tracking and measuring the feed cabin of the experiment model are proposed.

2. Principle and Method of CCD Measuring System

In the 50-m LT model, 3D CCD measuring system consists mainly of three CCD cameras (MTV-1881EX，resolution 795×596), image cards (Daheng CG210), computers, corresponding video wires, etc. The workings of the whole system are: From three different angles, CCD cameras videotape the feature points of the measured targets moving or rotating in any direction within the measuring range, and produce the video signals, which are transformed into digital signals by the image card and sent to the main control computers, which call and execute the programs to calculate the global coordinates of the measured targets (The length of each corresponding cable can be also obtained). Thus, according to the solved location and orientation of the feature points, the location and orientation of the targets can be determined.

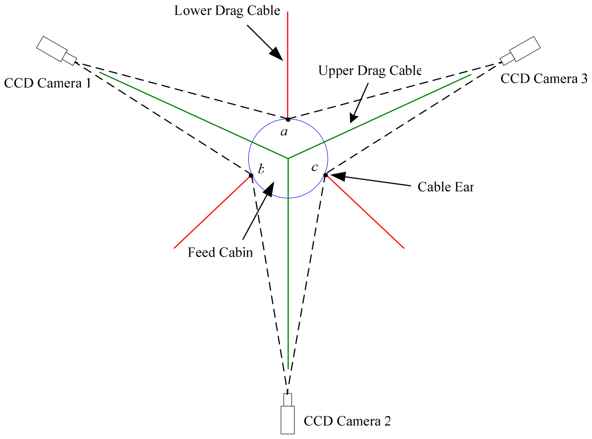

Figure 2: The Configuration of 3D CCD Measuring System

The feedback cabin of the 50-m LT experimental model is suspended by six cables with three evenly placed on the top and the rest the bottom. The other ends of the cables are connected with windlass on the ground through six armored concrete towers. After taking the places (the center of the cable “ear”) where the cabin intertwists three cables connected with its bottom as the feature points for videotaping, there are three feature points *a*, *b* and *c*. These feature points arrange crisscross with three CCD cameras of the same performance parameters, which are placed with the interval of $\pi/3$ between them (Seen in Fig. 2). Every camera reads and determines the projective coordinates of two of three feature points on the CCD target planes. With six projective coordinates of three feature points and according to the correlativity between the projective coordinates and the projective area near the feature points area on the target planes, the projective coordinates of each feature point on the target planes of two corresponding cameras can be determined. Therefore, by the application of the binocular visual positioning method, the global coordinates of three feature points on the cabin can be obtained.

Let P be the feature point of the target to be tested in the global coordinate system OXYZ. The relation between the global coordinates of P and its projective coordinates in one of the cameras can be expressed as follows.

$$\begin{pmatrix} x & y & z & 1 \end{pmatrix}^{\mathrm{T}} = \boldsymbol{RH}\begin{pmatrix} x' & y' & z' & 1 \end{pmatrix}^{\mathrm{T}} \tag{1}$$

Where, $(x,\ y,\ z)$ and $(x',\ y',\ z')$ are the global and projective coordinates of P respectively; $\boldsymbol{R}$ is the space coordinate rotation transformation matrix; $\boldsymbol{H}$ the space coordinate translation transformation matrix.

Realtime tracking and measuring of feature points of the feed cabin can be realized after static-state calibration. The principle is based on the boundary tracking algorithm for CCD image boundary detection and extraction. In practical experiment, no matter how the cabin moves, two adjacent target points can be always observed from each camera. Therefore, the global coordinates of the target point can be obtained by combining two of three cameras separately, that is to say, one target point is videotaped and tracked by two cameras at the same time. For example, CCD camera 3 and 1 can measure and track the target point *a* simultaneously. The square area near the left feature point a_t in the image captured by CCD camera 1 at time *t* can be used as the right template TR_t, while the square area near the right feature point a_t in the image captured by CCD camera 3 at time *t* can be used as left template TL_t. Then the registration of two image templates can be realized. Next, with TL_t and TR_t as the templates, the adjacent domain TL_{t+1} and TR_{t+1} of the corresponding points with the similar grey level distribution will be searched in the two images gathered by CCD camera 3 and 1 respectively at time t+1 (Seen in Fig.3). A judgment should be made whether two templates satisfy the maximum relativity. If so, the centers of two templates are considered as the projections of the target point. If not, the feature area will be continuously searched till the maximum relativity is satisfied.

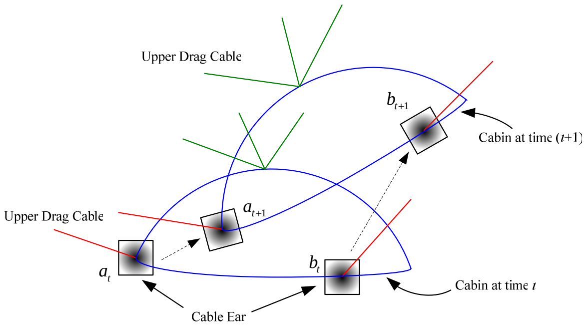

Figure 3: The Illustration of CCD Camera 1 at Two Consecutive Moments

In real-time tracking and measuring process, the rectangular coordinates (x_1, y_1, z_1), (x_2, y_2, z_2) and (x_3, y_3, z_3) of three cable "ears" *a*, *b* and *c* of the feed cabin can be obtained. Therefore, the locations and orientations of feed cabin can be calculated by applying the following formula.

With three evenly distributing on the cabin bottom, the rectangular coordinates of the bottom circle center O_1 are

$$x_{O_1} = (x_1 + x_2 + x_3)/3, y_{O_1} = (y_1 + y_2 + y_3)/3, z_{O_1} = (z_1 + z_2 + z_3)/3 \tag{2}$$

A line between O_1 and the top point O_2 is supposed as the symmetric axis Z of cabin. And the unit vector $\vec{k}$ of the line $\overrightarrow{O_1O_2}$ can be obtained as follows.

$$\vec{k} = (k_x, k_y, k_z)^{\mathrm{T}} = \frac{\overrightarrow{ab} \times \overrightarrow{ac}}{\left|\overrightarrow{ab} \times \overrightarrow{ac}\right|} \tag{3}$$

Where, $\overrightarrow{ab}$ and $\overrightarrow{ac}$ represent the vectors of the cable "ear" *a* pointing to cable "ear" *b* and *c* respectively. Therefore, the azimuth α and pitching β of the feed cabin are given as follows.

$$\alpha = \arctan \frac{k_{1y}}{k_{1x}}, \beta = \arccos k_{1z} \tag{4}$$

3. Experiment and Discussions

Table 1: The Measured Data and Error Analysis (mm)

No.	True Coordinate	Measured Coordinate	Error in X	Error in Y	Error in Z	Distance Error
1	5603, -3755, 7077	5595, -3743, 7071	8	-12	6	15.620
2	5503, -5946, 7726	5497, -5940, 7727	6	-6	-1	8.544
3	6603, -3747, 6128	6593, -3738, 6121	10	-9	7	15.166
4	6486, -5955, 6718	6482, -5952, 6719	4	-3	-1	5.099
5	4690, -3767, 6394	4687, -3761, 6392	3	-6	2	7.0
6	4537, -6087, 7097	4538, -6088, 7104	-1	1	-7	7.141
7	6117, -4480, 7150	6117, -4479, 7151	0	-1	-1	1.414
8	4465, -4055, 6183	4469, -4046,6180	-4	1	3	5.099
9	4457, -6084, 6732	4454, -6089, 6737	3	5	5	7.681
10	4493, -3233, 6215	4486, -3226, 6220	7	-7	-5	11.091
11	4464, -5287, 6678	4456, -5285, 6671	8	-2	7	10.817

To improve the calibrating precision, LED is adopted as the target point to be measured, which is approximately placed in the center of the cable “ear”. The measurement is conducted at night, which is of great help for the electronic theodolites to select the target accurately. Thus the accuracy of the reading data shown in the screen of electronic theodolite is increased. Table I below gives the measuring results and calculati- ons of different positions (The movement speed of the cabin is 2 cm/s). In Table I, true coordinate is the global coordinate of the target point measured by two electronic theodolites, and measured coordinate is the coordinate measured and calculated by 3D CCD measuring system. The fact that the average measured distance error of the target point equal to 9.53463 mm can be obtained from the analysis of the measured data.

4. Conclusion

Within measuring range of about 6 m, the comparison of the measured value and real value of the feature points shows the calibrating precision can be achieved as high as millimeter level (The movement speed of the cabin is 1.5-5 cm/s), with the maximum position error of 10mm in X direction, 12mm in Y direction, and 7mm in Z direction, which best satisfies the measurement precision requirement of 1.5cm for the 50-m LT experimental model. Static-state calibration influenced by the measurement precision of the electronic theodolites, accurate target selection and error reading affects the real-time tracking precision. The movement speed of the feed cabin should be less than 10 cm/s during the dynamic tracking of the cabin by CCD. In practical tracking, the tracking target will be lost if the background light varies a lot (For example, the sun is just behind the cabin when looking through a camera). In this case, the experiment should be stopped and conducted under other suitable conditions.

CCD real-time tracking method proposed in this paper is not only high in precision, but also low in cost, easy in operation, short in image processing time, and quick in data send, thus making the closed-loop control of the feed cabin much easier. With the small visual angle, if one needs to expand the measuring range, a cradle head should be designed for segmental measurement, a fact restricts the wide application of CCD to some extent.

Acknowledgments

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