Rotation center calibration based on line laser rotating platform

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***Abstract*—Line lasers are of great significance in many fields such as industrial inspection, machine vision, cultural relics identification, mechanical design, and medical oral cavity. The three-dimensional reconstruction of the line laser can accurately obtain the three-dimensional information of the surface of the object, and quickly complete the three-dimensional contour reconstruction of the object to be tested. In the online laser rotation scanning, the object rotates around a certain point, which is a rotation center, and the calibration of the rotation center is the main factor that restricts the accuracy of the three-dimensional contour. At present, the calibration of the center of rotation is mainly obtained by the characteristics of a circle (ball, cylinder, cone, etc.). This paper mainly introduces the basic process of rotating scanning, rotating center, and rotating methods as well as their advantages and disadvantages. First, the basic process of rotating scanning is briefly introduced. Secondly, the definition and content of the rotating center are introduced. Then, the calibration methods of three rotating centers (ellipse fitting method, symmetry method, plane fitting method) are introduced. Finally, the advantages and disadvantages of the three calibration methods and their respective applications are summarized.**

Keywords-Line laser; rotary scanning; Rotation center; calibration

I. INTRODUCTION

In today's life, two-dimensional information can no longer meet people's daily needs. The three-dimensional information has thus been deeply researched and developed. Among them, the line laser is widely used in the three-dimensional reconstruction process. Line laser three-dimensional scanning is to project one or more line lasers to the measured object, extract the laser stripe in the image, and calculate the three-dimensional data of the surface of the laser line, usually using high-precision three-coordinate, rotating platform or camera alignment The laser sensor performs positioning to complete three-dimensional scanning of the surface of the object to be measured, and obtain surface data of the three-dimensional object[1][2].

According to the different mechanical displacement platforms, mechanical scanning mainly has two implementations of translation platform and rotary platform. Rotating scanning is more convenient and faster. A more accurate rotation center calibration can improve the accuracy of point cloud reconstruction and improve the 3D contour reconstruction of the measured object.

The reconstruction of the rotating platform can be divided into three types according to the different movement modes: the first is that the camera rotates around the rotating axis [3], and the measured object does not move; the second is that the camera does not move, and the object rotates with the rotating platform [4] The third is that the camera and the object are combined and rotated at the same time[5].

The rotating platform is suitable for scanning objects with swivel features. The object is placed on a rotating platform for linear laser rotation scanning. At

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this time, the visible object is rigidly transformed around the axis of the rotating platform [6], and the left and right camera point clouds can be constructed by using the rotation center and the rotation angle obtained after the platform calibration process. The rotation matrix between the two, the rotation matrix is multiplied by the current point cloud, the point cloud obtained by the left and right cameras can be registered to the same coordinate system, thereby realizing the automatic registration of the point cloud on the surface of the rotating platform [7].

II. CAMERA CALIBRATION

Calibration is simply a matter of establishing a reference point between a pixel coordinate system of an image and a world three-dimensional coordinate system. The essence of the transformation relationship is the geometric principle of camera imaging. The ultimate goal of calibration is to obtain the camera's internal parameters as well as external parameters. The internal parameters of the camera are determined by the camera's own characteristics. The external parameters of the camera are used to establish the mutual conversion relationship between the local world coordinate system and the camera coordinate system in the actual process [8][9]. The camera's parameters have a direct impact on the accuracy of the reconstructed model, so the accuracy of the camera parameters is very important. In general, camera calibration is required before solving the center of rotation.

III. ROTATION CENTER CALIBRATION

Because the line laser scans once, it can only measure the surface of the object to be measured at a given angle of view. If you want to measure the contour of an object for a week, you can measure it by rotation, measure the object from multiple angles of view, and point cloud data from multiple angles of view. Spliced in the same coordinate system. Accurately calibrating the center of the turntable (rotation center) is the key to rotating measurements and multi-view assembly.

Rotation Center: In a plane, a figure rotates a certain angle around a point O to get the other figure to change into rotation, and point O is the center of rotation.

During the rotational scanning, the measured object starts from a fixed angle and starts to rotate 360 degrees around the axis of rotation or the center of rotation. However, the center of rotation of the rotating platform is unknown. In order to obtain the three-dimensional contour of the rotating object, it is necessary to obtain the rotation center of the rotating platform by means of a calibration block or a pasting marker point. After the center of rotation is obtained, the subsequent rotation and splicing can be performed. Since the subsequent splicing work is spliced according to the position of the center of rotation, the extraction work of the center of rotation is very important.

The schematic diagram of the line laser double triangle rotation scan is shown in the figure below, where the center of rotation is the center of the stage.

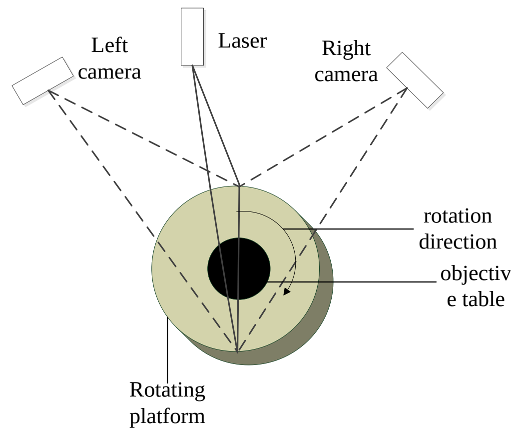

Figure 1. Schematic diagram of line laser double triangle rotation scanning

IV. ROTATION CENTER CALIBRATION METHOD

A. *Ellipse fitting method*

The center of rotation can also be obtained by dividing the plane edge of the rotating platform in the left and right images, and then performing ellipse fitting on the obtained plane edge, and obtaining the center coordinates of the ellipse by the least squares fitting method. It is the center of rotation of the rotating platform [10].

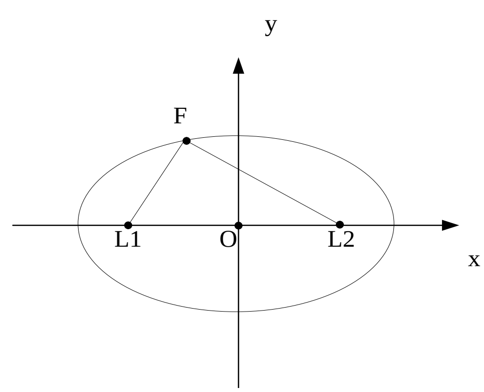

Figure 2. Ellipse Fitting

As shown in Figure 2 above, Point $F(x,y)$ is a point on the ellipse, and the focus of the ellipse is $L_1(x_1,y_1)$ and $L_2(x_2,y_2)$.

$$OL_1 + OL_2 = 2c \tag{1}$$

Since the sum of the distances from any point on the ellipse to the two focal points is a constant 2a, there is an error between the sum of the actual distances, and the error is θ. As shown in the following formula (2):

$$FL_1 + FL_2 = 2a + \theta \tag{2}$$

The above formula (2) is specifically expanded as follows:

$$\sqrt{(x-x_1)^2+(y-y_1)^2}+\sqrt{(x-x_2)^2+(y-y_2)^2}=2a+\theta \tag{3}$$

Using the above formula, the point cloud of the elliptical edge can be fitted by the least squares method, and the estimated values of the five parameters are obtained, and then linearized and solved iteratively.

The criteria for the iterative solution process are:

It is necessary to eliminate the edge point cloud data whose absolute value of the error θ is greater than or equal to 2.6β after each ellipse fitting. (β: standard error of unit weight after each iterative fitting)

Between two adjacent iterative fittings, the absolute value of the distance of any elliptical focus position must be less than a certain pixel value (typically 0.001 pixels). If it is greater than or equal to this pixel, the iteration will end immediately.

In the formula (3), the order:

$$l_1=\sqrt{(x-x'_1)^2+(y-y'_1)^2} \tag{4}$$

$$l_2=\sqrt{(x-x'_2)^2+(y-y'_2)^2} \tag{5}$$

Let FL_1, FL_2 be partial to x_1, x_2, y_1, y_2. Then the above formula expands to:

$$\frac{x-x'_1}{l_1}\Delta x_1+\frac{y-y'_1}{l_1}\Delta y_1+\frac{x-x'_2}{l_2}\Delta x_2+\frac{y-y'_2}{l_2}\Delta y_2+2\Delta a=l_1+l_2-2a_0+\theta \tag{6}$$

x'_1, y'_1, x'_2, y'_2 represents the initial value of the coordinate of the focus, and the focus satisfies the relationship as follows:

$$x_1 = x'_1 + \Delta x_1,\quad x_2 = x'_2 + \Delta x_2 \tag{7}$$

$$y_1 = y'_1 + \Delta y_1,\quad y_2 = y'_2 + \Delta y_2 \tag{8}$$

$$a = a_0 + \Delta a \tag{9}$$

The initial position obtained is used as the initial value, and the point cloud data of the ellipse edge is fitted by the least squares method step by step iteration [11], then the parameter (x_1, x_2, y_1, y_2, a) can be solved, and the elliptical center $O(x_0,y_0)$ of the last fitting is:

$$x_0=\frac{x_1+x_2}{2},\quad y_0=\frac{y_1+y_2}{2} \tag{10}$$

B. Symmetry method

Since the image on the rotating platform has symmetry after being rotated by 180 degrees and is symmetrical about the center of rotation, a plurality of laser lines can be selected on the auxiliary pattern to perform calculation of the center of rotation to ensure accuracy. Finally, the parameters obtained can be optimized by methods such as BP neural network.

In order to accurately calibrate the center of rotation, the straight line equations of the two straight lines s_1s_2 and $s'_1s'_2$ are fitted on the premise that the rotation angle of the rotating platform is known. Find the intersection O between the two lines. The intersection point O is the rotation center of the rotating platform. The point s_1 is located at the position of the point s'_1 after being rotated by 180 degrees, and point s_2 is rotated 180 degrees and is located at point s'_2. s_1, O, s'_1 three points are collinear, and after rotation, are symmetric with respect to the rotation center O before rotation [12]. The principle of symmetry is shown in Figure 4.2 below.

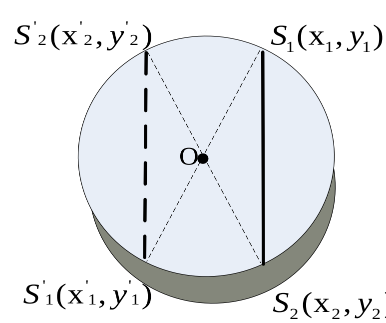

Figure 3. Symmetrical view of the center of rotation

The calibration process of the symmetrical rotation platform is:

(1) Firstly, the rotating platform is adjusted to the working position, the auxiliary pattern is pasted on the rotating platform or the circular calibration block is placed, and the line laser is passed through the center of the rotating platform;

(2) Rotate the rotating platform at an angle (15 degrees) and start collecting data;

(3) Extracting the center coordinates of the laser stripe in the data as pixel coordinates;

(4) Calculating the world coordinates corresponding to the pixel coordinate system and storing the sample set;

(5) After rotating 180 degrees, the sample set is derived for calculation of the rotation parameters.

C. Plane fitting

In the three-dimensional reconstruction of the rotating scanning mode, the obtained rotating point cloud is plane-fitted to fit the rotation center of the rotating platform [13]. The line laser emitter emits a laser beam that intersects the surface of the calibration block. As shown in the figure below, point A emits a line laser, and BC is the line of intersection between the laser and the calibration block. The plane formed between points A, B, and C is a light plane. The points in the light plane (Δ ABC) conform to the plane equation (11).

In online laser scanning, the acquired point clouds are all in the light plane, so all point clouds conform to the plane equation (11):

$$ax + by + cz + d = 0 \tag{11}$$

The n point cloud data obtained by the rotation scan are sequentially brought into the upper equation of the light plane.

$$\begin{cases} ax_1 + by_1 + cz_1 + d = 0 \\ ax_2 + by_2 + cz_2 + d = 0 \\ \vdots \\ ax_n + by_n + cz_n + d = 0 \end{cases} \tag{12}$$

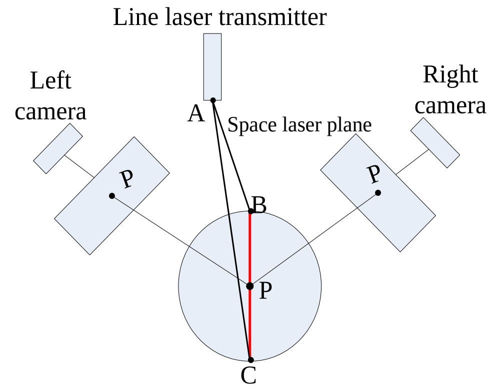

Figure 4. Light plane equation

There are 4 unknown n equations, and the values of four unknowns a, b, c, d can be solved by least squares method. The center of rotation of the rotating platform can be expressed as:

$$O = \left(\frac{1}{n}\sum_{i=1}^{n} x_i, \frac{1}{n}\sum_{i=1}^{n} y_i, \frac{1}{n}\sum_{i=1}^{n} z_i\right) \tag{13}$$

In general, by gradually increasing the height of the rotating platform, a series of center points can be fitted in a straight line, so that the rotation axis can be calibrated. Then through the Rodrigo rotation formula [14], we can complete the coordinate transformation and so on.

The comparison between the calibration methods of the center of rotation is shown in Table 1 below.

TABLE I. COMPARISON BETWEEN ROTATION CENTER CALIBRATION METHODS

calibration method	Advantage	Disadvantage	Applicable situation
Ellipse fitting method	It can reduce the error in the measurement process with high precision.	During the fitting process, the number of iterations is variable and it takes a lot of time.	Due to interference of factors such as position and angle, the extracted edge contour is elliptical. Or the calibration block is elliptical.
Symmetry method	The principle is simple and easy to understand, and the accuracy is high.	It is necessary to select multiple locations for testing, and to obtain an average value, which takes a lot of time.	Suitable for circular rotating platforms. Or a circular calibration block. The point cloud obtained by scanning has higher precision.
Plane fitting	The operation is simple, no need to manually paste the mark points, and the speed is fast.	The accuracy is low.	Suitable for circular rotating platforms. Or a circular calibration block.

V. CONCLUSION

This paper introduces the basic process of linear laser rotation scanning. The measured object starts from a fixed angle and starts to rotate 360 degrees around the rotation axis or rotation center to obtain the three-dimensional contour of the rotating object. The basic knowledge of the rotating center of the rotating platform parameters during the rotating scanning process is introduced, and the calibration methods of the three rotating centers are summarized. The principles and steps of these three calibration methods are analyzed in detail. The advantages and disadvantages of the three methods and their application are summarized. It lays a theoretical foundation for the study of the calibration method of the rotating center.

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