Method for Measuring Clearance of Automobile Body Panel with Double Structured Light System

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Abstract. According to the changes of the autobody measuring clearance often face the shooting angle problem caused by internal decline caused by the lack of data acquisition accuracy, a high precision and robust measurement of binocular gap line structured light and the system parameter calibration method of system integration. First the mathematical measurement model of the system is established according to the Zhang Zhengyou camera calibration model to calculate the camera parameters, the extrinsic parameters of the camera calibration of the light plane, while the introduction of auxiliary line structured light laser by solving the intersection of two camera coordinate system, finally gives the calculation model of the door gap and combined with the calibration data for the gap size. Compared with a three-dimensional scanning measuring device, the system can measure only two images at the same time. The experimental results show that when the shooting angle is less than 45 degrees at the working distance of 400mm and 50*50 field of view, the accuracy reaches 0.08mm, which meets the needs of fast and real-time measurement gap.

1. Introduction

With the rapid development of China's automobile industry in the intelligent manufacturing, automobile production in all aspects of the detection of measurement is particularly important. Which in the car body matching quality link, the body outside the board cover gap measurement is an important means of evaluation. Its measurement accuracy will directly affect the appearance of the vehicle, the car enclosed, the size of the external noise and switch the effect of the door. These indicators will directly affect the user's driving experience. At present, in the vast majority of automobile plants and parts factory or the use of traditional manual measurements, such as the feeler, Cubing model and coordinate machine and other means to measure. These are measured by contact method, only after the parts are tested after the match, not only can not achieve the process of matching parts of the gap in real-time measurement, and time-consuming and laborious, the measurement of substandard products can only be abandoned The So how to use advanced vision

Detection and laser measurement technology, objectively reflect the actual state of the gap has become an important issue. In order to solve this problem, Chen Yong and others proposed the use of monocular structure of the optical system to measure, but taking into account the loss of field of view of the reasons for the amount of data, the use of multiple viewing angle and always get the sensor pose, Up to ± 0.1mm [1]. Therefore, in this measurement system, whether the complete capture of the entire contour of the gap to become the key to the measurement.

For the blind problem of measurement, Li Xinghua uses the binocular line structure to measure the size of the round bar, and the use of high-precision gauge and guide rails on the two light plane angle calibration, the average absolute error of 0.059mm[2]. Xiao Hong use the system to measure the use of

limit matching to find the feature points by calculating the parallax measurement of the brake shoe thickness, accuracy of ± 2mm, which is due to binocular feature points corresponding to the error caused by excessive[3]. Therefore, the use of binocular structure of light system, how to binocular measurement of the point cloud data is also the key to determine the accuracy of the measurement accuracy. Liu Hui use the projector to obtain the corresponding point to solve the two-point cloud between the RT matrix, and the use of ICP algorithm for further point cloud registration. Wang Hua out of the two points in the frequency domain to register, the measurement accuracy of ± 0.05mm[5].

For the gap of the body cover, this paper presents the use of binocular structure of light system for measurement, the measurement system is a difficulty is the system calibration, the traditional calibration methods require more sophisticated calibration equipment or in the acquisition[7]. Three-dimensional data after the use of point cloud registration algorithm for registration, expensive, large amount of computing, can not meet the needs of real-time computing. A point cloud registration method is proposed for this problem. It is only necessary to perform a one-step RT conversion to complete the registration, without the need of complex point cloud registration algorithm.

2. Binocular structure light measurement system

As the gap measurement and shooting angle, and monocular vision may exist blind spot[8]. The measurement system consists of two cameras, two lines of light structure, the relative position of the relationship shown in Figure 1.
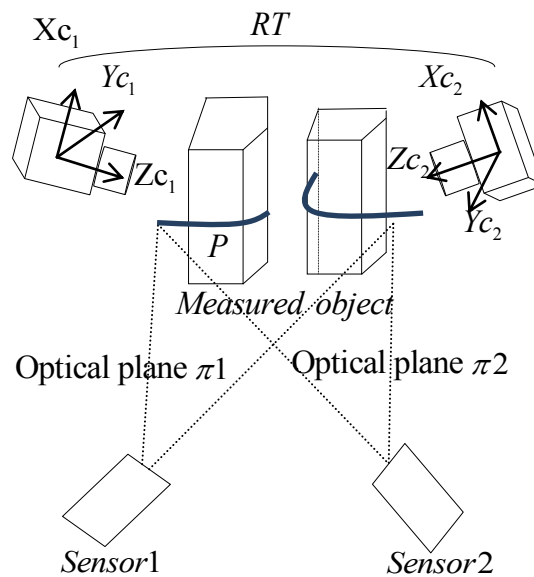
Figure 1. System structure.

After the two light beams of the laser are adjusted, the measured objects are irradiated from the left and right ends, and the camera is also connected to both ends of the measured object to facilitate the collection of the internal information of the gap of the measured object. Where the camera 1 coordinate system is, the camera 2 coordinate system is the center of the laser light point in the camera 1 coordinate system coordinates, according to the ideal aperture imaging model available

$$P_{z1} \begin{bmatrix} u_1 \\ v_1 \\ 1 \end{bmatrix} = \mathbf{A} \begin{bmatrix} P_{x1} \\ P_{y1} \\ P_{z1} \end{bmatrix}$$

(1)

Which is the parameter matrix in the camera $\begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$

(u_1, v_1) For the camera coordinates corresponding to the next point.
According to formula (1) available

$$f_x P_{x1} + (C_x - u_1)P_{z1} = 0 \tag{2}$$

$$f_y P_{y1} + (C_y - v_1)P_{z1} = 0 \tag{3}$$

$$A P_{x1} + B P_{y1} + C P_{z1} + D = 0 \tag{4}$$

Therefore, the three-dimensional coordinates of the point under the camera 1 can be obtained by the formulas (2) to (4)

$$\begin{cases} P_{x1} = \dfrac{u_1 - C_x}{f_x} P_{z1} \\[2mm] P_{y1} = \dfrac{v_1 - C_y}{f_y} P_{z1} \\[2mm] P_{z1} = \dfrac{C f_x f_y}{f_x f_y - A f_y(u_1 - C_x) - B f_x(v_1 - C_y)} \end{cases} \tag{5}$$

Because both cameras meet the theory of aperture imaging, we can obtain the three-dimensional coordinates of all the data points on the light bar in the two camera coordinate systems by acquiring the parameters of the two cameras in the light plane.
In addition, if the relative position of the two cameras and the two lasers is the same, we can transform the two camera coordinate systems by rigid body transformation

$$\begin{bmatrix} P_{x1}^{'} \\ P_{y1}^{'} \\ P_{z1}^{'} \end{bmatrix} = \mathbf{R}_b \begin{bmatrix} P_{x2} \\ P_{y2} \\ P_{z2} \end{bmatrix} + \mathbf{T}_b \tag{6}$$

Among them, for the rotation matrix and the translation matrix, you can point the camera 2 coordinates into the camera 1, the calculation.

3. Parameter calibration

First, an object plane is defined so that the rotation matrix is reduced by a column vector. According to Eqs. (1) to (5), the imaginary relationship of the image point to the spatial point

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = sM \begin{bmatrix} r_1 & r_2 & \mathbf{t} \end{bmatrix} \begin{bmatrix} P_x \\ P_y \\ 1 \end{bmatrix} \tag{7}$$

Which M is the parameter matrix in the camera, is any non-zero scale factor. Set the coherence matrix H, ie

$$H = \begin{bmatrix} h_1 & h_2 & h_3 \end{bmatrix} = sM \begin{bmatrix} r_1 & r_2 & \mathbf{t} \end{bmatrix} \tag{8}$$

By the projective matrix with the satisfaction of the orthogonal characteristics (with the dot product and the vector length equal), available

$$h_1^T B h_2 = 0 \tag{9}$$

$$h_1^T B h_1 = h_2^T B h_2 \tag{10}$$

Where $B = M^{-T} M^{-1}$ 。

(9) and (10), we can obtain the closed solution of the parameters in the camera from the matrix at that time $K \geq 3$.

$$f_x = \sqrt{\lambda / B_{11}}$$
$$f_y = \sqrt{\lambda B_{11} / \left(B_{11} B_{22} - B_{12}^2 \right)}$$
$$c_x = -B_{13} f_x^2 / \lambda$$
$$c_y = (B_{12} B_{13} - B_{11} B_{23}) / (B_{11} B_{22} - B_{12}^2)$$
$$\lambda = B_{33} - \left[B_{13}^2 + c_y \left(B_{12} B_{13} - B_{11} B_{23} \right) \right] / B_{11} \tag{11}$$

The laser strip is irradiated on a plane, assuming that the coordinates of the three points on the plane in the world coordinate system are $(0,0,0)$, $(1,0,0)$, $(0,1,0)$, then the coordinates in the camera coordinate system can be determined $P_{c1\sim3} = \mathbf{R} P_{b1\sim3} + \mathbf{t}$ from three points to determine the plane equation The Therefore, only need to know the plane relative to the camera coordinate system under the external parameters and then according to formula (2), (3) can be calculated on the laser bar point in the camera coordinate system under the three-dimensional coordinates. And then reverse the need to obtain the plane of the unilateral should be known through the internal reference to the external parameters, that is,

$$r_1 = \lambda M^{-1} h_1$$
$$r_2 = \lambda M^{-1} h_2$$
$$r_3 = r_1 \times r_2$$
$$t = \lambda M^{-1} h_3$$
$$\lambda = 1 / \left\| M^{-1} h_3 \right\| \tag{12}$$

In theory, more than two positions of the external solution to solve the plane.

Since all the points are in the light plane, it is possible to establish the coordinate system on the light plane and convert the point of the camera coordinate system to the coordinate system by using the rigid body transformation, which can effectively convert the 3D data into two-dimensional plane data, The calculation.

From the light plane available $Ax + By + Cz + D = 0$, set $lx = -\dfrac{D}{A}, ly = -\dfrac{D}{B}, lz = -\dfrac{D}{C}$

The unit vector $\mathbf{R_x}$ of the coordinate system TCP axis can be considered to be parallel to the axis of the camera coordinate system

$$\mathbf{R_x} = [0 \quad \frac{ly}{\sqrt{ly^2 + lz^2}} \quad -\frac{lz}{\sqrt{ly^2 + lz}}] \tag{13}$$

$$\mathbf{R_x} = [0 \quad \frac{ly}{\sqrt{ly^2 + lz^2}} \quad -\frac{lz}{\sqrt{ly^2 + lz}}] \tag{14}$$

The unit vector ^{TCP} of the coordinate system axis is

$$\mathbf{R_x} = \mathbf{R_y} \times \mathbf{R_z}$$

(15)

$$\mathbf{R_s} = \begin{bmatrix} \mathbf{R_x^T} & \mathbf{R_y^T} & \mathbf{R_z^T} \end{bmatrix}$$

(16)

$$\mathbf{T_s}^T = \begin{bmatrix} 0 & 0 & -\dfrac{d}{c} \end{bmatrix}$$

(17)

The auxiliary laser is used to intersect the optical plane by the auxiliary laser beam, and the camera 1 acquires the image simultaneously with the camera 2. Fig. Extract the sub-pixel center of the light bar through the matrix. Considering that the matrix will only solve the maximum eigenvalue at the intersection of the light bars, the normal direction at the intersection of the light bars can not be determined. We through the template matching method to remove the light bar part of the intersection, the image is divided into four single-line area.

$$d = \sum_{i=1}^{N} \left[y_i - (a + bx_i) \right]^2 \rightarrow \min$$

(18)

Respectively a, b, for partial alignment and solving equations can be fitted by two straight lines to solve the intersection coordinates. Finally, through (6) to solve the two camera coordinate system in the laser bar between the location of the transition relationship.

4. Size calculation

The clearance detection position on the body cover is shown in Fig. First of all, through the matrix to extract the light bar center, a reasonable choice of extraction area will greatly reduce the calculation of time[9]. So first through the image segmentation to find the location of the gap, only the light bar bending part of the convolution, the rest of the linear part of the gray-scale centroid method can be calculated. Considering that the gap internal information may be elliptical. The objective function of the polygon approximation algorithm [1] is changed to an elliptic function

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0$$

(19)

If the fitting error is less than the straight line fitting error, it is considered ellipse, that is,

$$f(A,B,C,D,E,F) = \sum_{i=1}^{m} (y(x_i) - y_i)^2 < f(k,b)$$

(20)

So you can get four inflection points $P_1 \sim P_4$, fitting two elliptical centers, the direction between the measurement direction, minus the corresponding ellipse radius is the gap measurement
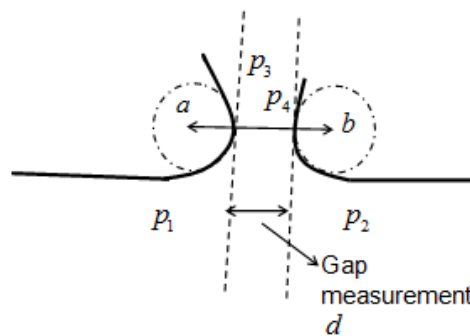
Figure 2. Gap measurement.

5. Experiment and discussion

We hope you find the information in this template useful in the preparation of your submission.

The experiment uses Basler's 1300-60gm camera with 35mm lens, and a 10mm pitch circular target. The working distance is 400mm, and the camera 1 is the global coordinate system. EXPERIMENTAL PROCEDURE 1) 6 images were taken by different orientations before placing the plane target in front of the camera. 2) The two lasers are turned on, so that the laser strip is irradiated on the target. In order to facilitate the extraction of the feature, the laser strip can not hit the circular feature point. 3) Turn off the external light source, open the auxiliary line structure light, intersect the laser, and collect the picture. Which need to collect the laser irradiation in four different locations of the target picture 4. Each position of the laser strip intersects the picture 4 sheets. Through the 10 target images to establish the camera internal parameters to optimize the calibration function

$$f(f_x, f_y, c_x, c_y, k_{1\sim2}, p_{1\sim2}, \mathbf{R}, \mathbf{T}) = \sum_{i=1}^{N} d^2\left(X_d^{'}, X_d\right)$$

(21)

Where t$^{d(X_d^{'}, X_d)}$he distance from the projection point to the actual projection point is calculated. The calculated back projection error is 0.03mm and the optical plane fitting error is 0.02mm, which can meet the measurement requirement. The measured gap measured by the experiment is 1.4 mm for the feeler measurement with an accuracy of 0.02 mm.

As the two lasers for the mechanical adjustment coincidence, and can not guarantee that the two laser light plane completely coincide. So the object will be measured before and after the move, not in the working distance, the laser pattern thicker, but does not meet the Gaussian distribution, but there are different levels of up and down as shown in Figure 3, and the laser out of the pupil of the angle there is a certain relationship , It is necessary to use the straight line segment in the image of the camera 1 to solve the point of the straight line segment in the image of the camera 2 to its average distance as the correction matrix to complete the point cloud registration as shown in Fig. 4 (c).

（a）　　　　　　　　　　　　　　　　（b）
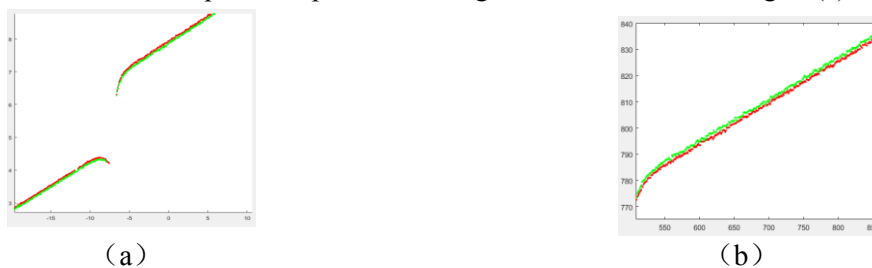
Figure 3. (a)Image coordinates before registration.　(b)Three dimensional coordinate before registration.

（a）　　　　　　　（b）

（c）
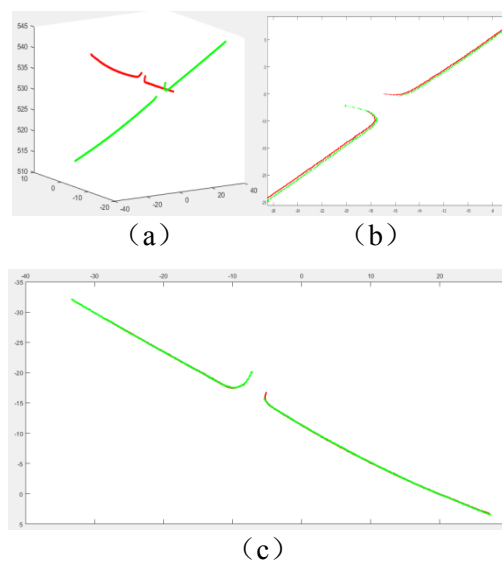
Figure 4. (a) before registration, (b) after

The square sum of the Eu-distance distance between the correction matrix in the different positions in the field of view and the corrected two-point cloud is as follows

Table 1. Use the correction matrix to correct the effect.

location	Fix the T matrix	Average distance
1	0.01，-0.16	0.36
2	0.03，-0.18	0.42
3	0.03，-0.18	0.38
4	-0.03，0.16	0.57
5	0.04，0.18	0.33
6	0.05，-0.10	0.48
7	0.09，-0.14	0.71
8	0.14，0.01	0.45
9	0.02，0.20	0.61
10	0.02，0.20	0.63

Because the gap can not guarantee a certain picture of the gap and the gap between the surface, so at different angles to capture the gap picture, as shown in Table 2. The experimental results show that the average error can be less than 0.1mm in the shooting range of 45 ° angle Table 2 measurement results from different angles.

Table 2. Measurement results from different angles.

Angel	Monocular measurement	error	Binocular measurement	error
0	1.4820	0.082	1.3686	-0.0314
5	1.5200	0.12	1.3663	-0.0337
10	1.6488	0.2488	1.3733	-0.0267
15	1.7150	0.315	1.3903	-0.0097
20	1.76191	0.36191	1.4186	0.0186
25	1.8128	0.4128	1.3714	0.0286
30	1.8790	0.479	1.3778	0.0222
35	1.7631	0.3631	1.4519	0.0519
40	1.8944	0.4944	1.4258	0.0258

45	1.9141	0.5141	1.4358	0.0358
50	2.2220	0.822	1.5323	0.1323
55	2.2750	0.875	1.5685	0.1685
60	2.3823	0.9823	1.7013	0.3013

6. Conclusion

In this paper, a binocular structured light measurement system is proposed based on the high precision and high robustness measurement of the gap of the body cover. And the principle of the system is introduced. The three-dimensional data is transformed into two dimensions by not only reducing the complexity of the calculation. The conversion relationship. And the correction method of the mechanical adjustment error due to the laser is given. Eventually completed the gap measurement. The system is measured at different angles at different angles, with a measurement accuracy of 0.1 mm within the 45 ° shooting angle and good robustness. In the future work, the construction of two lasers can spread the model, you can more accurately coordinate system 1, the other transplanted to the embedded in the production of small hand-held detection system is one of the future direction of development.

7. References

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