Study on multi-view calibration method in non-contact measurement

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Keywords: binocular calibration, multi-view calibration, coordinate system transformation，translation and rotation

Abstract. This study do binocular calibration experiments on the basis of the Z. Zhang calibration method, then unify coordinate system which can determine the position of the camera with respect to the world. The whole process use image processing software halcon to perform the multi-view calibration. It is argued that the method can rapidly, accurately achieve the calibration of eight cameras in convergence mode.

Introduction

In non-contact measurement the measurement technology using image measuring technique can overcome some problems in the traditional measuring method. It can achieve high efficiency, automation, dynamic testing requirements. Therefore, applying image measuring technique to geometric measurement is one of the important development direction of geometric measurement technology in the future.

The calibration of image measurement system is the basis and prerequisite of acquiring 3D information adopting computer vision technology and is also a key link to improve 3D measurement accuracy [4]. It is to build the corresponding points relationship between space object 3D world coordinates and the 2D image coordinates [3]. By the relationship we can recover the depth information from dealing with collected 2D images. So camera calibration is a very important step.

Because the measurement filed is large in experiments, the monocular or binocular doesn't realize measurement requirement. In order to meet the requirement, we use eight cameras. For now, binocular calibration method is mature, for example, Tsai radial alignment constraint two-step method [1], Z. Zhang plane pattern two-step method, etc. Z. Zhang calibration method [2] [5] is applied in the experiment to get two adjacent camera's position. This part of the principle is no longer described in this paper [2] [5].

Binocular vision system in convergence mode

Binocular vision system is the simulation of human vision. It generally uses the relative position of two cameras to shoot the same object. Two or more images need to be collected. By these images compute the parallax of same points in the scenecaptured in two cameras. Then use triangulation method to get the space point coordinates.

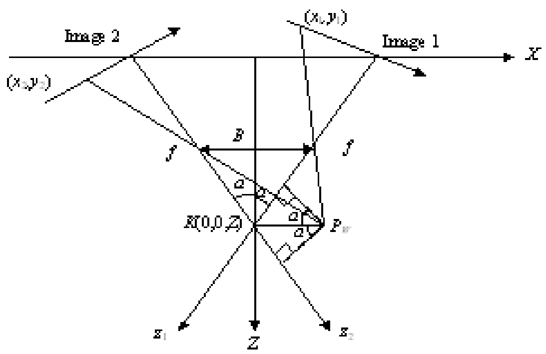

Fig. 1 Parallax figure of binocular imaging in convergence mode

In this work, optical axis of two cameras is not parallel but in a certain angle around the centers of their projection. Namely two cameras are in convergence mod, as show in Fig. 1. The baseline is located in x-z plane.

With a space point Pw corresponding to image point(x1,y1)and (x2,y2) respectively known, the optical axes of two cameras intersect at a2α angle to produce a point K or (0,0,z) in the X-Z plane. Make two perpendicular to z1 and z2 axes respectively through the point Pw, and we can know that the angles between the two perpendiculars and the X axis are both α. By use of similar triangle calculations:

$$\begin{cases} \frac{x_1}{f} = \frac{X\cos\alpha}{d - X\sin\alpha} \\ \frac{x_2}{f} = \frac{X\cos\alpha}{d + X\sin\alpha} \end{cases} \quad (1)$$

Here, d indicates the distance from the center of lens to node k, which is given by:

$$d = \frac{B}{2\sin\alpha} - f \quad (2)$$

From Eq.1 and Eq.2, we can obtain Eq.3 and Eq.4

$$x_1 r = (f\cos\alpha + x_1\sin\alpha)X \quad (3)$$

$$x_2 r = (f\cos\alpha + x_2\sin\alpha)X \quad (4)$$

And then we can obtain Eq.5

$$\frac{\cos\alpha}{\sin\alpha} = \frac{2x_1x_2}{(x_2 - x_1)f} \quad (5)$$

From the triangle formed by the camera coordinate system axis and the world coordinate system axis. Eq.6 is given

$$Z = \frac{B\cos\alpha}{2\sin\alpha} \quad (6)$$

Combining with Eq.5 and Eq.6, it follows that depth filed Z is given by

$$Z = \frac{x_1x_2B}{(x_2 - x_1)f} = -x_1x_2\frac{B}{Df} \quad (7)$$

Visibly, in the case of cameras in the convergence mode, depth information has more to do with parallax and x1.x2. By the above part of the analysis, for any point coordinates in a camera imaging plane can obtain the coordinates of the point with the aid of camera imaging model as long as there are coordinates of the matching point in the other imaging plane, and then measure the geometry size of space object, restore surface topography of the object.

Multi-view calibration

From the binocular calibration, we can get each camera’s internal parameters and relative position between two adjacent cameras.

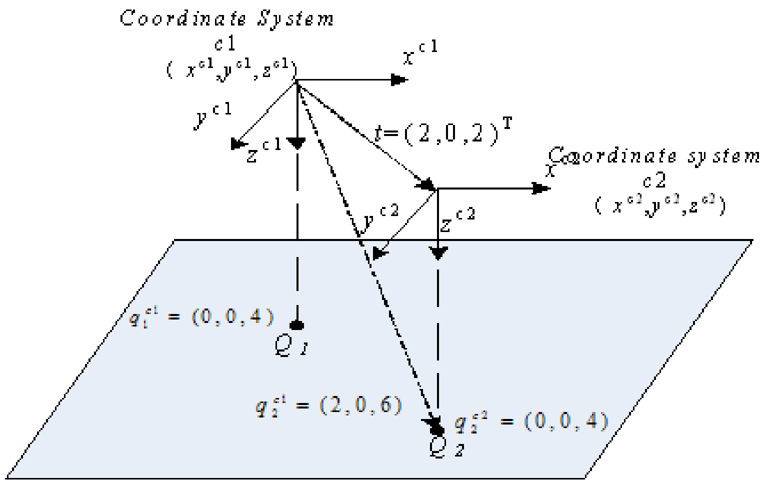

Fig. 2 the translation of coordinate system

In order to get 3D coordinate of spatial points, what we need is each camera's relationship with the world coordinate system. The key problem can be solved by the rotation and translation of the coordinate system .Fig. 2 is an instance of coordinate translation, q_2^{c1} indicates the coordinates of Q2 points in the coordinate system c1. In the same way, q_1^{c1} indicates the coordinates of Q1pointsin the coordinate system c1. This is depicted in Fig. 2. The coordinate systemc1, together with the point Q1, is translated by the vector t, resulting in the coordinate system c 2 and the point Q2.The points Q1 and Q2 have the same coordinates relative to their local coordinates system, i.e.

$$q_1^{c1} = q_2^{c2} \tag{8}$$

If coordinate systems are only translated relative to each other, coordinates can be transformed very easily between them by adding the translation vector:

$$q_2^{c1} = q_2^{c2} + t^{c1} = q_2^{c2} + o_{c2}^{c1} \tag{9}$$

In fact, this equation has been indicated vividly in Fig. 2.

It not only has the relative location relationship but also relative position relation between coordinate system and other coordinate system. If the coordinate system rotates, the position will change. Fig. 3 and Fig. 4 are instances that coordinate system c1rotate successively by y axis and z axis.

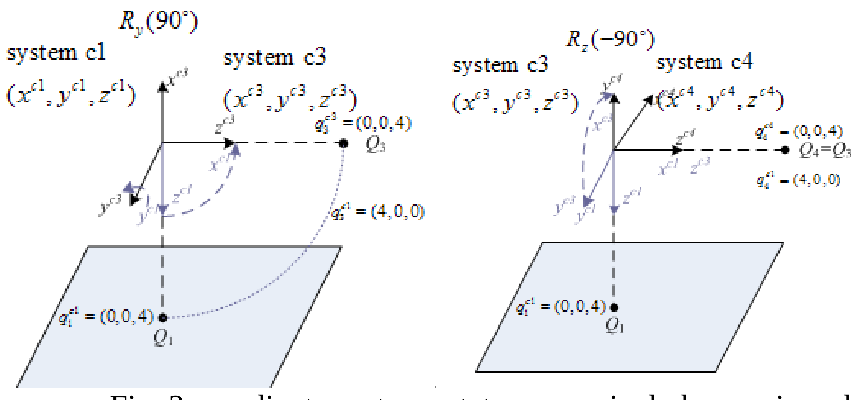

Fig. 3 coordinate system rotate successively by y axis and z axis

Just like the position of a coordinate system can be expressed directly by the translation vector, the orientation is contained in the rotation matrix. The columns of the rotation matrix correspond to the axis vectors of the rotated coordinate system in coordinates of the original one:

$$R = \begin{bmatrix} x_{c3}^{c1} & y_{c3}^{c1} & z_{c3}^{c1} \end{bmatrix} \tag{10}$$

For example, the axis vectors of the coordinate system c3 in Fig. 3 can be determined from the corresponding rotation matrix Ry (90) as shown in the following Eq:

$$R_y(90^\circ)=\begin{bmatrix}\cos(90^\circ) & 0 & \sin(90^\circ)\\ 0 & 1 & 0\\ -\sin(90^\circ) & 0 & \cos(90^\circ)\end{bmatrix}=\begin{bmatrix}0 & 0 & 1\\ 0 & 1 & 0\\ -1 & 0 & 0\end{bmatrix} \tag{11}$$

$$\Rightarrow \quad x_{c3}^{c1}=(0,0,-1) \;\; y_{c3}^{c1}=(0,1,0) \;\; z_{c3}^{c1}=(1,0,0) \tag{12}$$

Like in the case of translation, to transform point coordinates from a rotated coordinate system c3 into the original coordinate system c1, you apply the same transformation to the points that is applied to the coordinate system c3, i.e. You multiply the point coordinates with the rotation matrix used to rotate the coordinate system c1 into c3:

$$q_3^{c1} = R_{c3}^{c1} \cdot q_3^{c3} \tag{13}$$

To transform point coordinates from a rotated two times coordinate system c4 into the original coordinate system c1, you need to multiply the point coordinates with the rotation matrix used to rotate the coordinate system c1 into c4:

$$q_4^{c1} = R_{c3}^{c1} \cdot R_{c4}^{c3} \cdot q_4^{c4} = R_{c4}^{c1} \cdot q_4^{c4} \tag{14}$$

Grasping the transformation of coordinate translation and rotation, we can easily unify the camera coordinate system to world coordinate system, so that we achieve multi-view calibration work.

Experimentation and analysis

In the experiment, we selected eight industrial cameras produced by German AVT company. The camera's resolution is 2752×2200 and its model is GT2750. At the same time, we choose LM12HC prime lens produced by Japanese company KOWA and its focal length is 12.5 mm. By image acquisition software StreamPix, we got fifteen group images from different directions in the view of cameras. One group pictures are shown in Fig.4.

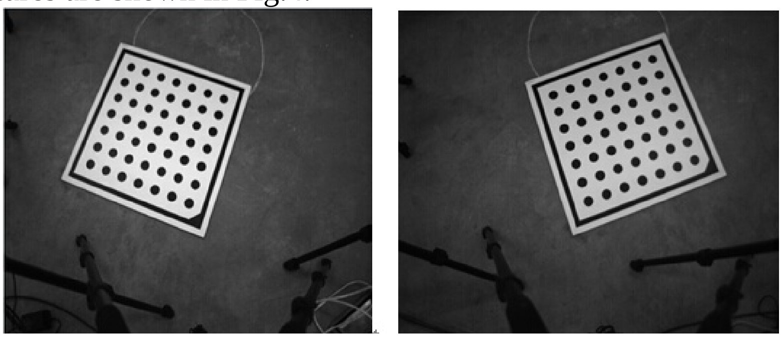

Fig. 4 image collected

According to the theory of Z. Zhang binocular calibration method, we used halcon for processing. The results are shown in Table 1 and Table 2.

Table 1 the internal experiment results of the binocular calibration

	f(m)	s_x(m)	s_y (m)	c_x (pixel)	c_y (pixel)	*k*
Theinitial value	0.0125	4.54e-006	4.54e-006	1376	1100	0
Camera 1	0.01281	4.53847e-006	4.54e-006	1378.71	1090.26	-4.59563e+6
Camera 2	0.01282	4.54022e-006	4.54e-006	1394.3	1085.27	-9.13819e+6
Camera 3	0.01282	4.53912e-006	4.54e-006	1376.62	1055.85	-2.86819e+6
Camera	0.01282	4.54054e-006	4.54e-00	1367.99	1063.31	-8.11049e+6

4			6			
Camera 5	0.01287	4.5403e-006	4.54e-006	1368.3	1103.57	-3.04711e+6
Camera 6	0.01282	4.54033e-006	4.54e-006	1349.46	1056.47	-6.41708e+6
Camera 7	0.01278	4.54127e-006	4.54e-006	1365.05	1071.67	-3.71099e+6
Camera 8	0.01283	4.54062e-006	4.54e-006	1406.2	089.21	-3.00793e+6

Table 2 relative position of the binocular calibration

relative position	Translation vector (m)			Rotation vector (m)		
1、2	-0.64571	-0.22269	0.173708	350.13	22.8962	44.8746
2、3	-0.79528	-0.23302	0.158131	355.704	23.115	38.6028
3、4	-0.58621	-0.20648	0.164599	353.574	21.6964	35.6382
4、5	-0.71697	-0.25793	0.190096	349.492	22.2737	41.2627
5、6	-0.60322	-0.18957	0.096172	357.661	20.9733	38.5994
6、7	-0.72371	-0.14519	0.13347	354.006	24.1018	35.3764
7、8	-0.74057	-0.27082	0.189398	350.484	23.4722	34.4733
8、1	-0.7191	-0.39828	0.241143	348.113	22.8389	50.4765

After the binocular calibration, we choose a group images that the calibration plate was in the center of the field, made the center of the calibration plate as the center of the world coordinate. By means of translation and rotation, we got the position relationship between eight cameras and the world coordinate. Specific parameters got are indicated in the table 6.

Table 3 eight camera positions relationship with the world coordinate

relative position	Translation vector (m)			Rotation vector ()		
Camera 1	0.276964	-0.958095	1.28948	211.291	349.353	346.607
Camera 2	-0.424074	-0.876372	1.28561	207.601	13.9452	29.5671
Camera 3	-0.94685	-0.21325	1.30395	190.276	31.4023	74.0782
Camera 4	-0.828566	0.417851	1.29421	164.352	28.7283	121.662
Camera 5	-0.215403	0.908501	1.283	150.681	7.85185	165.229
Camera 6	0.423923	0.87786	1.28967	147.482	346.895	203.245
Camera 7	0.984758	0.378911	1.28566	164.741	327.841	244.154
Camera 8	0.951595	-0.431327	1.29841	194.413	329.139	292.409

The calibration program need 150s to perform except image acquisition, so the time needed equally is 19.75s to get the relationship of camera coordinate system and world coordinate system. After we measure the distance of the adjacent camera and each camera to world coordinate system center, we know the calibration error is about 2 mm. The experimental result fully demonstrates that this multi-view calibration method is effective.

Summary

In this paper, we succeed in calibrating eight cameras but calibration precision is needed to improve. Under the condition of large measurement, more cameras may be needed to meet the requirements, therefore this calibration method can be widely used. In the next work, we will continue to improve the calibration precision and apply it to measurement.

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