Camera Calibration Based on Circular Marking Board

Xu CHEN¹, Jian-jun FANG¹ and Di CUI¹

College of Automation, Beijing Union University, No. 97, North Fourth Ring Road East, Beijing Chaoyang District.

Keywords: Machine vision, Image processing, Circular marking, Camera calibration.

Abstract. Camera calibration is one of the research hotspots in the field of computer vision. Its purpose is to determine the parameter model of the camera by single or multiple images taken by the camera, and then get the parameters of the camera. Aiming at the problem of camera calibration, a method of obtaining camera parameters by using circular marker plate is presented. After separating the background and the circular marker plate, the Canny operator is used to extract the marker plate, and the nonlinear least square ellipse fitting method is used to obtain the camera parameters. The calibration results show that the proposed calibration method is feasible and effective, it has good calibration precision and good robustness.

Introduction

Camera calibration is a key step in computer vision technology, and it is widely used in 3D reconstruction, attitude estimation and other fields. Camera calibration is based on monocular vision, binocular vision and multi-vision, and different methods correspond to different camera model. The model can be divided into two types, linear model and nonlinear model. According to the different calibration methods, can be divided into traditional calibration, self-calibration and active vision-based calibration method.

The traditional calibration used object such as a two-dimensional calibration plate and a three-dimensional calibration plate with known dimensions[1]. By establishing a correspondence between a point of a calibration object and its image point, using algorithm to obtain the camera's internal and external parameters. Tsai proposed a classical two-step calibration method in 1986, which first uses the radial uniformity constraint to solve the camera external parameters except for the translation in the direction of the optical axis of the camera, and then solve the other parameters of the camera[2,3]. Abdal-Aziz in the early 1970s proposed a direct linear transformation(DLT) of the camera calibration method, which established a linear model of the camera imaging geometry, which can be calibrated linear camera parameters[4]. Zhang of Microsoft Visual Research Institute put forward a calibration method based on checkerboard template. This method has been widely used because of its high precision[5]. However, if the target of this method is too small in the whole field of view, the calibration accuracy will be greatly reduced. Although the traditional calibration methods and calibration algorithms have been mature, and calibration accuracy is high, but their environmental adaptability is poor. The disadvantage of this method is it need to produce high-precision calibration objects, under no conditions placed calibration object situation can not be calibrated.

The self-calibration method does not require a calibration object, only used individual constraints and the scene constraints, and rely on a few images between the corresponding points to calibration[6]. In 1992, Faugeras first proposed the concept of camera self-calibration. In 1997 Hartley proposed QR decomposition method. The calibration process of the camera self-calibration method is simple and can be calibrated directly by the information in the scene and the constraints existing in the camera's own parameters without complicated and expensive camera marker points. The calibration response is fast. It is suitable for real-time online measurement system. However, this method is not high precision calibration, is not suitable for applications where accurate measurement needs.
The calibration method based on active vision is the calibration of known camera under certain motion[7,8]. It needs high precision active vision platform. The experimental condition is high and it is not suitable for the motion parameters unknown or can not control the movement of the camera.

Therefore, a calibration method of camera calibration with circular mark plate is introduced in this paper. And the above-mentioned method is different, the method used the circular marking board to achieve the camera calibration. Experiments show that this method has high accuracy, good robustness and wide application range.

**Camera Imaging Model**

Before the camera calibration, first need to understand the imaging model of the camera, the camera projects a three-dimensional scene onto the two-dimensional image plane of the camera through an imaging lens, the projections can be described by an imaging transformation, that is camera imaging model. Camera imaging model is a real camera geometric abstraction, the imaging process is the transformation photography of the spatial point, different camera imaging model corresponding to different parameters, different parameter collection also requires a different solution. At present, the more common imaging models are: linear model (hole imaging model) and nonlinear model.

**Commonly Used Coordinate System**

In order to describe the camera imaging process more intuitively, we define the world coordinate system (X, Y, Z), the camera coordinate system (x, y, z), the imaging coordinate system (u, v), the image coordinate system (r, c). The small hole imaging model shown in Fig. 1.

![Figure 1. The small hole imaging model.](image)

The point of the world coordinate system (X, Y, Z) is an arbitrary defined spatial 3D coordinate system; the camera coordinate system (x, y, z) takes the camera's optical center as the origin of coordinates, the z axis along the optical axis, and the image plane perpendicular to the image plane; imaging coordinate system (u, v) to the intersection of the optical axis and the image plane as an origin, the image principal point coordinates (u0, v0), where u and v axes are parallel to the axis of the camera coordinate system x-axis and y-axis, the coordinate system is a plane rectangular coordinate system; the image coordinate system (r, c) is the plane rectangular coordinate system on the image, and the lower left corner of the image is the origin.

**The Transformation Relationship of The Camera Coordinate System**

The ideal small hole imaging model is a linear model, as shown in Fig 1. Let Pw(Xw, Yw, Zw) be a point in space, the intersection between Pw and the optical center and the image plane intersect P'(x', y'), the spatial point Pw to the corresponding imaging point, for the following transformations:

1. The point Pw(Xw, Yw, Zw) is converted to a point Pc(xc, yc, zc) in the camera coordinate system, the transformation can be seen as being done by rotation and translation operations, the specific formula is PcT=RPwT+TT, among R(a, b, c) is a rotation matrix, T(t1, t2, t3) is the translation vector. The six parameters (a, b, c, t1, t2, t3) in R and T are called external parameter, which determine the positional relationship between the camera coordinate system and the world coordinate system.
(2) The point $P_c(xc, yc, zc)$ is transformed to the point $P'(x', y')$ in the image coordinate system, which is transformed into a perspective projection relationship. The relation is $x'= y*xc/zc; y' = f*yc/zc$, where 'f' is the focal length of the camera.

(3) Transforms $P'(x', y')$ into a point $Pn(u, v)$ in the imaging coordinate system, the formula is $u-u0 = x'/dx = sy*x'$; $v-v0 = y'/dy = sy*y'$, among $(u0, v0)$ is the image principal point coordinate, $dx, dy$ is the physical size in the $x$- and $y$-axis directions.

(4) After several times between the coordinate system transformation, the resulting relationship between $Pm$ and $Pn$ is Eq.1:

$$
\begin{bmatrix}
    u \\
    v \\
    1
\end{bmatrix}
= \begin{bmatrix}
    f_x & s & u_0 \\
    0 & f_y & v_0 \\
    0 & 0 & 1
\end{bmatrix}
[ R \ T]
\begin{bmatrix}
    X_{wv} \\
    Y_{wv} \\
    Z_{wv}
\end{bmatrix}
= N_1 N_2 X_{wv} = N X_{wv}
$$

Among them, $fx = f*sx, fy = f*sy$, $N$ is $3*4$ matrix, called the projection matrix. $N1$ is entirely determined by $fx, fy, u0, v0$, since they are only related to the internal mechanism of the camera, it is called the internal parameters of the camera. At this point, the camera's internal and external parameters have been introduced.

**Camera Imaging Model**

**Camera Calibration Based on Circular Marking Board**

The principle described in the previous section is the basis of camera calibration. It need to know the coordinates of enough 3D space points in the world coordinate system, and then project the points in the space to the image coordinate system, and establish algebraic relations. Therefore, the camera calibration process is divided into points to obtain the coordinates of space; to determine the correspondence between the coordinate points.

**Circular Marking Board**

In this paper, circular mark plate as the camera calibration target, as shown in Fig. 2.

![Circular marking board](image)

Figure 2. Circular marking board.

The circular plate around the selection of a black rectangular frame, making the logo plate is more easily extracted, the direction marks of the corners of the rectangular borders make the orientation of the calibration plate unique to the rectangular corner. There are 49 solid circles in $7*7$ solid circle, and 49 sets of world coordinate points are obtained by extracting the coordinates of the center point of the solid circle, so as to achieve the goal of camera calibration.

**Feature Extraction**

Firstly, the circular marker region is separated from the background region by using the threshold segmentation method.

Image segmentation is the basic problem in image processing. Threshold-based segmentation is the most basic problem of image segmentation, and its difficulty lies in the selection of threshold. It is proved that the choice of the threshold value is the decisive factor for the segmentation effect. Because threshold selection is the basis of image segmentation, multi-threshold segmentation can further improve the quality of image segmentation, but it is only the processing problem of
segmentation techniques, and there is no essential difference with single threshold segmentation. As shown in Fig. 3, after the threshold interval is determined, the threshold region is segmented to extract the circular marker region, and the red region is the region where the threshold value is located. It can be seen in Fig. 3 above the threshold area for the circular logo version of the area, the following figure shows the background area.

![Threshold region after the division.](image)

Canny edge detection operator is John F. Canny in 1986 developed a multi-level edge detection algorithm. In general, the purpose of edge detection is to reduce the data size of the image significantly, while preserving the original image attributes. Although there are many algorithms for edge detection, although Canny algorithm is old, but it can be said that it is a standard edge detection algorithm, and is still widely used in the study. In this paper, Canny filter is used to extract the edge of the marker plate. As shown in Fig. 4, the edge of the marker plate is detected, and the effect is good.

![Detect the edge.](image)

Finally, the least square ellipse fitting method is used to obtain the ellipse boundary, and then determine the center point.

**Feature Extraction**

In this paper, the Halcon platform based on the circular marking board camera calibration, the calibration required to capture images, the number of image acquisitions is related to the calibration accuracy.

In the use of halcon platform camera calibration required to make a circular marking board, the logo board used in this paper size (24*24)mm. In order to make the calibration result more accurate, we need to ensure the condition of the light source unchanged, and the exposure plate should be made in the same way.

Calibration algorithm flow:

1. Acquire the image, use the camera to collect at least 10 images from different directions to cover the four corners of the camera, because the four corners of the camera are prone to distortion, which will affect the accuracy of the calibration results.

2. Then, the image is separated from the background by the threshold segmentation algorithm, and the edge of the marker plate is found by Canny operator, and the region of the marker plate is determined.

3. By using the least square method of ellipse fitting, the ellipse boundary is obtained, and then the center point is determined, and the coordinates of 49 circular center points in each sub-image are obtained.

4. According to the coordinate transformation relations, the obtained coordinate points are brought into, and finally the calibration results are obtained.
Fig. 5 is the process of marking the plate in the process of different states. Fig. 5 (a) for the separation of signs and the background; (b) to obtain the edge profile of the sign board; (c) to determine the circular center point and obtain the center point coordinates; (d) is to mark the center point of the plate as the origin, the establishment of coordinate system. Among them, the Z-axis vertical signs, the direction towards the camera.

**Experimental Results Analysis**

According to the above principle and calibration steps, in the Halcon platform to do camera calibration experiment. A total of two sets of landmark images were collected, each with 15 images. The calibration results obtained are shown in Tab. 1:

<table>
<thead>
<tr>
<th>Parameter No.</th>
<th>f_x</th>
<th>f_y</th>
<th>s_x</th>
<th>s_y</th>
<th>u_0</th>
<th>v_0</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1</td>
<td>518.1971</td>
<td>519.5716</td>
<td>7.4196</td>
<td>7.4</td>
<td>309.26</td>
<td>235.301</td>
<td>-57.9974</td>
<td>-6.02093</td>
<td>619.493</td>
<td>-27405.2</td>
</tr>
<tr>
<td>No.2</td>
<td>510.5150</td>
<td>511.7554</td>
<td>7.41798</td>
<td>7.4</td>
<td>321.46</td>
<td>244.976</td>
<td>54.0286</td>
<td>-18.1617</td>
<td>608.032</td>
<td>-26641.7</td>
</tr>
</tbody>
</table>

Among, f_x, f_y are respectively the focal length in the x direction and the y direction, units are pixels; s_x, s_y are the cell distances in the x direction and the y direction, units are mm; u_0, v_0 as the main point coordinates, units are pixels; X, Y, Z is the relative distance between the camera and the image coordinate system, units are mm.

1) Analysis of the results: the formula \( f = \frac{(f_x dx + f_y dy)}{2*10^3} \) to verify the correctness of the results. For the first collection of images, \( f_1 = 3.84483 \text{mm} \) obtained by the above formula; \( f_2 = 3.78699 \text{mm} \) from the second collection of images. The actual focal length of the camera is 3.8 mm. By comparison, the calibration results are accurate.

2) Under normal circumstances the camera lens distortion exists. Fig. 6 shows the three kinds of distortion. The calibration results obtained in this paper, \( k < 0 \), so the distortion in Fig. 6(c), for the barrel distortion.

![Figure 6. Three kinds of distortion.](image)

In this paper, the camera calibration algorithm, the follow-up will be used to the library robot vision system for the manipulator on the book operation. The parameters obtained can be used to correct the distortion of the image, but also through the correction of the effectiveness of camera calibration verification accuracy.
Figure 7. Distortion correction effect.

From Fig. 7, we can see that there is obvious barrel distortion in the left image book spine. By correcting the parameters obtained by camera calibration, we can get the right image, we can see that the correction effect is obvious. But also from the side to prove the accuracy of calibration results.

Conclusions

From the experimental results, it can be seen that the camera calibration method based on the circular marker plate has successfully obtained the parameters of the camera, and compared with the actual results of the camera to achieve a good accuracy. At the same time, in the verification of the camera calibration results, by correcting the distorted book images obtained, it can be seen that the correction effect is good. At the same time, the algorithm is implemented on Halcon platform, which has good portability and wide adaptability.

Acknowledgement

This work has been supported by Great Wall Scholar Program Project (CIT&TD20150314) and he National Natural Science Foundation of China (4142018). Furthermore, the authors also would like to thank all who have helped to make this study.

References