International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 3 Issue 8 ǁ August. 2015 ǁ PP.08-17

The Technology Research of Camera Calibration Based On LabVIEW

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ABSTRACT: The technology of camera calibration is most important part for machine vision detection and location, the accuracy of calibration directly determines the processing accuracy of machine vision systems. In this paper, we use LabVIEW and MATLAB to calibrate the internal and external parameters of the camera, at the same time, we use dot calibration board, the circle edge is detected by Canny operator, then with the method of circle fitting based on subpixel edge extraction, the information of dots image coordinate is extracted. The present method reduces the difficulty of camera calibration and shortens the software development cycle, the most important is that it has a high calibration accuracy, which can meet the actual industrial detection accuracy, the results of experimental show that the method is feasible.

Keywords- camera calibration, machine vision, LabVIEW, MATLAB, Canny

I. INTRODUCTION

Machine vision is to use the computer and the visual sensor to replace the human eye to do the measurement and judgment [1], the technology of machine vision is more and more widely used in the field of industrial inspection, automotive manufacturing and medical image analysis, because of its flexible, rapid and non-contact characteristics, which can improve the intelligence of the industrial field.

Camera calibration is the most important part of machine vision applications, its purpose is through obtain the information of the acquisition of the two-dimensional image to get the information of the three-dimensional coordinates[2]. The camera calibration technology has been quite mature both at home and abroad, which can be divided into two categories: traditional calibration techniques and self-calibration techniques [3]. The disadvantages of the traditional calibration method are not flexible enough, the self-calibration of the camera can only be achieved by using the camera's corresponding relationship between the image and the image in the moving process, which does not depend on the reference object, the calibration accuracy and robustness of self-calibration method are poor compared to traditional calibration methods.

The calibration method of Zhang Zhengyou is a kind of method between the traditional calibration and self-calibration, its technique is flexible, at the same time, and the calibration accuracy is high, which is a common method used in camera calibration. In this paper, we achieve the camera calibration with the help of Zhang Zhengyou calibration method, LabVIEW and MATLAB tools.

II. LabVIEW Development Platform

LabVIEW is a graphical programming language (G language) introduced by NI, it can be able to provide a graphics programming, which is simple, intuitive and easy to users, what's more , it can save more than 85% of the program development time, compared with the traditional programming language, while the running speed is almost unaffected, which makes high efficiency. At the same time, it provides a wide range of interfaces and has great flexibility, which can be called with a variety of software such as DLL, Visual Basic and MATLAB.

LabVIEW Vision IMAQ provides a good platform for the development of machine vision, it contains various function library of image processing functions and integrates more than 400 functions for image display, processing, analysis, and other operations, which provides a complete development for the visual system [4-5], it can further shorten the development cycle of the visual system combined with the use of LabVIEW, which is widely accepted by industry, academia and research laboratories.

III. Mathematical Model of Camera Imaging

In the process of image acquisition of CCD camera, the geometrical position of the space is determined by the model of camera imaging. At present, the most of camera imaging model is based on the principle of pinhole imaging. This article is based on the pinhole model, considering the radial lens distortion to establish the model of imaging camera.

3.1 Pinhole linear model of camera

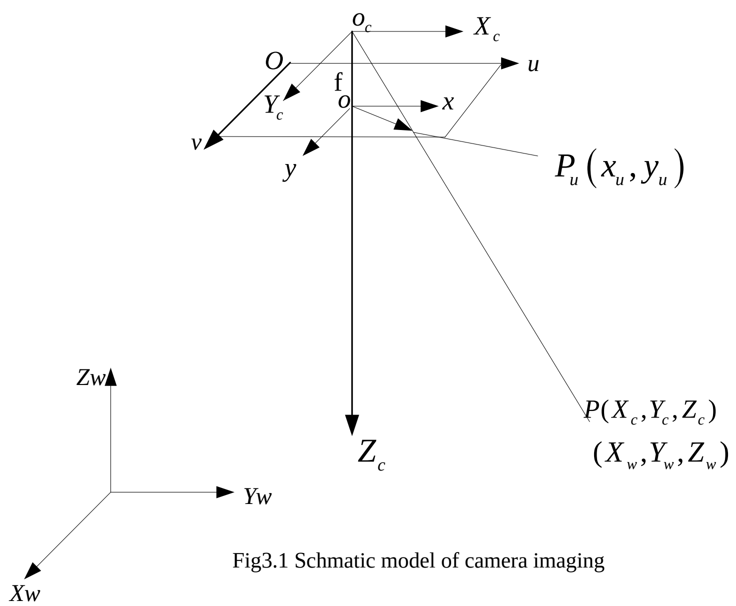

Fig3.1 Schmatic model of camera imaging

(1) Image coordinate system (u,v)

The image which is captured by CCD camera is stored in the computer with the form of an array. After the CCD camera acquisition of the image is stored in the form of an array of computer. Among those, (u,v) is the image coordinate system unit of pixels, while the actual application needs to be converted it into a physical unit of mm in the image coordinate system (x, y) , The relationship between the two coordinate systems is shown in figure 3.2:

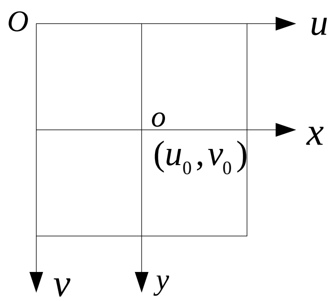

Fig. 3.2 Iamge coordinate system

The origin of o is defined in the intersection of the optical axis of the camera and the imaging plane, which is generally located in the center of the image. If the o's coordinates is (u_0, v_0), which is in the coordinate system (u,v), the physical size of each pixel in the x-axis and y-axis direction is dx, dy, then the any point in the two coordinates (x, y) and (u,v) have the following relations, as equation(3-1):

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{dx} & 0 & u_0 \\ 0 & \frac{1}{dy} & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \qquad (3-1)$$

(2)Camera coordinate system (X_c, Y_c, Z_c)

Select the optical center o_c of CCD camera lens as the origin of the camera coordinate system, the axis of X_c and Y_c is parallel to the axis of x and y, which is the image physical coordinate system, Z_c is the direction of camera's optical axis, and the intersection of the imaging plane is $o(u_0, v_0)$. The distance of $o_c o$ is the effective focal length of the camera, which is f, according to pinhole imaging model, the position of the spatial points on the image can be expressed as equation(3-2):

$$\begin{cases} x = \frac{fXc}{Zc} \\ y = \frac{fYc}{Zc} \end{cases} \qquad (3-2)$$

Written the 2-2 in the type of matrix form is as follow equation(3-3):

$$Zc\begin{pmatrix} x \\ y \\ 1 \end{pmatrix} = \begin{pmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} Xc \\ Yc \\ Zc \\ 1 \end{pmatrix} \qquad (3-3)$$

According to the equation of 3-1and 3-3, we can establish the relationship between the image coordinate system and the camera coordinate system, as shown in follow equation3-4:

$$Zc\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{dx} & 0 & u_0 \\ 0 & \frac{1}{dy} & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} Xc \\ Yc \\ Zc \end{bmatrix} = \begin{bmatrix} f_x & 0 & u_0 & 0 \\ 0 & f_y & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} Xc \\ Yc \\ Zc \end{bmatrix} = M_1 \begin{bmatrix} Xc \\ Yc \\ Zc \end{bmatrix} \qquad (3-4)$$

Among them, M_1 is the matrix of 3×4, which is the internal parameter matrix of camera. By collecting at least three images of calibration, we can obtain the inner parameter matrix of M_1, according to the establish equation of 3-4.

(3) World coordinate system (X_w, Y_w, Z_w)

The world coordinate system can be set at any position, which is to describe the position of the camera. The position relationship between the world coordinate system and the camera coordinate system can be determined by the rotation matrix of R and translation vector of T, the coordinates of space point P in world coordinate system and camera coordinate system are respectively (X_w, Y_w, Z_w) and (X_c, Y_c, Z_c) . Can be expressed as a matrix:

$$\begin{pmatrix} Xc \\ Yc \\ Zc \\ 1 \end{pmatrix} = \begin{pmatrix} R & t \\ 0 & 1 \end{pmatrix} \begin{pmatrix} Xw \\ Yw \\ Zw \\ 1 \end{pmatrix} = M_2 \begin{pmatrix} Xw \\ Yw \\ Zw \\ 1 \end{pmatrix} \quad (3-5)$$

Among them, R is an orthogonal unit matrix of 3 ×3, which is called rotation matrix, t is a column vector of 3×1, which is to express the translation between the two coordinates system, M_2 is matrix of 4×4, which is the external parameter matrix of camera, and it is related to the position of the camera in the world coordinate system. According to the equation of 3-3, 3-4 and 3-5, we can get the relationship between the image coordinate system and the world coordinate system, which is shown in the following formula 3-6:

$$Zc \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{dx} & 0 & u_0 \\ 0 & \frac{1}{dy} & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} R & t \\ 0 & 1 \end{bmatrix} \begin{bmatrix} Xw \\ Yw \\ Zw \\ 1 \end{bmatrix} = M_1 M_2 \begin{bmatrix} Xw \\ Yw \\ Zw \\ 1 \end{bmatrix} = H \begin{bmatrix} Xw \\ Yw \\ Zw \\ 1 \end{bmatrix} \quad (3-6)$$

Among them, H is a single stress matrix, which describes the position of the spatial points and the image plane, by means of a sufficient number of known points of the world coordinates and the corresponding image coordinates, according to the 3-6 formula, we can solve the single stress matrix of H, then in the case of Hand the internal parameter matrix of M_1 defined, we can get the external parameter matrix of M_2 ,from the above process, we can complete the linear model of the camera calibration.

3.2 Nonlinear model of camera

Since there will be some errors in the process of manufacturing and assembly of the camera lens, so in the practical applications, we should take the camera lens distortion into account. There are three types of lens distortion, which are radial distortion, eccentric distortion and thin prism distortion [6-7]. The practice shows that the radial distortion has the most influence on the imaging model of the camera, so sometimes, we only consider the radial distortion, if we consider too much distortion, it will increase the number of nonlinear parameters, which will lead to instability in solving results. In this paper, in the condition of the radial distortion, we establish the nonlinear model of the camera, the radial distortion equation of Zhang zhenyou is shown as follows:

$$\begin{bmatrix} x_d \\ y_d \end{bmatrix} = (1 + k_1\sigma^2 + k_2\sigma^4) \begin{bmatrix} x_u \\ y_u \end{bmatrix} \quad (3-7)$$

(x_d, y_d) is the coordinates of ideal imaging points, (x_u, y_u) is the actual imaging points of the coordinates, which is considered as the distortion, among them, $\sigma^2 = x_u^{\ 2} + y_u^{\ 2}$. Finally, we use the nonlinear least squares algorithm to solve the camera's parameters matrix of internal and external and distortion factor, take these parameters as the results of the camera calibration.

IV. Calibration Process

The calibration of the camera internal parameters is accomplished by using the Vision module of LabVIEW. After installing the Vision module of Development Module 2012 and NI Vision Builder for Automated Inspection 2012, it has added the independent calibration module of Calibration Training, which makes the calibration work more convenient and efficient[8]. The calibration process can be divided into three steps, the first is to study the template, followed by the calibration, and the last is to read and store the calibration information. There are two kinds of calibration template, the one is the board square, and another one is the circular calibration target,

The extraction algorithm of the center of circle's stability and positioning accuracy is superior to the checkerboard calibration plate extraction of corner, so in this paper, we use calibration template of 6 x 8 dot array, as shown in figure 4.1

Fig.4.1 6×8 dot array calibration board

Sticking the dot array to a smooth surface calibration board, the distance of center between the two adjacent dots of horizontal spacing and vertical spacing respectively is 24mm.Calibration algorithm flow is shown in Figure4.2.

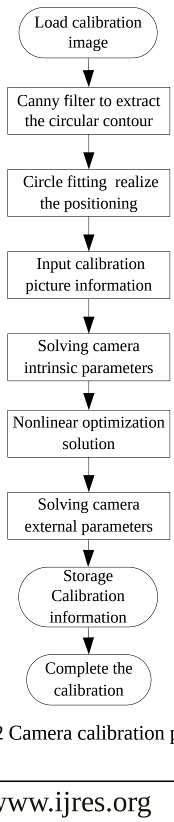

Fig. 4.2 Camera calibration process

4.1 Camera Internal Parameters Calibration Process

(1) In order to correct the error caused by the camera's nonlinear distortion and obtain the internal parameters of the camera, in this paper, we select the type of camera calibration, the Molel Camera (Grid) type.

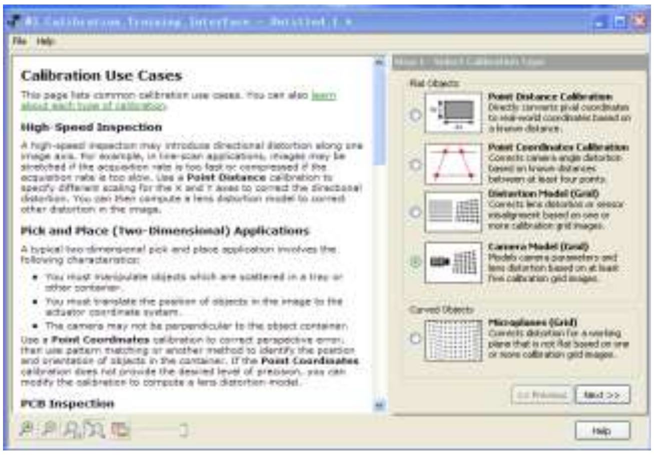

Fig.4.3 The First Step of Camera Calibration

(2) To load the pictures of the calibration plate .In this paper, we load the 8 calibration pictures, which are taken from the different angles of the camera.

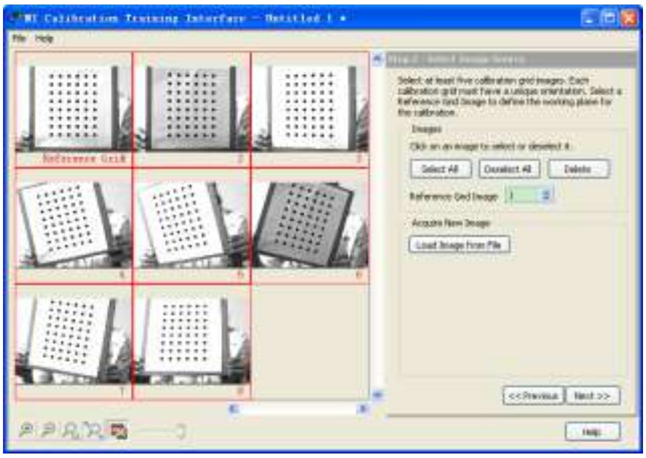

Fig.4.4 The Second Step of Camera Calibration

(3) To use Canny filter to extract the circular edge of the contour.

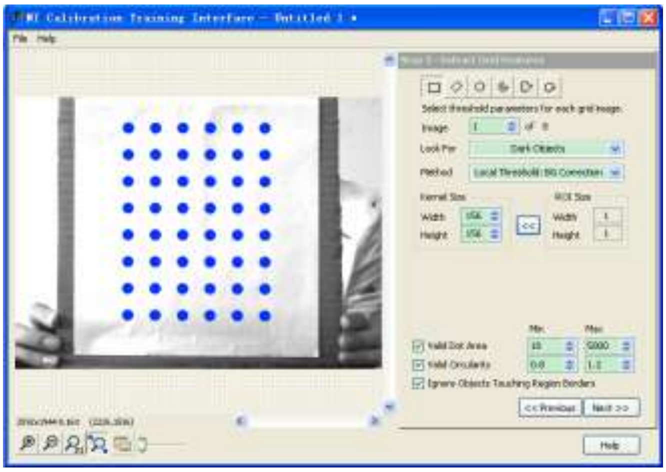

Fig.4.5 The Third Step of Camera Calibration

(4) To input the horizontal and vertical distance of the two adjacent center of the calibration board and measurement unit.

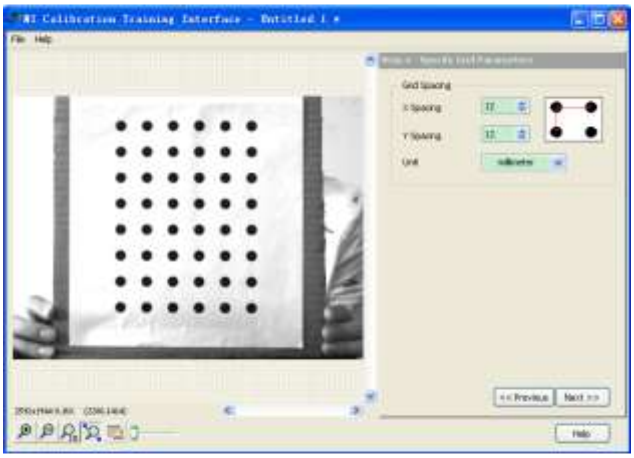

Fig4.6 The Forth Step of Camera Calibration

(5) To extract feature point coordinates by using circle fitting method, calculate the internal parameters of the camera and the camera calibration error.

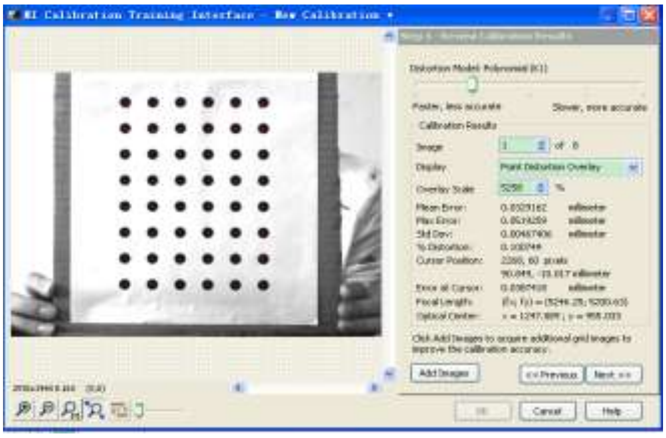

Fig4.7 The Fifth Step of Camera Calibration

(6)We establish a coordinate system to calibrate the pictures, which facilitates the transformation of coordinate next step.

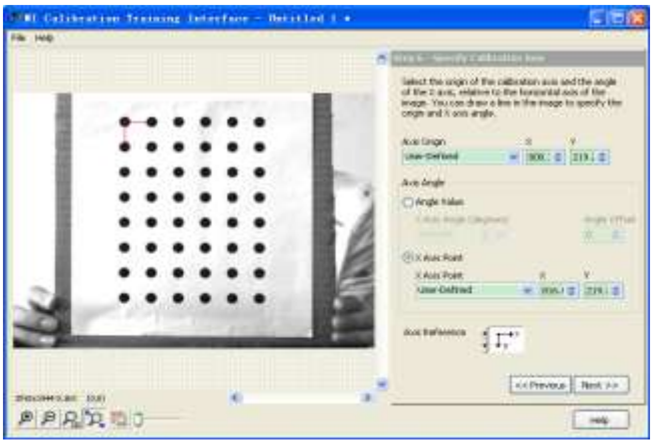

Fig4.8 The Sixth Step of Camera Calibration

(7)Calibration template learning, the calibration of the picture is saved to the PNG file format, which is easy to read and call the calibration template. As long as the relative position of the camera and the working plane is constant, it is not to be repeated. The internal parameters of the camera can be solved by the above calibration procedure:

$$M_1 = \begin{bmatrix} 5246.25 & 0 & 1247.889 \\ 0 & 5200.63 & 955.033 \\ 0 & 0 & 1 \end{bmatrix}$$

The physical size of the camera pixel is 0.0022mm * 0.0022mm, and we can get the effective focal length of the camera according to the internal parameter matrix which has been already obtained.

$$f = (5246.25 \times 0.0022 + 5200.63 \times 0.0022) \div 2 = 11.492$$

4.2 Camera external parameters calibration process

The camera external parameters calibration can be achieved by the MATLAB script node provided by LabVIEW, which can improve the processing speed. Complete the internal parameters of the camera calibration process, then we call calibration pictures, read the calibration dots coordinate information and serve the image coordinates (u, v) and the world coordinate (x, y) as the MATLAB script input and external parameter matrix as the output, and the program flow chart is shown in Figure4.9:

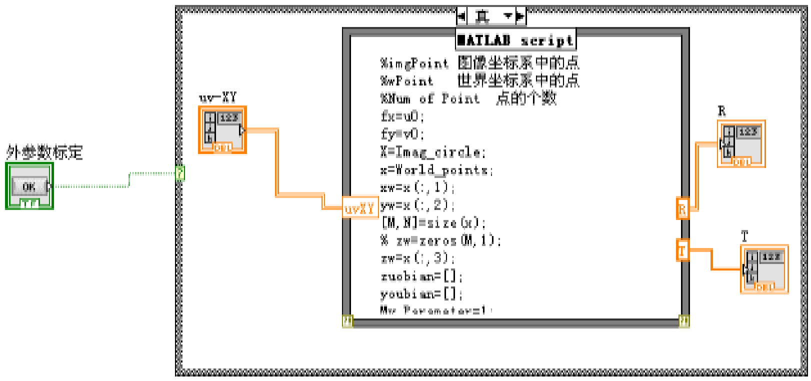

Fig.4.9 The solution Process of External Camera Parameter Matrix

Because the external camera parameter matrix is related to the position where camera is located in world coordinates, so 8 different angle calibration images have different parameter matrix, it means that we should determine it according to the specific circumstances.

V. The Experiment Result Analysis

After calibration, we can see calibration information. The table 5-1 is calibration of 6×8 dot array calibration parameters.

Table 5-1 The dot array calibration parameters (the average error is 0.0329 mm, the distortion is 0.1007%)

Object	Radius (pixels)	Radius (mm)	Center u (pixels)	Center v (pixels)	Center X (mm)	Center Y (mm)
1	38.62	4.8177	797.42	1175.7	0	120.0399
2	38.84	4.8418	990.58	1176.5	23.9907	120.0275
3	38.34	4.7912	798.83	792.49	-0.01	72.0019
4	38.71	4.829	991.32	984.38	24.0056	95.9729
5	38.55	4.8233	800.48	410.68	0.0305	24.05
6	38.95	4.8505	1184.25	1177.6	48.0221	120.0518

7	38.73	4.8292	1378.9	602.52	71.9943	47.9524
8	38.59	4.8025	1766.64	412.68	119.9734	24.0654
9	38.73	4.8364	1186.28	410.64	48.026	23.9388
10	38.63	4.8052	989.65	1559.67	24.0346	167.9068
11	38.65	4.8294	992.59	601.57	24.0156	47.9643
12	39.01	4.8521	1377.62	1178.48	71.9842	120.0471
13	38.74	4.8276	1572.51	412.01	95.9459	24.0206
14	38.82	4.8229	1571.61	1179.27	95.9874	120.029
15	38.86	4.8515	991.83	792.9	23.9934	71.9709
16	38.83	4.838	1378.7	794.09	72.02	71.9566
17	38.67	4.8129	1572.42	794.85	96.0157	71.9721
18	38.88	4.8599	993.46	410.88	24.0526	24.0195
19	38.43	4.798	798.22	983.74	0.003	95.9902
20	38.81	4.8224	1377.14	1370.58	71.9732	144.0363
21	38.77	4.8325	1185.01	985.04	48.0531	95.9574
22	38.78	4.8126	1766.32	1180.25	120.0372	120.0334
23	38.47	4.7896	1766.49	221.62	119.9199	0.131
24	38.54	4.8237	801.31	219.82	0.0563	0.0557
25	38.72	4.8207	1378.15	985.85	72.0009	95.9609
26	38.7	4.798	1570.65	1563.54	95.9297	167.943
27	38.48	4.7859	1766.89	604.04	120.0364	48.023
28	38.61	4.7856	1766.01	1372.57	120.0152	144.0104
29	38.32	4.7911	799.53	601.37	-0.01	48.0083
30	38.78	4.8133	1571.21	1371.5	95.9696	144.016
31	38.81	4.8437	1185.84	601.63	48.0321	47.9051
32	38.65	4.8241	1379.45	219.41	71.9581	-0.1
33	38.61	4.8288	994.01	219.92	24.0514	0.0264
34	38.55	4.7919	1766.83	795.67	120.0562	71.9947
35	38.56	4.7953	1572.08	986.61	96.0103	95.9581
36	38.57	4.8017	796.54	1558.18	0.0765	167.8593
37	38.77	4.8233	1183.79	1369.47	48.0282	144.0292
38	38.7	4.8195	990.09	1368.24	24.0084	144.0041
39	38.87	4.8499	1379.13	411.08	71.9719	23.9463
40	38.56	4.774	1765.47	1564.76	119.9616	167.9368
41	38.46	4.7928	796.96	1367.12	0.0324	143.9901
42	38.83	4.8196	1376.55	1562.34	71.9464	167.946
43	38.5	4.7818	1766.78	987.34	120.0743	95.9494
44	38.48	4.8085	1187.12	219.7	48.0689	-0.04
45	38.55	4.8005	1572.55	603.23	95.9929	47.98
46	38.46	4.7946	1572.5	221.11	95.9021	0.0861
47	38.87	4.848	1185.39	793.47	48.0391	71.9594
48	38.73	4.8126	1183.19	1561.09	48.0177	167.9397

In metrology, the accuracy of the measured value is evaluated by using standard deviation. In the paper, we use standard deviation to evaluate the calibration accuracy of the camera, which is shown by equation 5-1:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2} \qquad (5-1)$$

Among these, x_i is measurement value, $\overline{x}$ is the average value of a group of data, according to the above measured dot array data information, let's take the radius of the circle measured for an example, we can calculate the value of a radius of standard difference, which unit in pixel is $\sigma_{pixel} = 0.1563$ and unit in mm is $\sigma_{mm} = 0.0215$, through the results of the calculation, we can see the camera calibration with high precision, which can meet the requirements of the practical industrial measurement accuracy.

VI. CONCLUSION

In the paper, the calibration is based on the Zhang Zhengyou calibration method. First of all, we establish the camera calibration model, then we use the method combining LabVIEW and MATLAB to complete the intrinsic and extrinsic parameters of the camera calibration, the calibration method is fast and convenient, which shortens the period of software development and improves the data processing ability, at the same time, it reduces the camera calibration difficulty. The experimental results show that the calibration accuracy of the calibration method is 0.0215mm, the average physical error is 0.0329mm, which meets the requirements of the actual industrial measurement.

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