A Camera Calibration Technique Based on OpenCV

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***Abstract*—Camera calibration is very improtant in 3D computer vision systems. In this paper, the camera model in OpenCV (open source computer vision library) is discussed, the non-linear distortion of the tangential and radial distortion aberration are considered. Based on these, we introduce the corner extraction of the Camera Calibration Toolbox for Matlab, and an arithmetic of camera calibration based on OpenCV is given. The proposed algorithm can achieve accurate results. It has features such as computational efficiency and good cross-platform portability. It is able to meet the needs of 3D computer vision systems. Experimental results show the feasibility of the proposed method.**

Keywords-camera calibration; OpenCV; computer vision; lens distortion

I. INTRODUCTION

The design goal of three-dimensional computer vision system is to obtain image information from the camera, and calculate the location, shape information of three-dimensional objects, and thus to identify objects in the space. Each point's brightness of image represents the intensity of reflected light of a space object's surface point, and the geometric location of this point in the image correlates with the geometric location of space object's surface corresponding point. The geometric model for camera imaging determines the relationship between these locations. The geometric parameters of the model are known as the camera parameters, these parameters must be determined by experiment and calculation, the process of experiment and calculation is known as camera calibration [1]. Camera calibration is very important in computer vision research. An integrated computer vision system can generally be classified into 6 parts [2], including image acquisition, camera calibration, feature extraction, stereo matching, depth determination, and interpolation. Accurate internal and external camera calibration parameters can not only directly improve the measurement accuracy, but also lay a good foundation for the subsequent stereo image matching and three-dimensional reconstruction [3, 4].

By now, there are many camera calibration methods, such as calibration method based on the three-dimensional calibration reference proposed by Tsai[5], in which calibration of reference object is generally made up of the two planar template which are perpendicular each other, three-dimensional space coordinate of the reference object surface's calibration point need to be known before calibration, so this method needs a expensive accuracy calibration system. Zhengyou Zhang puts forward a calibration method [6] based on two-dimensional template, Zhang's calibration method only requires shooting the same calibration template for more than two images from different angles, and it can obtain the internal and external camera parameters, this method does not need to know the specific position and displacement information of planar template movement, and the planar template is easy to make, so this method is simpler and easier than other methods [7].

This project is supported by the National Natural Science Foundation of china under grant 60873020, and supported by Zhejiang provincial Natural Science Foundation of china under grants Z1080702

OpenCV (Intel® open source computer vision library) is open computer vision library which is developed by Intel®, it consists of a series of C functions and a small amount of C++ classes, and realizes many general algorithm about image processing and computer vision, and has a powerful ability to image and matrix operations. This library uses Zhang's calibration method in camera calibration. The camera calibration module of OpenCV provides a good interface for user, and supports for Windows, Linux platform, improving the development efficiency, the execution speed of the module is fast, and it has good cross-platform portability and can be applied to engineering.

II. CALIBRATION PRINCIPLE

A. *Camera model*

The choice of camera model directly influences the final calibration results, so it is very important to select the appropriate camera model and make sure internal and external parameters: Internal parameters give a description of the internal optical and geometry characteristics of camera, such as the image center, focal length, lens distortion, etc; External parameters are three-dimensional position and orientation of camera coordinates system compared with the world coordinates system. Commonly used pinhole mode[1,8] which ignores the lens thickness and distortion, it can not be good to reflect the actual situation. The camera model of calibration algorithm in OpenCV is based on pinhole model, and introduces the radial lens distortion and tangential distortion, it more truly reflects the actual distortion of the lens case compared with pinhole model and Tsai's model that only introduces first order radial distortion.

Suppose P_w (X_w, Y_w, Z_w) is a point of world coordinates system, P_c (X_c, Y_c, Z_c) is the coordinates of this point in the camera coordinates system, $P(x, y)$ is the physical coordinates of this point in the image plane coordinates system, $P(u, v)$ is the pixel coordinates in the image plane coordinates system, as shown in Fig. 1

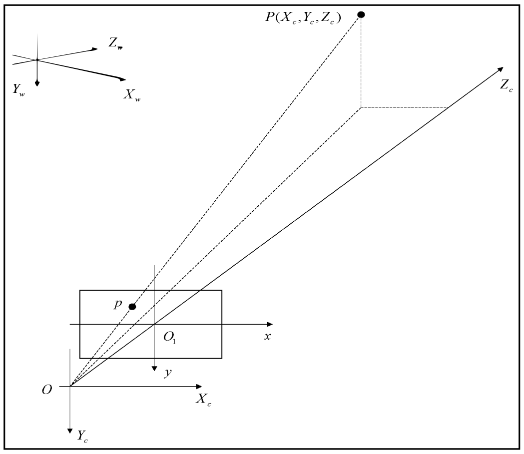

Fig.1. Coordinate system of camera calibration

The process of transforming the coordinates $P_w(X_w, Y_w, Z_w)$ of three-dimensional point P in the world coordinates system into the coordinates $P(u, v)$ in the image pixel plane coordinates system can be decomposed into the following 4-step transformation:

(1)The coordinates $P_w(X_w, Y_w, Z_w)$ in the world coordinates system are transformed into the coordinates $P_c(X_c, Y_c, Z_c)$ in the camera coordinates system.

$$\begin{pmatrix} X_c \\ Y_c \\ Z_c \end{pmatrix} = R \begin{pmatrix} X_w \\ Y_w \\ Z_w \end{pmatrix} + t \quad (1)$$

where $\boldsymbol{R}$ is a 3 × 3 rotation matrix, $\boldsymbol{t}$ is a 3 × 1 translation vector.

(2)The coordinates $P_c(X_c, Y_c, Z_c)$ in the camera coordinates system are projected in pinhole model to get physical coordinates $P(x, y)$ in the image plane coordinates system.

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} X_c / Z_c \\ Y_c / Z_c \end{pmatrix} \quad (2)$$

(3)Introducing the radial lens distortion and tangential distortion, to extend physical coordinates $P(x, y)$ into $P(x_q, y_q)$ in the image plane coordinates system.

$$\begin{pmatrix} x_q \\ y_q \end{pmatrix} = \left(1 + k_1 r^2 + k_2 r^4\right) \times \begin{pmatrix} X_c / Z_c \\ Y_c / Z_c \end{pmatrix} + \begin{pmatrix} 2p_1 xy + p_2\left(r^2 + 2x^2\right) \\ p_1\left(r^2 + 2y^2\right) + 2p_2 xy \end{pmatrix} \quad (3)$$

where k_1 and k_2 is the radial distortion coefficients, p_1 and p_2 is the tangential distortion coefficients, $r_2 = x_2 + y_2$.

(4)The physical coordinates $P(x_q, y_q)$ in the image plane coordinates system are transformed into the pixel coordinates $P(u, v)$.

$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} f_x x_q + u_0 \\ f_y y_q + v_0 \end{pmatrix}$$

$$\begin{cases} f_x = f \cdot s / \Delta x \\ f_y = f / \Delta y \end{cases} \quad (4)$$

where (u_0, v_0) is the base point (usually in the center of the image); f is effective focal length for the camera; s is the scale factor to adapt to a variety of uncertainties brought by sampling on the horizontal direction in the computer images; Δx is effective distance (mm / pixel) for the computer image in horizontal direction (x direction) between the two adjacent pixels. Δy is effective distance (mm / pixel) for the computer image in vertical direction (y direction) between the two adjacent pixels.

The above formulas are equivalent to follows:

$$s \cdot p = A\left(R \mid t\right) \cdot P \quad (5)$$

where $p = (u, v, 1)^T$ is homogeneous coordinates of image pixel points, $P = (X, Y, Z, 1)^T$ is homogeneous coordinates of space points, A is internal parameters matrix, $(R \mid t)$ is external parameters matrix, so that there was a mapping relationship between an image point and a space point.

B. Calibration Methods

Zhang's calibration method requires a planar lattice template which precisely locates lattice, as shown in Fig. 2. Then shooting image template from at least two different positions (relative calibration template) through the free movement of the camera or calibration template, and internal and external camera parameters are determined by direct linear transformation (DLT Transform) method through points on the template and its corresponding image points, this step will not consider the camera lens distortion, the process of calculation is solve linear equations and the speed is fast, but it doesn't consider the impact of lens distortion as a result of that the parameter values will not be accurate. Then take these initial values for parameters, using Levenberg-Marquardt algorithm for the smallest non-linear optimization to the distance between image points and re-projection points, considering distortion at the same time.

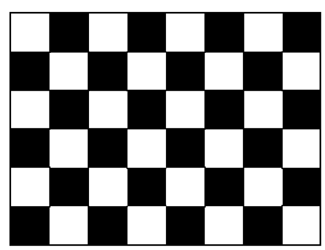

Fig.2. Calibration template

III. CALIBRATION BASED ON OPENCV

The module of calibration process based on OpenCV is shown in Fig. 3

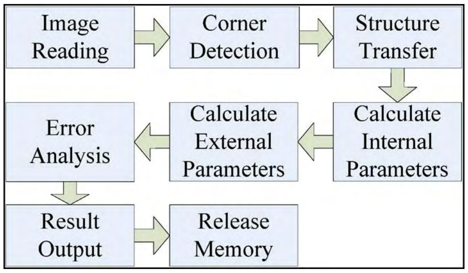

Fig.3. The module of calibration process

(1)Read a set of images for calibration.

(2)Process the image for corner detection:

The corner detection module of OpenCV has the regular failure of corner extraction, poor accuracy in the practical application. Therefore, we use Matlab camera calibration toolbox to improve accuracy and enhance the robustness in this step.

(3)Format conversion:

Convert the format of corner point coordinates detected by Matlab to the CvMat format of OpenCV.

(4)Calculation of internal matrix:

Initialize all the input parameters, and induce corner coordinates in the world coordinates system and image coordinates system into function cvCalibrateCamera2(). Then, we can get camera intrinsic parameters matrix by using this function, distortion coefficient vector, the rotation vector of each image, and the translation vector of each image.

(5)Calculation of external matrix:

Calculate the external parameters pictures of each picture (translation vector and rotation vector) using function cvFindExtrinsicCameraParams2(). Thus, the internal and external matrix and distortion coefficient vector which have gotten.

(6)Analysis of experimental results:

Calculate projection coordinates of the three-dimensional corner coordinates using function cvProjectPoints2() firstly, and then compare the calculated projection coordinates and the projection coordinates that were extracted using function cvNorm(), thus get a error.

(7)Finally, it should use function cvCreateMat() to release the memory space which allocated by function cvReleaseMat() for preventing memory leak.

IV. Experimental Results

We have developed a camera calibration program using VC++ 6.0 under Windows XP platform. This program is based on OpenCV 1.0 version and runs stably through testing, finding the corner successfully, the group the 640×480 pixel images as shown in Fig. 4, the process takes 0.6 seconds, meeting the actual use. Detected corner points is shown in Fig. 5, calibrated the camera parameters is shown in table 1.

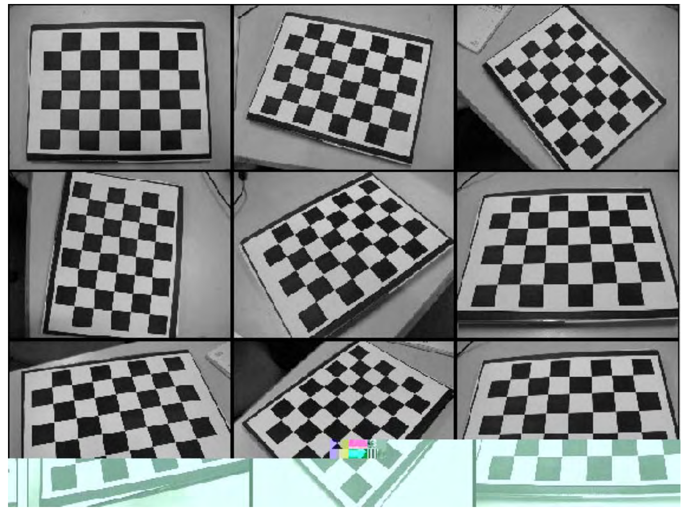

Fig.4. The picture of calibration template

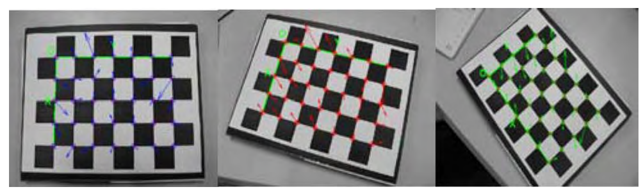

Fig.5. Detected corner points

TABLE I.
Camera Parameters

Focal length f_c	[716.542777 711.24402] ± [28.54080 25.00850]
Reference point (u_0, v_0)	[322.33944 196.08830] ± [9.84545 24.29547]
Distortion coefficient (k_1, k_2, p_1, p_2)	[-0.26177 0.75701 0.00146 0.00210] ± [0.03474 0.29103 0.00353 0.00090]
Error	[0.14809 0.27024]

V. Conclusions

OpenCV library is designed to make image processing and computer vision technology used more conducive and shorten the development cycle, the camera calibration program developed using OpenCV has many good features, such as the precise calibration results, efficient computing, cross-platform migration and so on, OpenCV can be effectively applied to all fields which need computer vision systems.

References

[1] L. Shapiro and G. Stockman, *Computer Vision*. Prentice-Hall, 2001.

[2] D. Forsyth and J. Ponce, *Computer Vision: A Modern Approach*. Prentice Hall, 2002.

[3] R. Sundareswara, P.Schrater, "Bayesian modeling of camera calibration and reconstruction," *Proceedings Fifth International conference on 3D Digital Imaging and Modeling*, 2005, pp. 394-401.

[4] T. Rodriguez, P. Sturm, and M. Wilczkowiak, "VISIRE: Photorealistic 3D reconstruction from video sequences," *Proceedings International Conference on Image Processing*, 2003, pp. 705-708.

[5] R. Tsai, "A versatile camera calibration technique for high-accuracy 3D machine vision metrology using off-the-shelf TV cameras and lenses," *IEEE Journal of Robotics and Automation*, 1987, 3(4), pp. 323-344.

[6] Z. Y. Zhang, "A flexible new technique for camera calibration," *Technical Report MSR-TR-98-71,* Microsoft Research, December 1998.

[7] Z. Y. Zhang, "A flexible new technique for camera calibration," *IEEE transaction pattern analysis and machine intelligence*, 2000, 22(11), pp.1330-1334.

[8] E. Karni and D. Schmeidler, "Utility theory with uncertainty," *In:Hildnbrand W, Sonnenschein H, Handbook of Maths Ec*, Vo. VI. Elsevier Science Publishers B.V. 1991, pp.1763-1771.