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Calibration of Optical Center Displacement for Zooming Image

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***Abstract*—According to the depth estimation of the Zooming images, the technology about the calibration of the optical center displacements of different focus is studied by combining the zooming camera features and the general methods of camera calibration. The thick lens model is proposed, and the external parameters of different focus are calibrated by using the method of plane templates. The experiment which is based on many groups of images shows that thick lens model is better in describing the camera zooming lens, the resulting optical center displacement can be used in the later depth estimation.**

Keywords—Zooming image; Depth estimation; Optical center displacement; Calibration

I. INTRODUCTION

The depth estimation of two images is a fundamental problem in computer vision, it is the key step towards image understanding, and has important applications in robotics, scenes understanding and three-dimensional reconstruction [1,2]. Zooming image is widely applied in visual surveillance, visual tracking, the environment apperceive of robot and map building, etc. As depth cues of a kind of monocular vision[3]. Ma and Olsen[4] were the first to advance a method to accomplish the depth estimation by using the Zooming lens, it shows that Zooming images can provide information about the depth theoretically. Then, Lavest[5,6] advanced an idea that accurate depth estimation must describe the Zooming lens by thick lens model, which is based on accurate research of optical properties of Zooming lens. Moreover, Asada and Baba[7,8] advanced a Zooming lens model according to the structure of practical lens, which includes three parameters whose names are focus, viewing angle and aperture. Fayman[9] applied the depth estimation of Zooming images to visual tracking, and advanced an active visual technology of Zooming tracking, widening applications in the depth estimation of Zooming images. All research is based on the calibration of Zooming lens.

II. CALIBRATION OF ZOOMING CAMERA

Camera calibration is considered important and useful in many computer vision problems. The so-called camera calibration is a process of establishing relationship between the position of camera image points and that of 3-D points according to determine intrinsic parameters and extrinsic parameters of the camera by the given camera model. Under the condition of fixed parameters of Zooming lens, zooming camera calibration has no much difference with ordinary camera calibration. But in order to establish an accurate model of Zooming camera, it is necessary to set up a form, record the calibration results in different settings of zooming lens. Moreover, camera calibration has itself characteristics, such as main point drift, the relationship between intrinsic parameters and extrinsic parameters of zooming camera with different lens, and only uses the suitable camera model to obtain accurate results to satisfy specific purposes.

Optical properties of zooming lens are controlled by three parameters whose names are focus, viewing angle and aperture. Zooming can gain images in different resolutions, you can focus to different distances to focus together target, and the brightness of the image can be adjusted to the lighting conditions by the aperture. This paper studied the technology of zooming images, zooming lens calibration is necessary. Limited to the experimental conditions, we use ordinary manual zooming camera as a tool to obtain images. As shown in Fig.1, manual zooming cameras, flat panel calibration and camera lens constituted the hardware part of calibration system.

Fig.1. Experimental equipment

TABLE I. ZOOMING CAMERA PARAMETERS

size	parameters
Camera	Canon EOS 500D
Lens	Canon EF 18-55mm IS Lens
Sensor types	CMOS sensor
Sensor size	22.3mm*14.9mm
Maximum resolution	4752*3168,Unit: pixel
Zooming	F18-F55 continuous Zooming

A. Zooming Image Acquisition

As the zooming image acquisition needs a focusing process at least, with the intrinsic parameters of the camera are constantly changing, so the problem that how to ensure the repeatability of a manual zooming must be considered. Although we can ensure the repeatability of focusing by the scale on the zooming ring for the manual zooming lens, the better method is to use the minimum and maximum focal lengths. As shown in Fig.4, we can focus with a focal length first, and then obtain images of different focal lengths. Fig.2 show two images of the minimum and maximum focal lengths. Two images are clearly visible, which can ensure the accuracy of image matching and depth reconstruction.

Fig.2. Zooming image acquisition

From the above discussion, we can determine three points:

1) Zooming camera calibration is based on manual zooming lens, using off-line calibration approach.

2) Ensure the stability of calibration data by using the approach including the fixed aperture, a focus and limit focusing.

3) Although only a single focus, not every image in the best focus position, we can still get clearer images.

B. Optical Center Displacement Calibration

In the thick lens model, the optical center displacement is that of the outside optical center H_0. As shown in Fig.3, the position of zooming camera and three-dimensional target point P keep unchanged. With the change of the focal length of camera, from f_1 to f_2, the position of both external and internal optical center H_0 and H_i are altered.

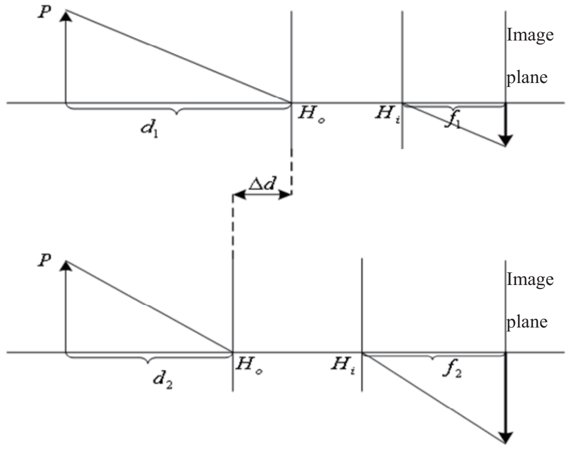

Fig.3. Displacement between focal lengths

The necessary parameter of the depth estimation of Zooming images is the displacement Δd of the external optical center H_0. As the position of the camera and three-dimensional target point keeps unchanged, as long as the object distance of all the various focal lengths are calibrated, which are the distance d_1 and d_2 between external optical center H_0 and three-dimensional target point P, we can get the displacement of the external optical center H_0 by the equality $\Delta d = d_1 - d_2$.

The method of plane template by Z Zhang is used to finish camera calibration in this paper[10]. Original point of the world coordinate system is fixed to the upper left corner of the calibration plate, Z-axis perpendicular to the plane of the calibration plate, as shown in Fig.4.

Camera intrinsic parameters are calculated in Eq.(1) and (2):

$$\begin{cases} v_0 = (B_{12}B_{13} - B_{11}B_{23})/(B_{11}B_{22} - B_{12}^2) \\ k_x = \sqrt{c / B_{11}} \\ k_y = \sqrt{cB_{11} / (B_{11}B_{22} - B_{12}^2)} \\ k_s = -B_{12}k_x^2 k_y / c \\ u_0 = k_s v_0 / k_y - B_{13}k_x^2 / c \end{cases} \quad (1)$$

Where, $c = B_{33} - [B_{13}^2 + v_0(B_{12}B_{13} - B_{11}B_{23})] / B_{11}^2$. After obtaining camera intrinsic parameters, from the homograph $\mathbf{H} = \lambda \mathbf{M}[\mathbf{n} \quad \mathbf{o} \quad \mathbf{p}] = [h_1 \quad h_2 \quad h_3]$, we can get:

$$\begin{cases} \boldsymbol{\lambda = 1/\|M^{-1}h_1\| = 1/\|M^{-1}h_2\|} \\ \boldsymbol{n = \lambda M^{-1}h_1} \\ \boldsymbol{o = \lambda M^{-1}h_2} \\ \boldsymbol{a = n \times o} \\ \boldsymbol{p = \lambda M^{-1}h_3} \end{cases}$$
(2)

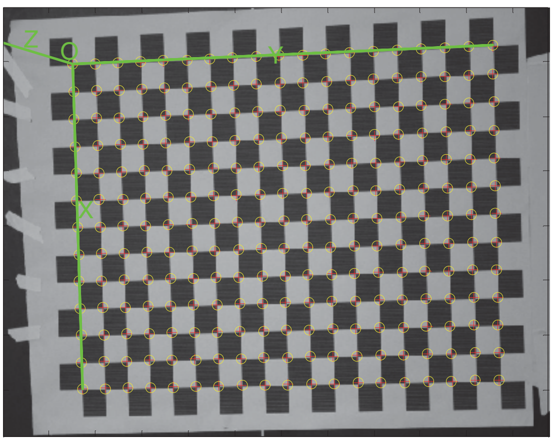

Fig.4. World coordinate systerm

According to equation (1) and (2), the internal and external camera parameters are calculated. The translation vector of camera external parameters is the straight-line distance from the camera optical center to original point of the world coordinate system. For the zooming camera, the translation vector is the straight-line distance from the external optical center to original point of the world coordinate system. Therefore, as long as a pair of zooming images of calibration plate are gained, we can calculate the camera optical center displacement.

III. Calibration results and analysis

In this paper, still, we only calibrate the optical center displacement of focal lengths between 18mm and 55mm. With the Calibration of Zooming center, we collect ten groups of Zooming images of the calibration plate as shown in Fig.5. Fig.6 shows the calibration results of optical center displacement between F18 and F55 .Fig.6 (a) shows the depth values from outer light between F18 and F55 respectively to the original point of the world coordinate system, namely the coordinate value of Z axis about the translation vector. Fig.6 (b) shows calibration curve of optical center displacement between the focal length of F18 and that of F55. TABLE II gives the statistical characteristics about the light displacement calibration results, and means will be used for calculating the depth of Zooming image.

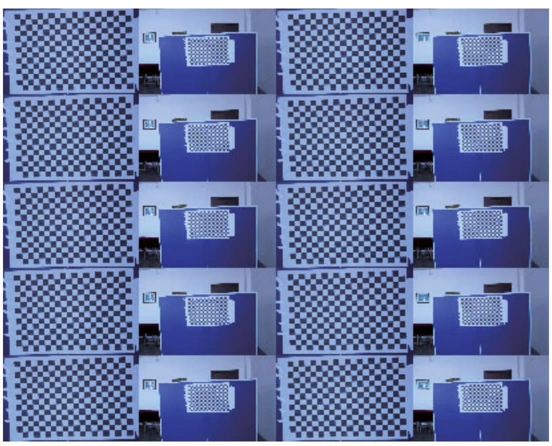

Fig.5. Ten groups of zooming images

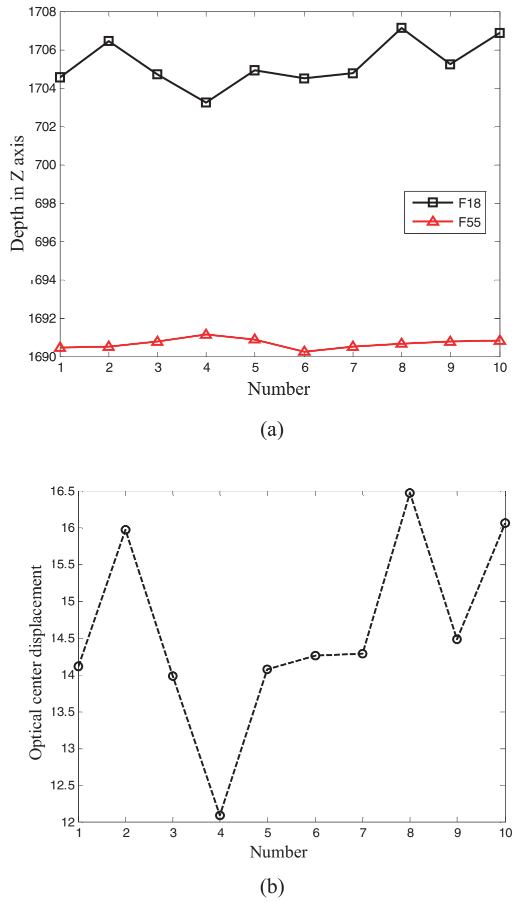

Fig.6. Calibration of the optical center displacement

TABLE II. CALIBRATION RESULTS FOR OPTICAL CENTER DISPLACEMENT

mean	Standard deviation
14.5740mm	1.2867mm

From the calibration results of the optical center displacement, the variable quantity of focal length is not equal to that of object distance. The variable quantity of focal length Δf is 34.5262 mm and the displacement of optical center is 14.5740 mm, because of the obvious gap between them, so the thick lens model is more suitable to describe the Zooming lens of camera.

IV. Conclusion

To accomplish the depth estimation of the zooming images, it is necessary to establish a monocular stereo vision system in this paper. From the own characteristics of zooming camera, the optical center displacements of different focus are calibrated by combining the methods of camera calibration. The experiment results show that the differences of the focal length are not equal to that of the object distance, and there is a significant difference between those two. Therefore, thick lens model is better in describing the camera zooming lens.

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