Homework 1 Camera Calibration

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I. Introduction

This report will explain the method and principle of camera calibration and compare it with the original OpenCV library. The process of computing the camera parameters is called camera calibration. Generally, the camera calibration process uses images of a 3D object with a geometrical pattern (e.g. checker board). The pattern is called the calibration grid. The 3D coordinates of the pattern are matched to 2D image points. Implicit calibration is the process of finding the projection matrix without explicitly computing its physical parameters. [1]

II. Implementation Procedure

Fig.1. shows the overall projection from world coordinates to pixel coordinates through Intrinsic matrix and Extrinsic matrix. We use a 2D 7*7 checkerboard to do the camera calibration. Before we started it, we took ten photos at fixed focus with different rotations and positions (Fig. 2).

"We will have one set of new extrinsic parameters (define homography) for each view. However, the intrinsic parameters stay the same. Computing multiple H's from multiple views can lead us to a unique set of intrinsic parameters."

First, we have to find the Homography matrix, H (Fig. 3) by Singular Value Decomposition (SVD).

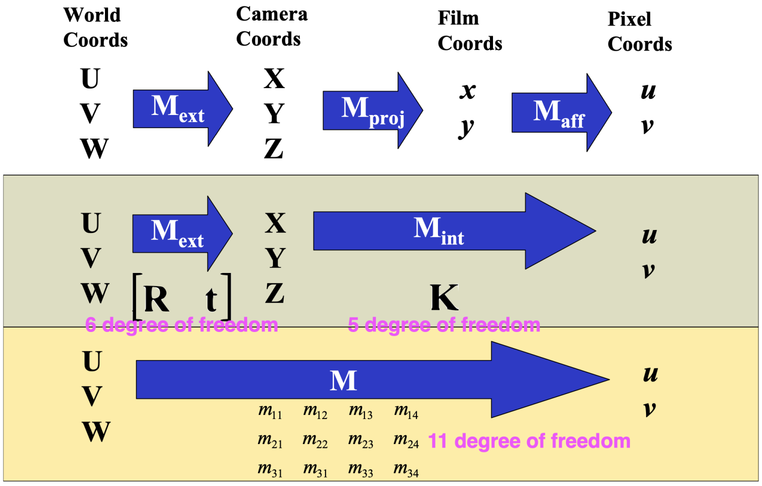


Fig. 1. Overall forward projection

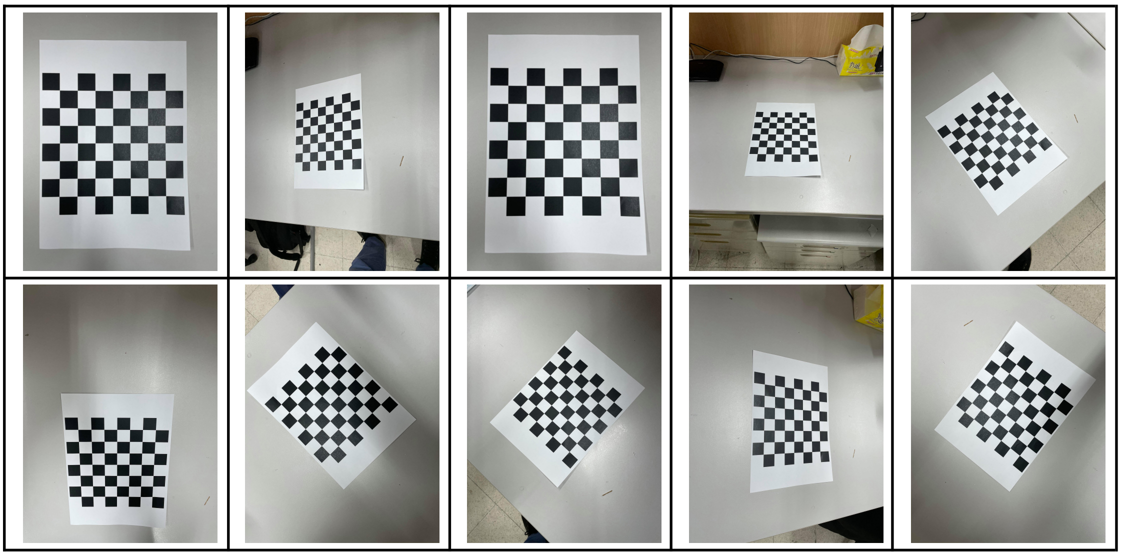


Fig. 2. Images taken with fixed focus

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \sim \underbrace{\begin{bmatrix} f/s_x & 0 & o_x \\ 0 & f/s_y & o_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & t_1 \\ r_{21} & r_{22} & t_2 \\ r_{31} & r_{32} & t_3 \end{bmatrix}}_{\textbf{Homography } H} \begin{bmatrix} U \\ V \\ 1 \end{bmatrix}$$

$$\boldsymbol{H} = (\mathbf{h}_1,\ \mathbf{h}_2,\ \mathbf{h}_3) = \underbrace{\begin{bmatrix} f/s_x & 0 & o_x \\ 0 & f/s_y & o_y \\ 0 & 0 & 1 \end{bmatrix}}_{\mathbf{K}} \underbrace{\begin{bmatrix} r_{11} & r_{12} & t_1 \\ r_{21} & r_{22} & t_2 \\ r_{31} & r_{32} & t_3 \end{bmatrix}}_{(\mathbf{r}_1,\ \mathbf{r}_2,\ \mathbf{t})}$$

Fig. 3. Homography H

Secondly, when we have matrix H, we are able to find matrix B (Fig. 3) from H and then calculate intrinsic matrix K by Cholesky factorization since B is positive definite.

$\mathbf{B} := \mathbf{K}^{-\top}\mathbf{K}^{-1}$ **is symmetric and positive definite**

$$\mathbf{B} = \begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{12} & b_{22} & b_{23} \\ b_{13} & b_{23} & b_{33} \end{pmatrix}$$

Fig. 4. Matrix B

After getting the unique intrinsic matrix K, we can find the extrinsic matrix [R|t] of each photo (Fig. 5) and plot it through the code provided by TA.

$$H = \begin{bmatrix} \mathbf{h}_1 & \mathbf{h}_2 & \mathbf{h}_3 \end{bmatrix} = \rho \begin{bmatrix} \mathbf{r}_1 & \mathbf{r}_2 & \mathbf{t} \end{bmatrix}$$

$$\begin{aligned} \mathbf{r}_1 &= \lambda \mathbf{K}^{-1}\mathbf{h}_1 \\ \mathbf{r}_2 &= \lambda \mathbf{K}^{-1}\mathbf{h}_2 \\ \mathbf{r}_3 &= \mathbf{r}_1 \times \mathbf{r}_2 \\ \mathbf{t} &= \lambda \mathbf{K}^{-1}\mathbf{h}_3 \\ \lambda &= 1/||\mathbf{K}^{-1}\mathbf{h}_1|| \end{aligned}$$

Fig. 5. Extrinsic matrix by K and H

III.Experimental Result

There are two different datasets. One from TA (Fig .5), and the other from us (Fig. 2). Each of the dataset will apply two different methods. The result shown in Table 1.

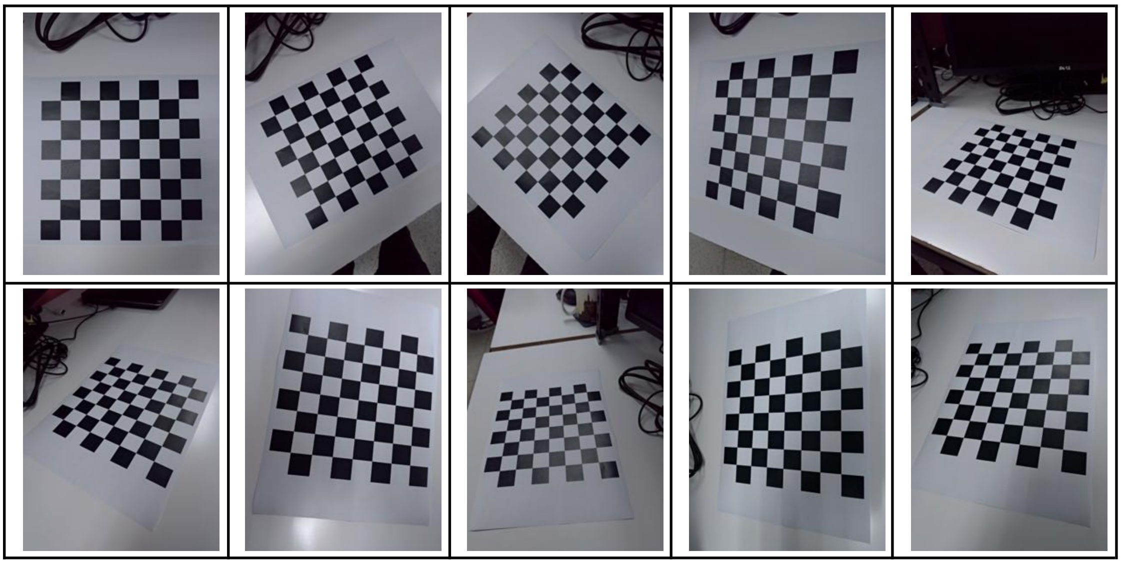
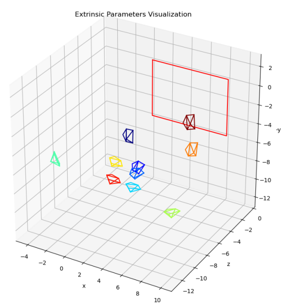
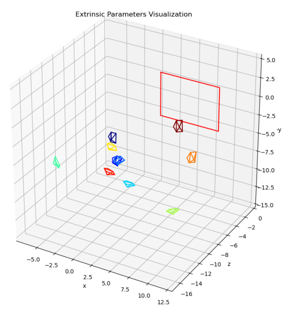


Fig. 5. Images provided by TA

Result	OpenCV	Our Implementation
Images provided by TA (Fig. 5)		

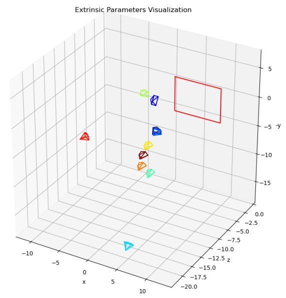
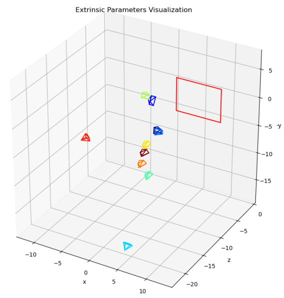
Images taken by us (Fig. 2)		

Table 1. Experimental Result

IV. Discussion

We show that our result is almost the same as openCV's result. Moreover, we found that the precision of axes between our results and opencv's results are different. From our points of view, the reason why the precisions are different is that the type of matrix operations we used is float32 and calibrateCamera in openCV use more precise type and this difference causes the difference of precision.

V. Conclusion

In this report, we showed the procedure and principle of camera calibration in detail. In the experiment, we implement the procedure and demonstrate our results that is almost the same as calibrateCamera in openCV.

VI. Work Assignment Plan Between Team Members

309551146 何昀儒	Implement the Calibration and conclusion
0856074 梁定能	Verify and discussion
409556005 徐大賢	Report and discussion

VII. Reference

[1] https://www.sciencedirect.com/topics/computer-science/camera-calibration

[2]
https://medium.com/%E6%95%B8%E5%AD%B8%E5%B7%A5%E5%BB%A0/camera-calibration%E7%9B%B8%E6%A9%9F%E6%A0%A1%E6%AD%A3-1d94ffa7cbb4

[3] https://en.wikipedia.org/wiki/Camera_resectioning

[4]
https://docs.opencv.org/2.4/doc/tutorials/calib3d/camera_calibration/camera_calibration.html