Performance Calibration of Photogrammetric Optical Systems

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Abstract: The performance of a digital optical imaging system with a CCD sensor depends on the precision of the optical elements in the design and assembly. The lens fabrication and assembly introduces offset and misalignment between mechanical and optical axes. A precise analysis and experimental estimation of optical system parameter errors can be used to improve the image quality through software algorithms. In this manuscript, we report our work about a method to measure optical system parameters like principal point, focal length, and distortion etc of optical imager using Simulation Tools, Open CV and an Autocollimator Theodolite. These parameters are very crucial for the synthetic error analysis of digital optical imaging system. The calibration experiments result in estimation of optical performance parameters, which are used to develop image enhancement algorithms. The parameters are extracted from a set of image templates using different methods. In part I, we present the calibration analysis and in part II, the experiment results are presented that show excellent agreement with the calibration model.

Keywords: Photogrammetric, Principal point, Focal length, Distortion, OpenCV, Autocollimator Theodolite, MATLAB.

I. INTRODUCTION

Imager calibration is used to determine intrinsic and extrinsic parameters for imaging systems, but it is also used to determine the complete lens distortion model. The intrinsic parameters include focal length, principal point, skew coefficient, distortions. The extrinsic parameters can include the rotation matrix and translation vector between the imager coordinate system and the world coordinate system. Imager calibration has been studied extensively in computer vision and photogrammetry, and even recently new techniques have been proposed. In the first part, we presented the theoretical analysis of optical parameters using pin hole imager model. In the present part, we describe the experimental results.

1.1. Types of parameters: Two types of parameters need to be recovered are
- Intrinsic imager parameters
- Extrinsic imager parameters

Intrinsic imager parameters: These are the parameters that characterize the optical, geometric, and digital characteristics of the imager
- Effective focal length \( f \).
- The transformation between image planes coordinates and pixel coordinates.
- The geometric distortion introduced by the optics.

Extrinsic imager parameters: These are the parameters that identify uniquely the transformation between the unknown imager reference frame and the known world reference frame.

1) Finding the translation vector between the relative positions of the origins of the two reference frames.
2) Finding the rotation matrix that brings the corresponding axes of the two frames into alignment.

Recently, many calibration methods were compared and described. Most of them were based on Tsai, Heikkila & Silven or Zhang methods [1] [2]. All three methods are based on the pinhole camera model and include radial distortion models.

Zhang’s method uses a checkerboard pattern, which is placed in front of the camera. At least three different images in various angles and positions must be acquired for the computation of camera calibration model. After the acquisition of the images the images the algorithms for detection of corners are used and corners of the checkerboard pattern are extracted. These points are used in calculations for camera calibration. This method is also used in OpenCV and Camera Calibration.

Imager Calibration: The imager calibration is implemented by 3D reference object based calibration. Before the calibration it is necessary to adjust the 3D scanning system. It must be set to cover the whole scanning area. This means determining the position of the imager, zoom and focus on the scanning surface. It is necessary to use appropriate calibration objects, patterns or shapes. These patterns are then used in the calculations of intrinsic and extrinsic parameters of the system based on images acquired by the digital imager. The most commonly used is the checkerboard pattern and Asymmetric pattern Fig. 1.1. This pattern is printed on a solid flat surface and has predefined dimensions and parameters (for example, checkerboard pattern of 6x6 squares and 20x20mm size each).

![Fig.1.1. Standard imager calibration patterns](image-url)

Fig.1.1. Standard imager calibration patterns

II. MATLAB CALIBRATION TOOL BOX

Imager calibration toolbox is a robust tool in the mathematical computing environment of MATLAB, which allows us to calibrate the imagers of the optical based 3D scanning systems. It represents a fundamental building block that can be extended to cover the overall calibration of the 3D scanning system.

The procedure involves
- grabbing a set of images of the grid pattern
- extracting the grid corners
- extracting boundary of the calibration grid
- Prediction of corners
- Extracted corners

Fig. 2.1. Calibration images with different orientation

Fig. 2.2. Process of extraction of grid corners

Fig. 2.3. Extracting boundary of the calibration grid

Fig. 2.4. Prediction of corners

The final detected corners are shown

Fig. 2.5. Extracted corners

Final results: add some text

| Focal Length:   | fc = [1351.9701, 1351.9701] |
| Principal point: | cc = [255.50000, 255.50000] |
| Slew:           | alpha_c = 0.00000 degrees |
| Distortion:     | k = [0.00000, 0.00000, 0.00000, 0.00000] |

Note: The numerical errors are approximately three times the standard deviation (for reference).

Fig. 2.6. Re-projection error Analysis
Disadvantages

- The main disadvantage of camera calibration toolbox is the need of carrying out certain steps manually (especially in comparison with fully automated calibration method via OpenCV), thereby extending the time of calibration.
- The most time consuming is the determination of borders of calibration pattern. Because in every calibration image (there are normally more than 20 images) it is necessary to define four border points as we done in section of “Extract the grid corners”.
- It is necessary to manually enter some configuration parameters and also confirm and execute individual calibration steps.
- The another main disadvantage is matlab tool box wouldn’t work for the asymmetric pattern which is most accurate pattern to compute the calibration process, as it would be done by centroiding of circles, whereas chessboard pattern will be done by corners extraction of squares.

III IMAGER CALIBRATION USING OPENCV

OpenCV (Open Computer vision) is a set of open source libraries for applications in computer vision systems. Currently these libraries consist of more than 2500 optimized algorithms and are available for several programming languages (C, C++, Python, and Java) and also for several operating systems.

Table 1. Showing results of OpenCv calibration with pentax lens of 25mm focal length

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Plot 3.1 Showing plot of f_x and f_y focal length

Plot 3.2 Showing plot of C_x and C_y imager centre

Fig. 3.1. Experimental Setup

Fig. 3.2. Calibration screen for chessboard pattern

Fig. 3.3. Calibration screen for asymmetric pattern
IV Imager Calibration Using Auto Collimator Theodolite

The autocollimator theodolite we employ in the experiment is the Leica 6100A. Figure 4.1.1(a) shows its external view. It has a small size, high accuracy 0.5″ and simple operation. We can use its auto-collimation eyepiece to determine whether the cross lines coincide, as shown in Figure 4.1.1(b). Other experiment devices consist of the optical table and auxiliary fixtures. It is worth noting that the aperture of the autocollimator should be comparable or larger than the aperture of the digital optical imaging system in order to avoid vignetting.

![Image of autocollimator theodolite](image)

4.1. Calibration Algorithm and Experiment:

The calibration objective should be focused on the inclination of the image plane and the distortion. The basic block diagram of the calibration process is shown below.

![Calibration flow diagram](image)

Disadvantage compared to the previous calibration technique is the need to create custom calibration system based on available OpenCV libraries and knowledge of a particular programming language and development environment.
4.2. Image Processing

The image obtained by the digital optical imaging system is shown in Figure 4.2. An appropriate image processing method should be adopted to obtain the precise centre position of the cross line which represents the outgoing ray of the theodolite. For the pixels in the first area, we regard the pixels in the same row as a group, and determine their gray value centre of gravity (i.e., weighted average). For the pixels in the second area, we consider pixels in the same column as a group, and also determine their gray value centre. Finally, we use the least square method to fit the two straight lines. The point of intersection of the two lines is considered as the centre of the cross line. This work provides a basis for further algorithm.

Since the light intensity of the theodolite could be adjusted by a knob, obtaining image before experiment and observing whether the image is saturation is also important.

![Fig. 4.2.1(a) Calibration experiment device (b) imaging method sketch map.](image)

![Fig. 4.2: Image of cross line of theodolite. (a) original image; (b) partially enlarged view](image)

**Pseudo-Code for Finding Centroid:**
Step 1: Read the image
Step 2: Extrude the image with a bounding box of 50 pixels around the maximum.
Step 3: Threshold the extruded image.
Step 4: Extrude the exact image of interest.
Step 5: Using “Sobel” method to detect the edges
Step 6: Draw lines onto the tips of the edges
Step 7: Construct the inner square of the cross hair.
Step 8: Point the 4 intersection points like (x1, y1), (x2, y2), (x3, y3), (x4, y4).
Step 9: Draw lines between (x1, y1) and (x3, y3) and draw lines between (x2, y2) and (x4, y4).
Step 10: Mark the dot of the two diagonals (Centroid)

4.3. Finding Focal length:

Secondly, we can obtain a series of focal lengths utilizing the incident light in different directions and their image point \((u_{Ri}-u_0)\) \((v_{Ri}-v_0)\). The average focal length is considered as the focal length value of the system, \(n\) represents the number of test points except for the principal point:

\[
\beta_i = a \cos (\beta_i \cos \delta_i)
\]

\[
f = \frac{\sum_{i=1}^{n} \left( (u_{Ri} - u_0)^2 + (v_{Ri} - v_0)^2 \right)^{\frac{1}{2}}}{n} \tan (\beta_i)
\]

Imager captured images with 0.5deg shift (horizontal) from right to left:

![Fig. 4.3: Finding Focal length](image)

After capturing images we find centroids of all images both in vertical and horizontal we get

\((u_{R1}, v_{R1}), (u_{R2}, v_{R2}), \ldots, (u_{Rn}, v_{Rn})\)
Optical systematic error analysis method, imager calibration using MATLAB Tool Box and imager calibration using Open CV proposed in this paper can perform analysis on the sensitivity of factors (such as position error of principal point, error of focal length, inclination of the image plane and the distortion) that may influence the accuracy of the photogrammetric optical system.

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REFERENCE


