euspen's 20th International Conference & Exhibition, Geneva, CH, June 2020
www.euspen.eu

A metrologic approach for camera calibration using traceable artefact

Safouane El Ghazouali[1], Alain Vissière[1], Hichem Nouira[1]

[1]*Laboratoire commun de métrologie (LNE – CNAM)*

safouane.elghazouali@lne.fr

Abstract: Large dimension parts scanning is still a challenge in the field of dimensional metrology due to the required accuracy. Indeed, the measurement uncertainty is increasing with the size of the scanned object. Nowadays, camera-based scanning technologies enable to achieve a high level of accuracy on small surfaces in microelectronic domain (example of card inspection). Nevertheless, similar level of accuracy also is usually demanded for large volume parts. This topic is currently investigated by National Metrology Institutes (NMIs) under the project 17IND03 (LaVA). One objective of LaVA project is the improvement of the process of camera-based scanning techniques such as photogrammetry and computer vision by enhancing camera calibration also called camera re-sectioning. Camera calibration is an essential step for intrinsic and extrinsic parameters extraction, leading to correct efficiently the errors due to the decentering or misalignment of the lenses. The classical camera re-sectioning procedure is based on the observation of a printed black and white checkerboard; in this case, camera re-sectioning accuracy depends mainly on the precision of the printing machine. Therefore, a traceable material standard defined with a specific pattern is proposed in this paper. Both printed and traceable mechanical artefact have been experimentally investigated and compared.

Dimensional metrology, photometry, photogrammetry, camera calibration, robotics, 3D reconstruction

1. Introduction

3D scanners have evolved in recent years in various industries such as automotive, aeronautical, medical robotics, electronics, etc. 3D scanners are mainly used for reverse engineering and quality control. The geometry errors of an object can be extracted through camera-based devices [1]. The uncertainty associated to the 3D forms inspection depends on the accuracy of the scanning system [2]; however, the accuracy of calibration target impact the quality of estimation of the camera parameters [3]. To achieve a micrometric level of accuracy, a metric camera is required. Metric camera is an equipment in which focal length and internal dimensions are exactly known or can be determined through the calibration process [4]. Camera calibration allows to estimate intrinsic and extrinsic parameters such as focal length and principal point. Several approaches of camera re-calibration has been proposed [5] [6]. In this paper, a review of camera model and calibration methods will be presented, the influence of target quality on the calibration process will be detailed, and experimental results of the new target will be discussed.

2. Review on camera calibration

Most of camera calibration methods are based on the **pinhole model**. This model assumes that a camera is characterized by its focal length (separated into two elements: horizontal f_x and vertical f_y), the skewness s which specify the non-perpendicularity of the two axes, and its principal point defined by the coordinates c_x and c_y. The pinhole camera model used to describe tha mathematical relationship between a 3D point and its projection on the image plane using perspective transformation [7]. According to this approach, a 4 by 3 matrix called camera matrix defines the parameters of the model, it allows the mapping of the world scene to the image plane [8].
The following equations (1 & 2) define the relation between a world point and its projection on the image plane, where r_i are the rotation vectors and t the translation vector:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & s & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_1 & r_2 & r_3 & t \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \quad (1)$$

$$m = \boldsymbol{K}[\boldsymbol{R}\ \boldsymbol{t}]P \quad (2)$$

Eq1 can be reworded in eq2 where $P(X, Y, Z)$ are the coordinates of 3D points, $m(u, v)$ are the coordinates of the projection point in pixels, $\boldsymbol{K}$ is the matrix of intrinsic parameters (which doesn't depend on view scene). $[\boldsymbol{R}\ \boldsymbol{t}]$ is the rotation-translation matrix and it defines the extrinsic parameters of the camera. It should be noted that as long as the camera focal is fixed, there is no need to change the intrinsic camera matrix. Based on eq1 the objective of camera calibration is to estimate the matrix $\boldsymbol{K}$.

2.1. Calibration methods

Several methods have been proposed to calibrate cameras. Tsai method [5] require a minimum of *9* points per image to solve the calibration problem with a set of n linear equations. Zhang method [6], relies on the observation of a known pattern (Figure1) placed in different orientations, where features points can be easily extracted to compute the transformation between *n* image points.

(a) *(b)* *(c)*

Figure 1. *(a) checkerboard grid (b) asymmetric circles (c) circles grid*

Feng et al. [9] compared the two calibration methods from the experimental point of view and conclude that Zhang is more robust, complete and accurate. In the following section, Zhang method will be used as calibration procedure in this article to compare targets. Matlab community has already developed a single camera calibration function that makes use of planar checkerboard with accurate results, the following experiments are based on this application taking account of radial distortions, principal points, skew and tangential distortion [10].

3. Influence of the target on calibration accuracy

The commonly used checkerboard pattern is printed and glued on a supposed flat surface which eliminate large paper deformations, however local aberrations can be generated from the process of gluing affecting the positin of the 3D coordinates (X, Y, Z). The accuracy of existing algorithms for pixel coordinates extraction can reach a sub-pixel level, nonetheless the processing of each image pattern is done independently of the rest of the images, which makes it difficult to perform accurate pixel extractions [11]. Indeed, the characteristics of calibration target pattern affect the calibration accuracy. More experimental details about the influence of target quality will be given in the expermiental section.

3.1. Mechanical artefact

Metrological traceability is defined as the property of measurement results to be related to a reference through a documented unbroken chain of calibration. To Validate this property, a mechanical standard is designed. The used artefact is a white rigid polymer with a thin black layer (0.2mm), the part is perforated at the depth of 0.2mm in order obtain the color difference in the checkerboard pattern which allows corners detection (Figure2). The calibration of the artefact is done using Micro vu Precision measurement machine for which the uncertainty is 2.5 µm

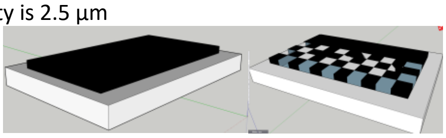

Figure 2. Manufacturing steps of the artefact

4. Experiments and results

Camera calibration is performed at a working range of 120 mm using an industrial high resolution camera DFK-AFU 420 CSS with unchangeable focal length of 8mm (figure3). The resolution of the taken images is 1920 x 1080 (pixels).

Figure 3. Camera calibration setup using artefact

The following table shows the results of calibration using printed checkerboard and the artefact. Four tests have been performed for each standard, each test contains at least 15 images, where f_x and f_y are the estimated focal lengths converted from pixel to mm unit, c_x and c_y are principal point coordinates expressed in pixel, MRE represent the obtained Mean Reprojection Errors [12] and *s(parameter)* is the standard deviation of the parameter, concidering a rectangular distribution.

Table 1 Estimated intrinsic parameters for the tested targets

	f_x	f_y	MRE	c_x	c_y
Artefact	7.9503	7.9769	0.36	1009.40	677.90
	7.9649	7.9566	0.43	1028.00	669.92
	7.9364	7.9248	0.39	1017.30	659.38
	7.8880	7.8720	0.37	1020.30	663.87
mean	**7.9348**	**7.9326**	**0.38**	**1018.70**	**667.70**
s(*)	**0.0334**	**0.0457**	**0.03**	**7.69**	**8.02**
Printed checker-board	8.3034	8.2726	1.17	1013.3	560.58
	8.5753	8.6038	1.07	988.36	624.89
	8.1420	8.1714	1.25	993.09	714.80
	8.1080	8.0960	1.32	995.81	698.36
mean	**8.2822**	**8.2859**	**1.14**	**997.6**	**649.60**
s(*)	**0.2131**	**0.2239**	**0.11**	**10.884**	**71.09**

The presented experiments show a notable difference between mean reprojection error, furthermore the analysis of standard deviation allows to validate the stability of intrinsic parameters estimation. In the case of mechanical artefact, the obtained standard deviation is about 40 µm while the printed pattern gives a standard deviation of 200 µm.

5. Conclusion and perspectives

This paper presented a study of a specific machined artefact and the influence of a target quality on the estimation of camera parameters. A machined checkerboard can be used for the calibration of a camera since the estimation of intrinsic parameters is stable compared to a printed pattern, the objective is to ensure metrological traceability, this will allow validation of the extraction of surface parameters which will be useful for 3D reconstruction. The continuity of work will constitute a comparative analysis of the existing calibration patterns and their impact on the accuracy of intrinsic and extrinsic matrix estimation.

References

[1] Wang Qi, Fu Li, and Liu Zhenzhong, "Review on camera calibration," in *2010 Chinese Control and Decision Conference*, Xuzhou, China, 2010, pp. 3354–3358.

[2] A.-I. García-Moreno, D.-E. Hernandez-García, J.-J. Gonzalez-Barbosa, A. Ramírez-Pedraza, J. B. Hurtado-Ramos, and F.-J. Ornelas-Rodriguez, "Error propagation and uncertainty analysis between 3D laser scanner and camera," *Robotics and Autonomous Systems*, vol. **62**, no. 6, pp. 782–793, Jun. 2014.

[3] A.-S. Poulin-Girard, S. Thibault, and D. Laurendeau, "Influence of camera calibration conditions on the accuracy of 3D reconstruction," *Opt. Express*, vol. **24**, no. 3, p. 2678, Feb. 2016.

[4] O. R. Kolbl, "Metric or Non-Metric Cameras," *PHOTOGRAMMETRIC ENGINEERING*, p. 11, 1976.

[5] R. Tsai, "A versatile camera calibration technique for high-accuracy 3D machine vision metrology using off-the-shelf TV cameras and lenses," *IEEE J. Robot. Automat.*, vol. **3**, no. 4, pp. 323–344, Aug. 1987.

[6] Z. Zhang, "A flexible new technique for camera calibration," *IEEE Trans. Pattern Anal. Machine Intell.*, vol. **22**, no. 11, pp. 1330–1334, Nov. 2000.

[7] Z. Zhang, "Perspective Transformation," in *Computer Vision: A Reference Guide*, K. Ikeuchi, Ed. Boston, MA: Springer US, 2014, pp. 592–592.

[8] P. Sturm, "Pinhole Camera Model," in *Computer Vision: A Reference Guide*, K. Ikeuchi, Ed. Boston, MA: Springer US, 2014, pp. 610–613.

[9] X. Feng, M. Cao, H. Wang, and M. Collier, "The Comparison of Camera Calibration Methods Based on Structured-Light Measurement," in *2008 Congress on Image and Signal Processing*, Sanya, China, 2008, pp. 155–160.

[10] "Single Camera Calibrator App - MATLAB & Simulink - MathWorks France." [Online]. Available: https://fr.mathworks.com/help/vision/ug/single-camera-calibrator-app.html?requestedDomain=. [Accessed: 04-Dec-2019].

[11] Q. Tian, Y. Li, J. Wang, and T. Chang, "Improvement of Camera Calibration Accuracy Based on Periodic Arrangement Characteristics of Calibration Target Pattern," *Transactions of Tianjin University*, vol. **23**, Apr. 2017.

[12] L. Tan, Y. Wang, H. Yu, and J. Zhu, "Automatic Camera Calibration Using Active Displays of a Virtual Pattern," *Sensors (Basel)*, vol. **17**, no. 4, Mar. 2017.