Parametric Study on Bouguet's Camera Calibration Method Applied for Edge-Based Structural Deflection In-plane Measurement

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ABSTRACT

In this paper, a parametric study will be conducted on Bouguet's camera calibration method. The main disadvantages of the method include too many checkerboard image sampling and a lot of clicking of chessboard pattern image. Four checkerboards that have same outer dimension but different size in small squares will be used as tools to determine minimum sampling amount of checkerboard's image and the best suitable checkerboard for the particular measurement system. A DSLR Canon 7D camera with 50mm fixed lens is used as a sensor. Focal length as one of parameters resulted from calibration process for each checkerboard is then compared with lens's focal length. Finally, the calibration process is applied for structural in-plane deflection measurement. A simple beam rig is used as a structural model. Repeatability and accuracy of the measurement is also to be analyzed. The results show that the minimum number of image sampling for good result is 12 times and 12x12 square checkerboard is the best for particular measurement system. Accuracy of the measurement using 12x12 checkerboard with 12 times image sampling is around 4.5%.

Keywords: *Bouguet, calibration, camera, checkerboard, structural deflection*

NOMENCLATURE

F	lens focal length (mm)
f_o	computed focal length (mm)
f_y	focal length (pixel), obtained from calibration process
d_y	camera pixel dimension (mm), y direction

1.0 INTRODUCTION

A catastrophic failure of the structure frequently causes casualties and significant material losses. Such failures may be prevented by implementing continuously or periodically condition monitoring of the structure. Condition monitoring of the structure - widely known as SHM (structural health monitoring) - is growing rapidly at present. Most of the structural conditions can be monitored through static and dynamic parameters. The advantages of static rather than dynamic monitoring are the ease of measurement and cheaper operating cost. It makes the static deflection measurement system for structure attractive to be studied [1].

Vision based method for static deflection measurement is a non-contact type method using cameras as the primary sensors.

At present, the optical non-contact measurement method widely used are photogrammetry and computer vision. Although both method use camera as main sensors, the main goal of photogrammetry is accuracy, while computer vision is flexibility [2]. While conventional photogrammetry commonly used for measuring the deflection of the structure, edge based photogrammetry is in developing stage[3]. In the field of computer vision, the most widely used method is digital image correlation (DIC). Yoneyama(2007), applied DIC technique to measure vertical deflection of bridge girders[4].

The most important step in vision based measurement is camera calibration. The goal of camera calibration is to acquire a relationship between image pixel and metric unit of real world. The goal is achieved by identifying correspondence between image and scene and computing map from scene to image[5].

Bouguet method is a multi-plane calibration type. The advantages of this type include: only requires a plane with chessboard pattern as a calibration tool, does not have to know positions/orientations, and the code is available online[5]. The main disadvantages of the method include a number of checkerboard image sampling and a lot of clicking of chessboard pattern image.

In this paper, a parametric study is conducted to determine minimum image sampling and a suitable checkerboard dimension for particular measurement system. The results of this study is then applied to edge-based structural deflection in-plane measurement.

Deflection measurement of the structure commonly uses single camera (in-plane measurement) or stereo cameras (stereo vision measurement). In-plane measurement needs an assumption that the deflection is in the plane parallel to that of image sensor[3]. Edge-based computer vision for structural deflection is still a chalenging field to develop.

In general, edge detection has the following steps[5]:

1. Filtering – Filter image to improve performance of the edge detector with respect to noise.
2. Enhancement – Emphasize pixels having significant change in local intensity.
3. Detection – Identify edges by thresholding.
4. Localization – Locate the edge accurately and estimate edge orientation.

2.0 BOUGUET METHOD FOR CAMERA CALIBRATION [6,7]

According to the dimension of the calibration objects, Zhang classifies calibration techniques roughly into three categories: 3D reference object based calibration, 2D plane based calibration, and self-calibration[4].

Bouguet method is categorized as a 2D plane based calibration. The methos used a planar checkerboard as shown in Figure 1.

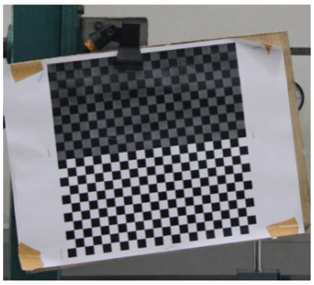


Figure 1. Calibration board with chessboard pattern

Techniques in this category are required to observe a planar pattern shown at a few different orientations [4]. Different from Tsai's technique, the knowledge of the plane motion is not necessary [4]. Because almost anyone can make such a calibration pattern, the setup is easier for camera calibration.

In general, many of calibration algorithm estimate camera's intrinsic and extrinsic parameters through non-linear iterative minimization by using feature points. Bouguet uses lines and planes to separate intrinsic and extrinsic parameters and then extracting closed form solution for these parameters by optimizing existing geometrical boundary condition on scene. User friendly code and simple calibration board make Bouguet method quite flexible and easy to operate.

The step of Bouguet calibration process for single camera is as follow:

1. Load checkerboard images.
2. Extract the grid corners. Four times clicking on extreme corners on rectangular chessboard pattern are needed to determine plane boundary.
3. Do Calibration process. Output of this process include: focal length, principle coordinate, skewness, distortion constants, and pixel error.
4. Re-extract the grid corners on images.
5. Do calibration optimization.

For single camera calibration, Bouguet gives 20 and 25 checkerboard images as an example for calibration process. This is a large amount of images to process. Being bored and tired possibly make the user doing mistake in clicking the corner. The motivation of this activity is triggered by this fact.

To get the focal length in mm from the calibration code output, the following equation is used [7],

$$f_o = f_y \, x \, d_y \quad (1)$$

3.0 IN-PLANE MEASUREMENT

Vision based in-plane measurement is a measurement using a camera, in which a changes position of the measured object is in parallel to the plane of the camera sensor [8]. The measurement system is ilustrated in the Figure 2.

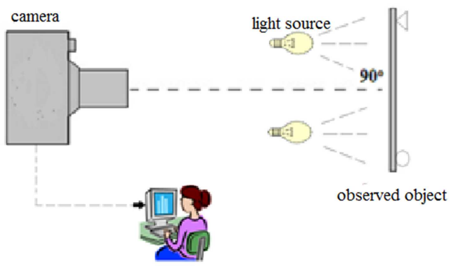


Figure 2. Vision based in-plane measurement

The measurement system consist of single camera and a computer for data analysis. A light source is used when the environment condition have insufficient lighting.

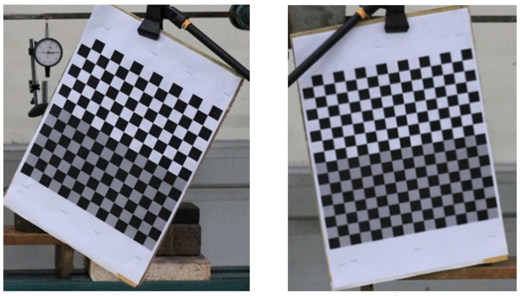
The step of in-plane measurement can be summerized as follow[8]:

1. Calibration proses: Before doing measurement, a calibration process need to be conducted. The aim of the process is to get relationship between image pixel and metric unit of real world.
2. Taking of object image: take object image before and after loading.
3. Edge detection: Object image is used as input for edge detection code.

4. Curve fitting process: to get equation of the resulted edge line after loading.

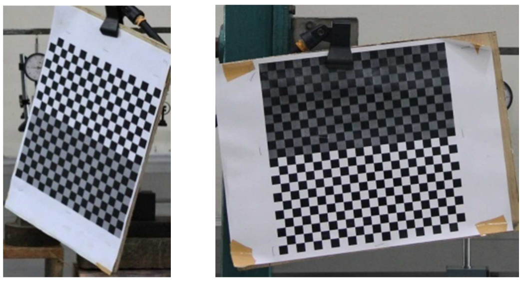
4.0 PARAMETRIC STUDY

In this study, 4 checkerboards wich have same outer dimension but different small squares size are used. Figure 3 and 4 show the checkerboards.



(a) (b)

Figure 3. Checkerboard (a) 12 x 12 (b) 14x14 squares



(a) (b)

Figure 4. Checkerboard (a) 16 x 16 (b) 20x20 squares

Each Checkerboard is then used in calibration process with a number of different position. Images sampling are taken with different amounts. In this case: 18, 12, 9 and 6 times. Figure 5 is an example of images sampling process.

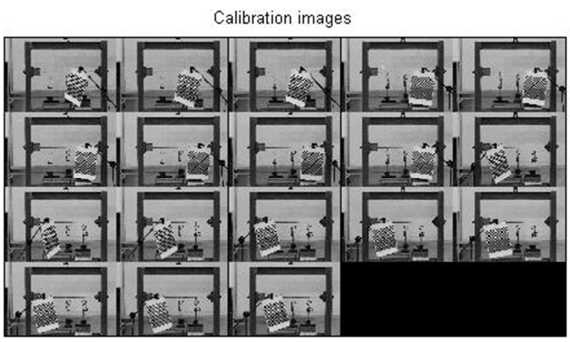


Figure 5. Sampled images with 18 times sampling

These images are then entered into calibration code. The comparison of lens's and resulted focal length is used as accuracy criterion for the best checkerboard and minimum sampling number.

5.0 EXPERIMENTAL SET-UP

Experimental set-up consist of a beam with pin-roll support as shown in Figure 6. Three dial gages is used to sense vertical deflection when the beam is loaded. A camera is set in front of the rig and the sensor plane can be assumed parallel with vertical deflection of the beam. A waterpass is used for the purpose.

Figure 6. Experimental set-up

Figure 7 shows the location of dial gages in the rig.

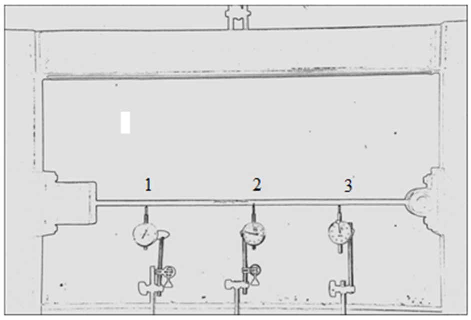


Figure 7. Numbering of the location of dial gages

6.0 RESULTS and DISCUSSION

Camera data:
Camera : Canon EOS 7D
Sensor size : 22.30 mm x 14.90 mm [9]
Max resolution : 5184 x 3456 piksel (17.9 MP)
Lens focal length : 50mm
Camera to be set in maximum resolution (17.9MP)

Checkerboard data:
Dimension of small square (20x20) : 13.13 mm
Dimension of small square (16x16) : 16.06 mm
Dimension of small square (14x14) : 18 mm
Dimension of small square (12x12) : 20.57 mm

Measurement data:
Dial gage readings:
Point 1 : 0.93 mm
Point 2 : 1.41 mm
Point 3 : 0.885 mm

Deflection in pixel using Canny method:
Point 1 : 3
Point 2 : 5
Point 3 : 3

Bact to equation (1), d_y is a vertical pixel dimension (*y* direction) and its value is obtained by dividing sensor size in *y* direction (=14.90mm) by its relevant image resolution (=3456 pixel). d_y =14.90/3456 = 0.0043mm. f_y is focal length in pixel. Computed focal length f_o is obtained from equation (1).

Table 1 shows computed focal length f_o in y direction.

Table 1. Computed focal length f_o

No	Checkerboard dimension	f_o (mm)			
		18	12	9	6
1	20x20	55.48	55.87	56.15	56.21
2	16x16	55.25	55.9	54.83	56.01
3	14x14	56.44	57.66	54.52	57.25
4	12x12	53.61	51.03	51.42	65.88

Table 2. Error

No	Checkerboard dimension	Error (%)			
		18	12	9	6
1	20x20	10.96	11.74	12.3	12.42
2	16x16	10.5	11.8	9.66	12.02
3	14x14	12.88	15.32	9.04	14.5
4	12x12	7.22	2.06	2.84	31.76

From Table 2, checkerboard with 12x12 squares and 12 times sampling has the smallest error (2.06 %). The amount of 9 times sampling also has small error (2.84 %).

Based on this result, the 12x12 checkerboard is then used in the deflection measurement for knowing consistency of the measurement.

Table 3 shows the variation of deflection in all measurement points with different amount of sample.

Table 4 shows the relevant error of Table 3.

Table 3. Deflection (mm) with variation in amount of sample (fixed lens 50mm – checkerboard 12x12)

No	Amount of sample	Deflection (mm)					
		1		2		3	
		pinhole	distortion	pinhole	distortion	pinhole	Distortion
1	18	0.84	0.85	1.41	1.41	0.84	0.85
2	12	0.83	0.85	1.39	1.41	0.83	0.85
3	9	0.84	0.84	1.4	1.4	0.84	0.84
4	6	0.82	0.84	1.37	1.41	0.82	0.84

Table 4. Error (fixed lens 50mm – checkerboard 12x12)

No	Amount of sample	Error (%)					
		1		2		3	
		pinhole	distortion	pinhole	Distortion	pinhole	distortion
1	18	9.26	8.93	0.21	0.14	4.75	4.41
2	12	10.2	**8,93**	1.28	**0.14**	5.76	**4.41**
3	9	9.58	9.58	0.57	0.57	5.08	5.08
4	6	11.8	9.26	3.05	0.21	7.46	4.75

Pinhole model is not accurate for all measurement wcompared with model that include distortion in the computation.

Error avaraging in all points by using 12x12 checkerboard show the result as follow:

- Amount of sample 18 : (8,93 + 0,14 + 4,41)/3 = 4,5%
- Amount of sample 12 : (8,93 + 0,14 + 4,41)/3 = 4,5%
- Amount of sample 9 : (9,58 + 0,57 + 5,08)/3 = 5,1%
- Amount of sample 6 : (9,26 + 0,21 + 4,75)/3 = 4,74%

12x12 checkerboard with minimum amount of sampling 12 times will give highest accuracy.

Point 1 has the lowest accuracy followed by point 3. This fact is normal because of the difference of deflection of point 1 and 3 is 0.045 mm while the convertion factor is around 0.28.

Point 2 has the highest accuracy (below 1%).

7.0 CONCLUSION

The parametric study shows that the best checkerboard is 12x12 squares for particular measurement system and minimum amount of sampling for highest accuracy is 12 times. The accuracy of beam deflection measurement using edge based computer vision method shows good results (4.5%).

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