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PHOTOGRAMMETRY REQUIREMENTS FOR DIGITAL CAMERA CALIBRATION APPLYING *TCC* AND *MATLAB* SOFTWARE

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Abstract. The result of photogrammetry is a digital object or terrain images on the plane or in three-dimensional space. Precise data on the object is photocopied by a professional digital camera equipped with the calibrated system of optical lens (evaluation of distortion parameters for optical lens). Camera calibration is performed in a laboratory or employing special calibration software and using special field testing. However, Lithuania doesn't own similar laboratories. Therefore, an important point is obtaining proper software for the verification of these works. European countries have been using plenty of various software and different test field calibration (plate), including two-dimensional, three-dimensional, etc. Therefore, choosing the simplest, cheapest and most acceptable method of camera calibration is essential. Research was made applying the *Canon EOS-1D Mark II* (resolution - 21 million points, with the focal length of the lens reaching 21 mm). The optical system was calibrated using *Tcc* (Germany) and *MatLab* software. The calibration processes were done taking a different test field of camera calibration. The article analyzes calibration results and offers suggestions on camera calibration.

Keywords: photogrammetry, digital camera, calibration, test field calibration.

1. Introduction

High precision digital, professional, fixed focal length lens ensures that a calibrated camera is used for precise close-range photogrammetry work. Calibration is set at the photo-camera and the lens optical decentring correction. The process requires creating the pictures of objects conducting deformation tests, controlling compliance with the constructed object and producing solutions to other important purposes. Camera calibration could be performed in a special laboratory or employing specific software and special different configuration of test field calibration (plate). However, Lithuania does not own calibration laboratories, which makes important to conduct scientific research, and therefore camera verification tests employing suitable software and referring to the obtained results suggest the preferred method and calibration work.

2. The Goal of Camera Calibration

The purpose of camera calibration is to determine the model of a geometric camera referring to the parameters of interior orientation (Luhmann *et al.* 2006):
- focal length of the camera (c);
- image coordinates of the principal point (x_0, y_0);
- radial – symmetric distortions (A1, A2);

- tangential (asymmetric or decentring) distortion (B1, B2);
- affinity and shear of the image coordinate system;
- additional parameters.

3 different camera calibration methods characterised by the used reference object and the time and location of calibration can be introduced (Sužiedelytė-Visockienė, Bručas 2009a):
- Laboratory calibration. The parameters of interior orientation are determined employing goniometers, collimators or other optical alignment techniques where the image direction or angles of light rays are measured through the lens of the camera. The advantage of this method is that calibration takes place under laboratory conditions, and hence, better accuracy of defining unknown quantities is achieved. Laboratory calibration is generally used only for metric cameras and applied before surveying.
- Test field calibration. This type of calibration is based on a suitable targeted field of object points with known coordinates and distances. The images of the test field are taken from different positions and directions from several camera stations (the number of camera stations depends on the size of the test field), thus ensuring good ray

intersection and filling the format of the image. Neighbouring images should be overlapped. The coordinates of the measured image and approximately known object data are processed by bundle adjustment so that to provide the parameters of the camera model (interior orientation) as well as to adjust the coordinates of the tested field and parameters of exterior orientation. Test fields can be either mobile or stationary.

– Self-calibration. For this type of calibration, the images acquired for measuring the actual object are used. In this case, the test field is replaced by the actual object that must be imaged under conditions similar to those required for test field calibration itself (spatial depth, tiled images and suitable ray intersections). Self-calibrations do not require the coordinates of the known reference points. The parameters of interior orientation can be calculated solely by the photogrammetric determination of the object shape. If employed, reference points can be used for defining a particular global coordinate system for the parameters of exterior orientation.

The procedure for camera calibration can be divided into several stages: making images of the test field target, processing the resulting images and the estimation of camera parameters.

Determining the parameters of cameras (camera calibration) is absolutely necessary for processing successful images (Sužiedelytė-Visockienė, Bručas 2009b).

The following (3, 4) sections describe calibration procedures for non-metric camera *Canon EOS 1D Mark II* with *Tcc* (Germany) applying *Matlab* software.

3. Digital Camera Calibration Applying *Tcc* Software

The calibration of the non-metric camera *Canon EOS 1D Mark II* was performed applying *Tcc* software and the calibration test field (plate) – cube (Abraham 2004) (Fig. 1).
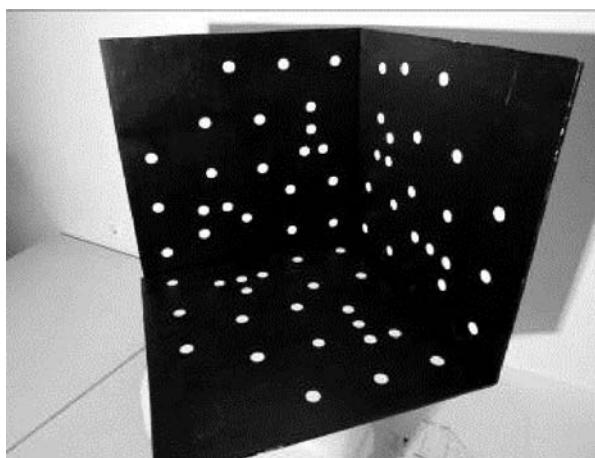

Fig. 1. Test field of camera calibration

The test field consists of retro reflective targets, including the known coordinates and distances. In order to capture all types of distortions and stabilize the determi-

nation of focal length (when using longer focal lengths in particular), the images were taken considering:

– different orientations; at each station, the camera was rotated around its optical axis by 0°, 90° and –90°;
– different inclinations.

All parameters of the automated camera (zoom, auto focus, aperture, white balance, etc.) were kept constant during capturing data (turned off) (Wojtas 2010). In that particular case, for successful processing of calibration, 30 images were taken.

The images were processed and computations of camera calibration parameters were made employing *Tcc* software. During the adjustment procedure, software created an approximate 3D model of the points marked on the test field. The coordinates are required to number retro reflective targets detected in the image and to set up correspondences between the targets in different images. Software also created a file with calibration parameters and a new project.

The accuracy of the obtained results is defined by standard deviation from the weight unit (δ_0) in units µm. Standard deviation (δ_0) shows the accuracy of measuring the mean point for all images of adjustment statistics. The value of standard deviation cannot exceed 15 µm.

The parameters of camera calibration are recommended to be calculated in the first approach to image processing:

– focal length of the camera (c);
– scale coefficient (sxy);
– principal point coordinate x_0, y_0 corrections in the images (xh, yh);
– radial-symmetric distortion of the camera (A1).

The focal length of the new objective is shown in the project file. The new camera calibration parameters calculate in the second approach the image processing. The calculation results are given in Table 1.

Table 1. Results of *Canon EOS 1D Mark II* calibration applying *Tcc* software

Approach	Distortions	c, mm	δ_0, mm	Coment
1	A1	19.716	9.739	30 images
2	A1	19.718	9.807	corect c
3	A1, A2	19.925	231.00	δ_0 is very big. Calculate A2 impossible
4	A1	19.719	9.843	corect c
5	A1, A2	19.923	8.561	corect c
6	A1, A2	19.910	27.707	corect c
7	A1, A2	19.947	7.194	corect c
8	A1, A2, B1	19.948	8.395	corect c
9	A1, A2, B1	19.933	8.267	corect c
10	A1, A2, B1	19.935	11.326	δ_0 is bigger, corect c (9 approach)
11	A1, A2, B1	19.939	8.15	good result

In the result file there is given these photo-camera calibration parameters in the unit pixel:

c   3.11558077E+003
sxy   1.00049666E+000
xh   −1.75566691E+001
yh   9.49991289E+000
A1   −8.30927617E-009
A2   6,62456720E-016
B1   −5.71643097E-008

Calibration parameters have been tested referring to two overlapping object images. The images have been processed applying *PhotoModeler* (Russia) software. The qualities of the object 3D model are defined a value of root mean square (*RMS*) by the measure point in the images and a triangulation process result. The triangulation accuracy is defined as the discrepancies points coordinates of images with geodetic coordinates. Those are points plane (E_{XY}) and height (E_Z) discrepancies. The accuracy of *RMS* is shown in Fig. 2.
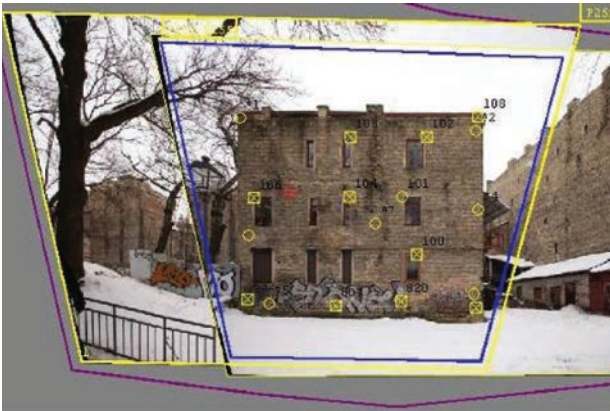

Fig. 2. The geometry model of object

The value of *RMS* is 0.386 pixels which is 2.5 mm (Fig. 2). The results of calculating triangulation are:

$$E_{XY} = E_Z = 6.0 \text{ mm.}$$

This is a good result. The calibration parameters of the new definite camera could be used for making corrections to optical errors in images made by the camera.

4. Digital Camera Calibration Applying *MatLab* Software

MatLab is widely used software package of interactive digital computation and data visualization. To calibrate *MatLab* software environment, digital cameras use *Toolbox_kalib* program. The main steps of camera calibration applying *MatLab* program are as follows (Heikkilä, Silvén 1997; Marzan, Karara 1975; Zhengyou 1999).

Creating the chess plate for test field calibration (Fig. 3). Following recommendation that the plate has to complete at least a wise half of the image, the plate of 1320×1320 mm (11×11 size of squares) has been chosen.
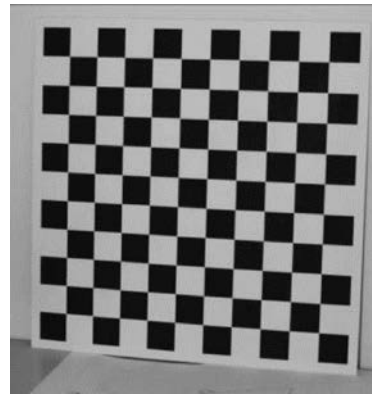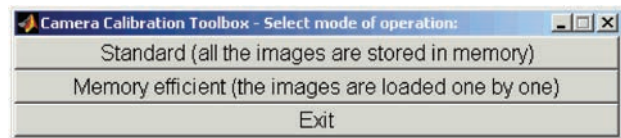

Fig. 3. Test field of camera calibration

Taking the images of the calibration plate applying a digital camera.

The function of calibration starts from the *Matlab* command window, save **calib_gui.** This command opens the way to upload a Table 2 to select images.

Table 2. The models of the image input

Camera Calibration Toolbox - Select mode of operation:
Standard (all the images are stored in memory)
Memory efficient (the images are loaded one by one)
Exit

The programme proposes two modes of image input to the computer: standard and memory efficient.

In the standard mode, all the images to be used in the calibration process are input into memory once reading from the disk is not repeated. This reduces referral to the number of computer memory as well as increases image processing and display functions of speed.

If images are large or very large, the program can display the warning message **OUT OF MEMORY.** In this case, the mode of high performance memory (Memory Efficient) is used: each image is loaded separately adding images to a folder on the computer screen above the Table 3 of the main options.

Table 3. The main options of the camera cabration toolbox

Camera Calibration Toolbox - Standard Version			
Image names	Read images	Extract grid corners	Calibration
Show Extrinsic	Reproject on images	Analyse error	Recomp. corners
Add/Suppress images	Save	Load	Exit
Comp. Extrinsic	Undistort image	Export calib data	Show calib results

For selecting the function **Image Names** in the **main options**, enter the name and format of the images.

MatLab **main options** for selecting the function **Extract grid corners** made measurements the main four plate corners in the images (Fig. 4).
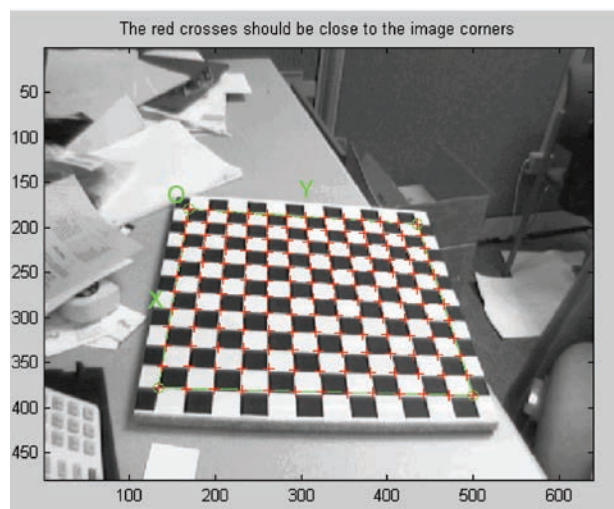

Fig. 4. The image marked with the measured plate – chess corners

The basic corners of the plate could be measured manually or automatically. First, measuring a non-automatic mode is recommended.

The calibration parameters of calculating select the main options table **Calibration function.** The click starts the calibration process of calculation taking place at two stages. The first stage calculates the focal length of the objective (c) and image coordinates of the principal point (x_0, y_0). In the second stage – calculated distortion. Camera *Canon EOS-1D Mark II* that obtained results of the calculations are have the following parameters:

c = [3162.45189];

x_0, y_0 = [2794.85759, 1883.93452];

A1, A2, B1 = [–0.07673, 0.05097, –0.00026];

δ_0 = [0.89353].

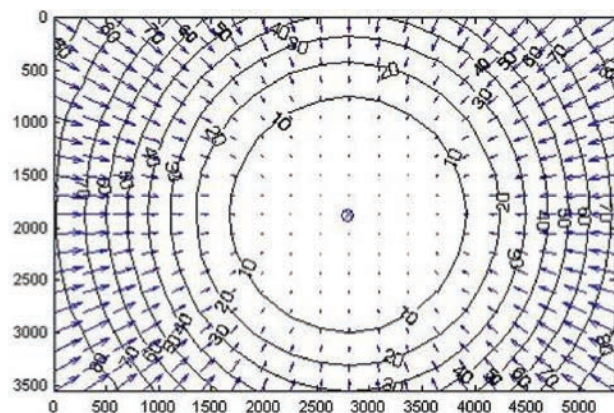The program allows monitoring the location of distortion (Fig. 5).

Fig. 5. Distortion of camera lens

A visual expression of the distortion of camera lens (Fig. 5) shows that the largest distortion of optical lens reaches 80 pixels (~0.5 mm) and is situated around the edges.

The obtained results, similar to those received from calculations using *Tcc* program, were verified referring to the images of the same object (see Section 3). A geometric model of the measured point for measuring the root mean squared error *RMS* = 0.428 pixels is 2.7 mm. The triangulation result are shown that average error of measured points in the geodetic coordinates are E_{XY} = 5 mm, E_Z = 6 mm. The result is good.

5. Summary of Results

The calibration values of the accuracy of the *Canon EOS-1D Mark II* are shown in Table 4.

Table 4. Calibration accuracy of the camera

Rate/Software	*Tcc*	*MatLab*
Objective focal length (c), mm	19.94	20.24
Precision of calibration δ_0, mm	8.15	5.6
RMS, mm	2.5	2.7
Triangulation:		
E_{XY}, mm	6.0	6.0
E_Z, mm	5.0	6.0

6. Conclusions and Recommendations on Digital Camera Calibration

1. Camera calibration is prepared to take the images of a special test field (plate) that has to include as large area as possible. The angle of view of the camera depends on the focal length of the objective: the shorter is the focal length of the objective, the wider is the angle of view.

2. The camera must be stable when shooting the test field. Therefore, it is recommended to use a tripod. Images shooting necessary to be used are manual objective focus and the lens focusing to infinity. Images are taken in three positions: from the middle, left and right. The camera is rotated at 360°. There are 4 test field images in each position. It has to proceed and be repeated only changing the angle of the test field.

3. The images of the test field are possible to be processed applying software described in the article, namely *Tcc* and *MatLab*. Finalizing camera calibration with the help of the above mentioned software has determined that the index (δ_0) of calibration accuracy has not exceeded the recommended value 15 µm.

4. The calibration results obtained using software *Tcc* influence the number of the identified points of the test field image. In case software recognises less than 13 points on the plate, the calculations of calibration have to be cancelled. The number of identified points is proved by the size of the formed file of the image. The size must not exceed 1 kb.

5. To process the images of calibration, test field software *MatLab* requires extensive resources of the operational system built in the computer. In case the available amount of memory is not sufficient, software suspends the calculation procedure.

6. The final amendments of the images representing the measured objective were made. Defects were caused by the distortions of the lens of the camera made by software *Tcc* and *MatLab* when executing photogrammetric measurements. Therefore, the mean square error (parallax) of the geometric measurements of the model points differs only by 0.2 mm while the accuracy of triangulation results tends to remain constant. High accuracy of triangulation calculations indicates that the results obtained employing software *Tcc* and *MatLab* are considered to be satisfactory and reliable.

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