THE EFFECT OF DIFFERENT CALIBRATION METHODS ON THE ACCURACY OF THREE DIMENSIONAL MODELS

Z. Duran [a], M. E. Atik [a*]

[a] Istanbul Technical University, Civil Engineering Faculty , Geomatics Engineering Department, 34469, Istanbul Turkiye - (duranza, atikm)@itu.edu.tr

ABSTRACT:

The main objective of photogrammetry is to obtain a three-dimensional model using terrestrial or aerial images. Calibration of the camera and detection of the orientation parameters are important for obtaining accurate and reliable 3D models. For this purpose, many methods have been developed in the literature. However, since each method has different mathematical background, calibration results may be different. In this study, the effect of camera interior orientation parameters obtained from different methods on the accuracy of three-dimensional model will be examined. In this context, a test area consisting of 21 points was used. The test network was coordinated in a local coordinate system using geodetic methods. Some points of the test area were selected as the check point and accuracy analysis was performed. Direct Linear Transformation (DLT) method, MATLAB, Agisoft Lens, Photomodeller, 3D Flow Zephyr software were analysed.

1. INTRODUCTION

Today, with the developing technology, 3D modelling finds its place in every area of life. Photogrammetry is the most reliable and useful method for 3D modelling of the real world. Recording of historical artifacts (Duran and Aydar, 2012), 3D modelling of the surface (Nex and Remondino, 2014) and in different situations where measurement must be made without contact with objects (Linder, 2009), photogrammetry is widely used. Among the existing methods, Structure From Motion (SFM) is a popular algorithm. This algorithm creates 3D models using photographs taken from different angles of an object. The positional accuracy of the created models is affected by camera calibration. Therefore, accurate calibration of the camera is important in terms of 3D modelling.

In this study, the effect of camera calibration values obtained from different popular software on 3D model accuracy was investigated. MATLAB, Agisoft Lens, Photomodeller, 3D Flow Zephyr and Direct Linear Transformation (DLT) methods have been selected. A three dimensional test area was created to evaluate the calibration results.

2. MATERIAL AND METHODS

2.1 Material

Application was carried out with a Nikon D800 camera (Figure 1). The camera with a variable lens is set to a focal length of 24 mm.

Figure 1. Nikon D800 Digital SLR Camera

Within the scope of the study, a test network was established. The test area contains 21 points (Figure 2). The local coordinates of the points were determined by geodetic measurements.

Figure 2. Test area

2.2 Camera Calibration

The camera calibration is one of the classic problems of the field of photogrammetry. Calibration of a camera can be regarded as the inverse of photogrammetric process. The internal orientation is known in the photogrammetric process and the coordinates of the object points are searched, but in camera calibration, the coordinates of the object points are known and the elements of the internal orientation are searched (Kraus, 1993).

Camera calibration is performed to obtain the camera's internal orientation parameters. With these parameters obtained as a result of the calibration, the spatial beam is fixed to the projection centre (Ozdemir and Duran, 2017). Interior orientation parameters are calibrated focal length c, coordinates of principal point coordinates (x_0, y_0) and distortion parameters. When the camera focuses on a point, the focal length is represented by c. The focal length should be precisely determined because it affects the coordinates due to the mathematical model of photogrammetry. Most of the cameras

used in photogrammetry produce photographs which can also be considered central projections of sufficiently accurate spatial bodies. The central point of the central projection is called the projection centre. The projection centre's projection point on the image is called the principal point.

Radial distortion is the image displacement that occurs when the rays coming from different angles to the lens focus on or behind the projection plane due to angular magnification caused by the lens. Radial distortion affects the position of the point on the image radially. Radial distortion should be modeled with high accuracy because of its positional effect on coordinates. The tangential distortion occurs if the lens elements and the centres of the image sensor are not coincident and their planes are not parallel (Ozdemir and Duran, 2017).

3. APPLICATION

In the scope of the study, the camera calibration was performed. Thus, the internal orientation parameters of the camera have been determined. The camera was calibrated using each method and software. Each software has a calibration pattern. The calibration process is performed and the results are shown below.

3.1 Calibration with Agisoft Lens

Calibration with Agisoft Lens was performed on the computer screen using the test area of the software. The test area, similar to the chessboard, is shown in the Figure 3.
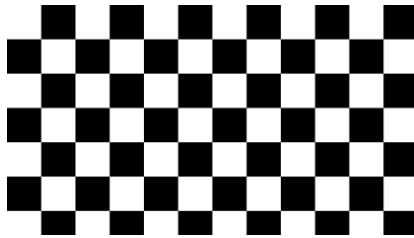

Figure 3. Agisoft Lens calibration test area

The captured images are used in the calibration process via the software interface. 13 photos of the calibration paper were taken from different angles and evaluated through the software. As a result of the process, interior orientation parameters were calculated. The interior orientation parameters calculated in pixels are transferred to the table in mm.

Parameters	Values
	mm
Focal Length (mm)	24.30197
Principal Point x	0.029
Principal Point y	- 0.178
K1	-0.0008763
K2	0.0008753
K3	-0.0008282
P1	0.0000000
P2	0.0000000

Table 1. Agisoft Lens interior orientation parameters

3.2 Calibration with Photomodeller

Calibration with Photomodeller software was done by printing the calibration network of the software on A4 paper. There are 100 control points on the calibration paper (Figure 4).
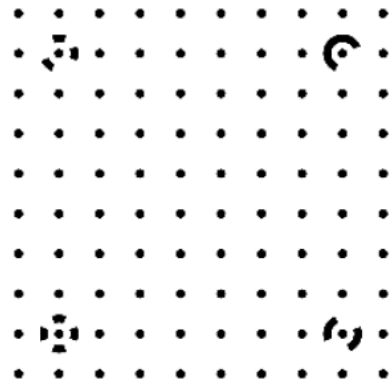

Figure 4. Photomodeller calibration test area

13 photos of the calibration paper were taken from different angles and evaluated through the software. Calibration results are kept in a file with the specific extension of the software and the parameters are given in the metric system (Figure 5).
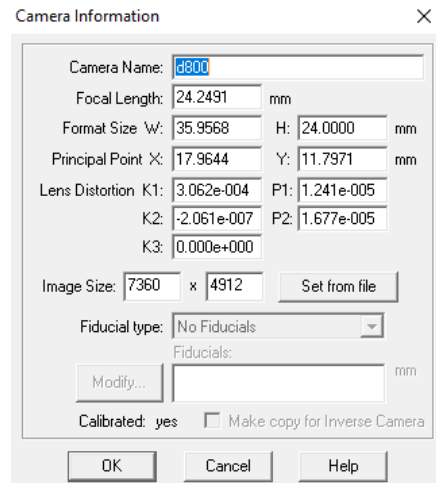

Figure 5. Photomodeller calibration interface

Parameters	Values
	mm
Focal Length (mm)	24.2491
Principal Point x	17.964
Principal Point y	11.797
K1	0.0003062
K2	-0.0000002
K3	0.0000000
P1	0.0000124
P2	0.0000168

Table 2. Photomodeller interior orientation parameters

3.3 Calibration with 3D Flow Zephyr

The program uses the Procedural Perlin Noise image (Figure 6), unlike other software for calibration. The image is reflected directly on the computer screen via the software. 13 photos was obtained.
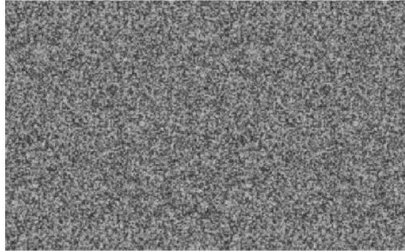

Figure 6. Procedural Perlin Noise image

After the photos are uploaded, the software performs the calibration on a single window. The obtained calibration values are as follows.

Parameters	Values
	mm
Focal Length (mm)	24.1469
Principal Point x	17.982
Principal Point y	11.745
K1	-0.0008726
K2	0.0000713
K3	0.0001438
P1	0.0000000
P2	0.0000000

Table 3. 3D Flow Zephyr interior orientation parameters

3.4 Calibration with MATLAB

Camera Calibrator is used in the computer vision toolbox for calibration via MATLAB. MATLAB Camera Calibrator estimates camera interior orientation, exterior orientation, and lens distortion parameters. The program benefits from previous studies for necessary calculations (Zhang, 2000).

The test area used by the program is in the form of a chessboard. A checkerboard image can be created within the software in different sizes and dots. The left half of the checkerboard image is in black and white and the right half is in black and gray to define the coordinate system (Figure 7).
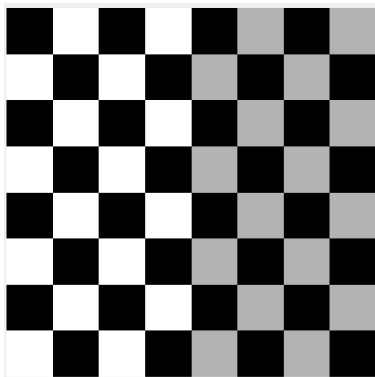

Figure 7. MATLAB calibration test area

When the software completes the calibration process, it sends the results and errors to the MATLAB workspace in a variable. The interior orientation parameters produced with MATLAB are shown in the table below.

Parameters	Values
	mm
Focal Length (mm)	24.3622
Principal Point x	17.993
Principal Point y	11.822
K1	-0.0007385
K2	-0.0003338
K3	0.0040482
P1	0.0000062
P2	-0.0000012

Table 4. MATLAB interior orientation parameters

3.5 Calibration with Direct Linear Transformation (DLT)

Direct Linear Transformation (DLT) method is a linear calibration method. It was developed in 1971 by Abdel-Aziz and Karara (Abdel-Aziz et. al., 1971). The major advantage of this method is that the solution is linear and does not have an approximate value problem. With DLT equations, it is possible to reach the space coordinates directly from the image coordinates (Tasdemir et. al., 2009). In addition to the parameters added to the 11 parameters, DLT equations are given in the following equations. There are 16 parameters in direct linear transformation method. 11 are used for conversion.

Basic equations of DLT are obtained by rearranging the mathematical model of photogrammetry. This equation (1 and 2) shows the relationship between the image coordinates and the object coordinates.

$$u - \Delta u = \frac{L_1 x + L_2 y + L_3 z + L_4}{L_9 x + L_{10} y + L_{11} z + 1} \tag{1}$$

$$v - \Delta v = \frac{L_5 x + L_6 y + L_7 z + L_8}{L_9 x + L_{10} y + L_{11} z + 1} \tag{2}$$

where   x,y,z = object coordinates of point

The parameters from L1 to L11 are the camera calibration parameters. L12, L13, L14 related to radial distortion, L15, L16 are the parameters related to tangential distortion. The parameters were calculated using MATLAB (Table 5 and Table 6). The calculated parameters are as follows. Calibration with DLT was performed on the prepared 3D test area. For 3D coordinate calculation, DLT parameters must be calculated on at least 2 images. Below are the parameters of 2 images (Figure 8).

Figure 8. Images used for DLT calibration

Parameters	Values
L1	-0,322373374
L2	-23,01061838
L3	3,576539156
L4	19,75360416
L5	-23,40591264
L6	0,005902536
L7	-2,545372994
L8	25,94926373
L9	0,056994319
L10	-0,158729043
L11	-0,896653801
L12	-0,000125723
L13	-9,75E-07
L14	4,95E-09
L15	0,000672215
L16	0,000295521

Table 5. DLT parameters for image 1

Parameters	Values
L1	0,140190398
L2	0,95382684
L3	2,485046498
L4	-3,584883124--
L5	0,06446149
L6	1,051023064-
L7	4,307002585
L8	-5,303660721
L9	-0,028437462
L10	-0,17646057
L11	-0,79326842
L12	0,02108416
L13	-0,000139306
L14	2,62E-07
L15	0,033999895
L16	0,001409398

Table 6. DLT parameters for image 2

The interior orientation parameters obtained by using the DLT parameters are as follows (Table 7).

Parameters	Values
	mm
Focal Length (mm)	25.5206
Principal Point x	0.513
Principal Point y	1.138
K1	0.0104792
K2	-0.0000701
K3	0.0000001
P1	0.0173360
P2	0.0073831

Table 7. DLT interior orientation parameters

3.6 Comparison of Calibration Parameters

The obtained calibration parameters were compared and visualized using graphs. For focal length, the methods gave similar results except DLT. The focal length that was computed by DLT, had higher value. The closest value to the original value was the computed focal length by 3D Flow Zephyr software.
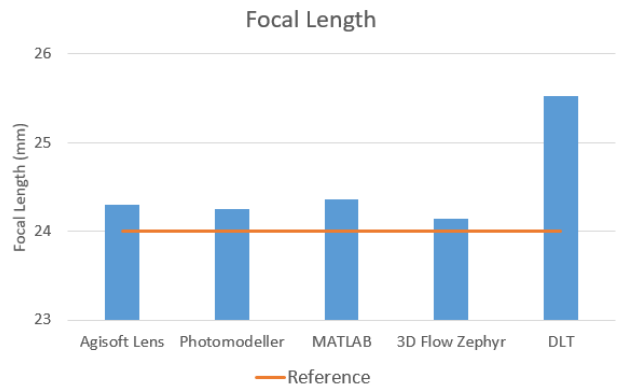

Figure 9. Focal length values

In radial distortion graph, there were three distortion values. Photomodeller software calculated distortion values K1, K2 and K3 near to 0.
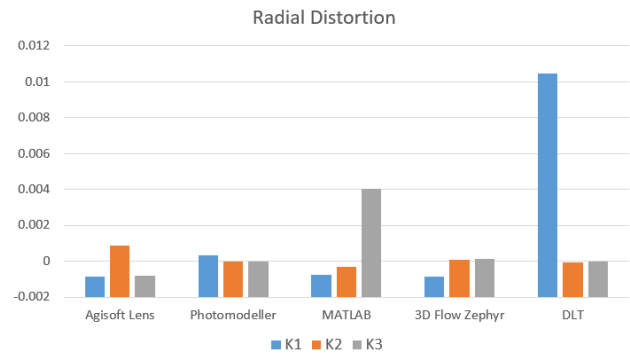

Figure 10. Radial distortion values

Significant results were obtained at the tangential distortion. While the methods outside the DLT were calculated to be almost 0, DLT calculated high value tangential distortion. It is note that with similar test areas, the interior orientation parameters have been calculated with different values. Thus, the softwares offer the diffrerent interior orientation parameters The effects of the changes on the accuracy of the 3D model to be produced was examined.
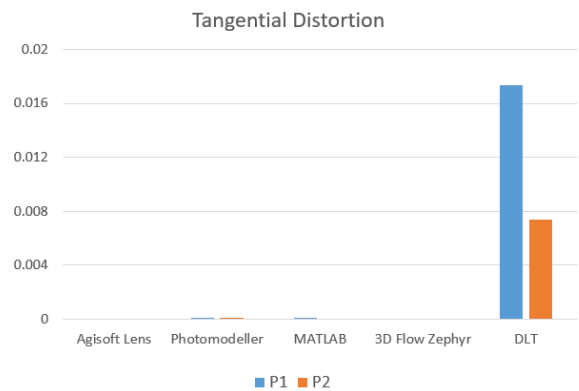

Figure 11. Tangential distortion values

4. RESULTS AND DISCUSSION

A test area of 21 points was used in the study. 11 points of the test area were identified as control points and 10 points as check points. A 3D model was created in Agisoft Lens by using 15 images taken with Nikon D800 camera (Figure 9). The model is coordinated and scaled in the local coordinate system.
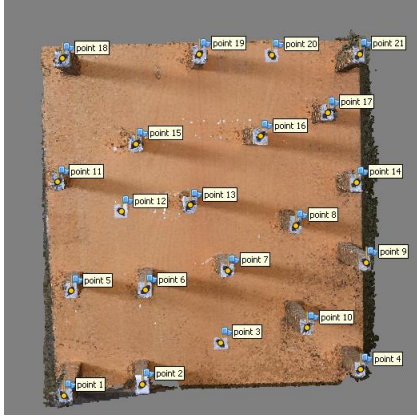

Figure 9. 3D model of test area.

Camera calibration parameters can be entered as input to Agisoft Lens. Calibration parameters calculated from other software was given to the software by converting to pixel value. The software calculates and corrects 3D coordinates according to the calibration values. In addition, root mean square error (RMSE) was calculated by the software. The DLT method and the coordinates were calculated using its mathematical model. The root mean squared error values of the 10 check points was shown in Table 8.

Method	$RMSE_X$ (mm)	$RMSE_Y$ (mm)	$RMSE_Z$ (mm)	$RMSE_{XYZ}$ (mm)
Agisoft Lens	**0.011**	**0.019**	**0.110**	**0.077**
Photomodeller	0.232	0.317	0.125	0.412
3D F. Zephyr	0.276	0.327	0.137	0.450
MATLAB	0.191	0.523	0.719	0.909
DLT	0.024	0.024	4.629	4.629

Table 8. RMSE errors of each method for 3D model

The highest accuracy in terms of both planimetry and altimeter accuracy has been obtained with Agisoft Lens software. $RMSE_X$, $RMSE_Y$ and $RMSE_Z$ values were 0.011 m, 0.019 m and 0.110 m respectively. Calibration values calculated with Photomodeller, 3D Flow Zephyr and MATLAB are different especially in terms of image main point coordinates. This difference has led to incorrect calculation of the coordinates. The DLT method gave similar results to Agisoft Lens in terms of planimetric accuracy. However, the accuracy of the Z value is 4.629 m. Therefore, it is understood that DLT method cannot be used in terms of height evaluation.

5. CONCLUSION

In this study, the effects of different calibration methods on accuracy of 3D model were investigated. Mathematical reasons behind the different results of different methods should be examined. Because this situation affects the accuracy of 3D models. Due to this situation, the software should not arrive immediately as a result of incorrect calculation. The scope of the study can be extended by evaluating each software in itself. However, as a result of this study, inferences can be obtained for future studies.

REFERENCES

Duran, Z., Aydar, U., 2012. Digital modeling of world's first known length reference unit: The Nippur cubit rod. Journal of Cultural Heritage 13, 352-356.

Nex, F., Remondino, F., 2014. UAV for 3D mapping applications: a review. Applied Geomatics 6, 1-15.

Linder, W., 2009. Digital Photogrammetry – A Practical Course, 3 ed. Springer-Verlag Berlin, Heidelberg.

Kraus, K., 1993. Photogrammetry, I. Fundamentals and standard processes. Photogrammetry, 1.

Ozdemir, E. and Duran, Z. 2017. Comparison of Commonly Used Camera Calibration Software. Afyon Kocatepe Üniversitesi Fen Ve Mühendislik Bilimleri Dergisi, 17(4), 1-11.

Zhang, Z. 2000. A Flexible New Technique for Camera Calibration. IEEE Transactions on Pattern Analysis and Machine Intelligence. Vol. 22. Number. 11. pp. 1330–1334.

Abdel-Aziz, Y.I., & Karara, H.M. 1971. Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. Proceedings of the Symposium on Close-Range Photogrammetry (pp. 1-18). Falls Church, VA: American Society of Photogrammetry.

Tasdemir, S., Urkmez, A., Yakar, M., Inal, S. 2009. Determination Of Camera Calibration Parameters At Digital Image Analysis. 5. Uluslararası İleri Teknolojiler Sempozyumu (IATS'09), 13-15.