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Full Length Research Paper

Analysis of camera calibrations using direct linear transformation and bundle adjustment methods

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Main feature of photogrammetry is the measurements which are made on photographic projection of the objects instead of making them directly on the object. Because of its indirect measurement feature, it has various application areas. Widespread use of photogrammetry increases the importance of calibration of cameras in the frame of photogrammetric principles. In this study, images of test fields shot by Nikon Coolpix 950 digital camera were analyzed using Bundle adjustment method while images of test fields obtained from portable roentgen device were analyzed using Direct linear transformation (DLT) method and all the results obtained from different methods were compared.

Key words: X-ray photogrammetry, calibration, digital photogrammetry, direct linear transformation.

INTRODUCTION

Photogrammetry is a branch of technology, science and art where reliable results are obtained by recording, measuring and explicating the emitted electromagnetic energy and topographic images given shape by physical objects and reflected beams from the surrounding formed by them (Aytaç, 1978). As it can be understood from the definition of photogrammetry that the main feature of this science is that measurements are done on the projection of the object instead of doing it directly on the object. Photographic projection can be visible light rays, near infrared or rays of a selected spectrum region. There is no restriction except making photographic projection of the object directly or indirectly. If an object is invisible because of its characteristics or it is in a form which can not be recorded photographically, the object is transformed to a form, it is visible or its projection can be made photographically without changing the metric properties of it. In this case to analyze the object provided, it is recorded photographically, photographic measurement methods should be taken into account. As new digital photogrammetric systems, which make the technologies used conventional photogrammetry that was invalid, are used widely; films and photographs named as hardcopy is forsaken (Göktepe, 2005).

Photogrammetry is the art and science of determining the position and shape of objects from photogographs (Kraus, 1993). Until now, this technique is used in analysis of human and animal anatomy (Karabork, 2009; Ege et al., 2004), architecture (Yilmaz et al., 2007), production of topographic maps (Pesci et al., 2007), three-dimensional motion analysis for different aims (Goktepe et al., 2009; Yagisan et al., 2009), and many others.

Photograph machines used in close photogrammetry are named as metric and non-metric photograph machines. Machines internally oriented and having a constant radial distortion values determined by calibration are generally named as metric photograph machines. Machines that do not have these mentioned properties are named as non-metric photograph machines. However, for some machines having stable internal orientation, it is possible to determine internal orientation factors by using additional hardware such as middle point procurers like the metric machines. For the photograph machines that do not have internal orientation and middle point procurers, tuning is done by adding unknown parameters of internal orientation factors into the mathematical model used.

MATERIALS AND METHODS

Calibration is done by using two methods. These methods are Bundle adjustment method (Table 1) and Direct linear transformation (DLT) method (Table 2).

Bundle adjustment method

They are the unit pictures that are taken into account in block

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Table 1. Bundle adjustment method.

NN	dx(mm)	dy(mm)	dz(mm)
2	0.09	0.40	-0.22
4	0.27	-0.07	0.24
6	-0.20	0.07	1.36
8	0.17	-0.47	0.69
10	-0.07	-0.03	0.32
12	0.00	-0.09	-0.26
14	0.13	-0.13	-0.45
16	-0.35	-0.06	-0.31
18	-0.06	-0.56	0.20
20	-0.22	-0.47	0.56
22	0.06	0.08	0.03
24	-0.01	-0.16	-0.18
26	0.12	0.03	-0.12
28	0.09	0.02	0.22
30	-0.07	0.16	-0.06
	δx(mm)	δy(mm)	δz(mm)
	0.16	0.26	0.47

Note: For Bundle adjustment method; δx = 0.159 mm, δy = 0.258 mm, δz = 0.472 mm.

Table 2. DLT method.

NN	dx(mm)	dy(mm)	dz(mm)
2	0.01	-0.24	-0.51
4	-0.13	-0.19	0.45
6	0.09	-0.07	-1.14
8	0.10	0.22	-1.01
10	0.41	-0.06	-1.29
12	-0.52	0.18	-0.77
14	-0.05	0.28	1.14
16	0.40	-0.19	0.27
18	-0.09	0.10	1.06
20	0.06	0.14	-0.27
22	-0.18	-0.23	1.09
24	-0.19	0.14	1.21
26	-0.31	-0.05	-0.21
28	-0.50	0.10	0.42
30	0.09	0.03	0.13
	δx(mm)	δy(mm)	δz(mm)
	0.27	0.18	0.80

Note: For DLT method; δx = 0.266 mm, δy = 0.177 mm, δz = 0.797 mm.

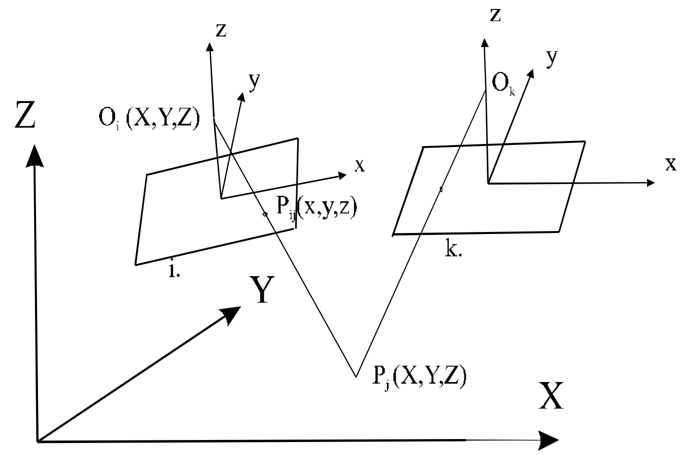

Figure 1. Co-linearity condition.

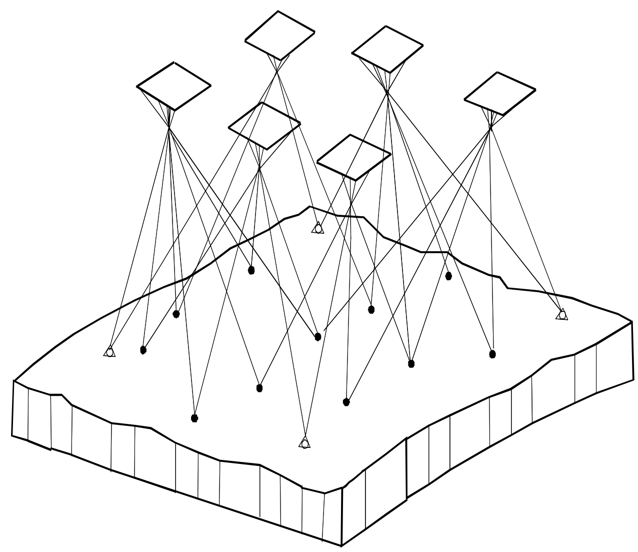

Figure 2. Block balancing by bundle adjustment.

balancing with Bundle adjustment. It is defined mathematically in co-linearity condition. Co-linearity condition necessitates that O_i projection center; P_{ij} picture point and P_j place point are on a line (Figure 1) (Karara, 1971). Co-linearity equation is defined as:

$$\xi = \xi_0 - c * \frac{r_{11}*(X-X_0)+r_{21}*(Y-Y_0)+r_{31}*(Z-Z_0)}{r_{13}*(X-X_0)+r_{23}*(Y-Y_0)+r_{33}*(Z-Z_0)}$$

$$\eta = \eta_0 - c * \frac{r_{12}*(X-X_0)+r_{22}*(Y-Y_0)+r_{32}*(Z-Z_0)}{r_{13}*(X-X_0)+r_{23}*(Y-Y_0)+r_{33}*(Z-Z_0)}$$

As a point in the field is present in many pictures, there are lots of beams that may represent it (Figure 2). In ray balancing process,

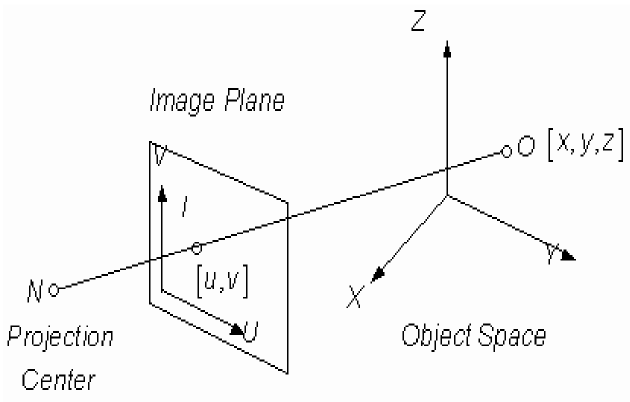

Figure 3. General view of picture and object coordinate system.

check points and picture points in the field, beams for rays in all pictures are balanced as being a whole.

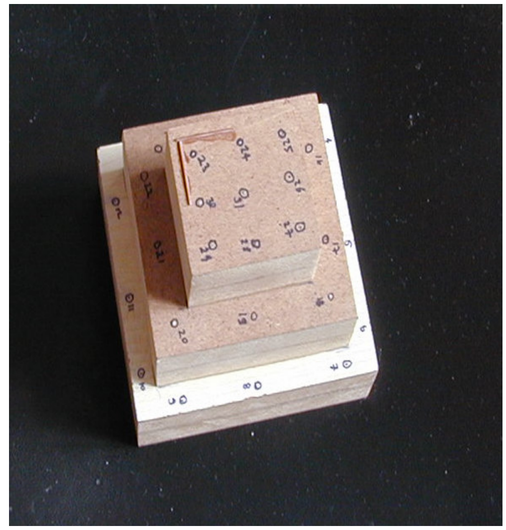

Figure 4. Test field.

DLT method

Mathematical model of DLT are depending on calculation of picture coordinates of a point (x, y) by using object coordinates of that point (Karslı, 1996).

$$x = \frac{L_1X + L_2Y + L_3Z + L_4}{L_9X + L_{10}Y + L_{11}Z + 1}$$

$$y = \frac{L_5X + L_6Y + L_7Z + L_8}{L_9X + L_{10}Y + L_{11}Z + 1}$$

11 Transformation parameters (L_1, L_2, ……, L_{11}) used in equations can be calculated by means of 6 points whose coordinates are known in both systems (picture coordinate system and object coordinate system) (Figure 3) (Toz, 1987).

RESULT AND APPLICATION

A test field was established in order to compare the above mentioned methods: Beam and DLT (Figure 4) (Göktepe, 2005). 31 check points made of radio pack material, which can be sensed by both visible light and roentgen rays, were placed on MDF material on three different planes. Object coordinates of check points were measured by 3D coordinate measurement device having trademark Ferranti in three series. Average values of these coordinates were taken as object coordinates in calculations.

Images of test field shot by Nikon Coolpix 950 digital camera were analyzed by Pictran 2.01 software after forming a stereo model. Images of test field obtained by roentgen device available in Selçuk University Meram Medical Faculty were transferred to computer scanning at 300 dpi resolution. These images were analyzed by DLT method. Absolute precision values of check points obtained by both methods were; Correlation between calculated standard deviation was employed in variance analysis for each three coordinate values.

Results of variance analysis for each three coordinate values seem to be statistically significant. In comparison of the results obtained by DLT and Bundle Adjustment methods, it can be seen that the values for both methods at X and Y directions are very close to each other and the results obtained by Beam method are more precise at Z direction.

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