

THE OUTDOOR RAPID CALIBRATION TECHNIQUE AND REALIZATION OF NON-METRIC DIGITAL CAMERA BASED ON THE METHOD OF MULTI-IMAGE DLT AND RESECTION

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ABSTRACT:

For non-metric CCD digital camera features and the needs of Rapid field non-metric cameras calibration, the error sources was detailed analyzed and a mathematical calibration model has been founded. Both detailed multi-image group iterative method for solving DLT coefficient, the elements of interior orientation and distortion parameters of lens and the multi-image resection method for solving the elements of interior orientation, elements of exterior orientation and distortion parameters of lens have been discussed. A standard steel cage (e.g. Figure 1) has been made for real calibrating non-metric cameras outdoor quickly. In order to verify the accuracy, each method mentioned has been used to solve elements of interior orientation and distortion parameters with the same camera (e.g. Figure 2) and the same test images. The results of accuracy show that the maximum X error was 0.2585mm, the maximum Y error was 0.6719mm and the maximum Z error was 0.1319mm by using multi-image DLT algorithm. On the other hand, the maximum X error was 0.1914mm, the maximum Y error was 0.9808mm and the maximum Z error was 0.1453mm by using multi-image resection algorithm. The forward intersection accuracy of the two methods was quite, and the both were less than 1mm. By using multi-image DLT algorithm the planimetric accuracy was less than 0.2585mm and the height accuracy was less than 0.6719mm. On the other hand, by using multi-image resection algorithm the planimetric accuracy was less than 0.1914mm and the height accuracy was less than 0.9808mm. The planimetric accuracy of resection algorithm was the better than DLT algorithm, but the elevation accuracy of DLT algorithm was the better than resection algorithm. In summary both method can be accepted for non-metric camera calibration. But also the solver accuracy in the inner orientation elements and distortion parameters was not very high has been noted. However for non-metric camera, the true value of inner orientation elements and lens distortion were unknown did not affect the accuracy of photogrammetry.

1. INTRODUCTION

The digital camera is based on the Semiconductor Technology, The Charge Coupled Devices (CCD), which are arrange in a line or a rectangular region square, constitute the imagesensitive linear array or the imagesensitive surface, auxiliary by optical system, mechanical device and electronic circuit's equipment. The digital CCD camera has the volume small, facile, durable, the actual maintenance convenience as well as merits and so on strong earthquake resistance ability. More importantly, speaking of the digital CCD sensor's character and the sensitivity, it can be stability for a long time. This means that the digital CCD camera may be calibrated(Wang Lei, 2002). The GDOP of digital CCD camera's focal plane decides in these photoconductive cells's geometry position precision. Each photoconductive cell is equal to a pixel, it records a single color value, forms a picture element, and all picture elements form an image. A digital CCD camera's big advantage is each element's position does not change. Therefore it does not need to use the collimation marks to determine the CCD camera's internal relevant position. Otherwise the film is not so, it has the film distortion error.

There are two types digital cameras can be use for photogrammetry: metric digital camera and non-metric digital camera. With the rapid development of science and technology, the performance of normal non-metric digital camera is increasingly enhanced, which easy satisfies many photographic conditions with a low cost. Therefore, the digital camera is used to the close-range photogrammetry widely. But in generally

speaking, the elements of interior orientation are unknown and the lens distortion is too bigger for normal non-metric digital camera. These shortcomings badly influence measurement accuracies. Recently the research of non-metric digital camera calibration was more and more.

In the literature that I have seen(HE Min, 2011a)(Miao Hongjie, 2005), in the digital camera calibration, which generally is based on outdoor standardization field or indoor standardization field, we can obtain elements of interior orientation and/or the lens distortion by solute the resection equation or direct linear transformation (DLT) equation. When we solute interior orientation parameters and lens distortion parameters simultaneously in three dimension with multi-Images, we find it difficult.

In this paper, we has founded two mathematical model of the camera calibration, put forward the adoption of the multi-images iteration method to calculate the coefficients of the DLT/resection and distortion parameters in groups by three-dimensional ground control points (GCP), The precision of camera calibration are confirmed by the experiments of multi-image resection and forward intersection, and the satisfactory effect is obtained.

2. ANALYSIS OF ERROR SOURCES

The errors which the digital CCD camera produces are mainly divided into the spectrum error and the geometrical error. The spectrum error, which is mainly caused by CCD, consists of

background noise, accidental noise and invalid pixel. The geometrical error mainly is produced by its optics lens and the image sampling circuit. The geometrical error divides into optics error and the electricity error generally. Then we introduced separately the CCD camera produces spectrum error and geometrical error's analysis and examination.

2.1 Spectrum Error

2.1.1 Determination and Elimination of Background Noise:

When the camera lens cap is close and the f-number is 22, we release the shutter and get a gray matrix from the photo. This matrix is called background noise. Background noise can affect signal-noise ratio of the digital image. A good camera and the sampling system should have a low amplitude and uniform background noise. The way of eliminating the background noise is to use current image to subtract its background noise.

2.1.2 Elimination of Accidental Noise: The accidental noise is presents the random along with the time change gradation step change, when carries on the examination, may absorb many phantoms continuously to the identical scenery. Takes its gradation average value to take the final grey level, like this may eliminate the accidental noise effectively the influence.

2.1.3 Elimination of Invalid Pixel: The CCD maybe exist individual damage cell or the cell of physical character is unstable. This kind of cell is called invalid pixel. The way of Elimination is to interpolate this invalid pixel by the neighbouring pixel

2.2 Geometrical Error

The geometrical error of the digital CCD camera mainly refers to the lens distortion error. It includes the radial distortion error and the tangential distortion error. The lens distortion error generally performs for the centre small and peripheral big. The radial distortion error is

$$\begin{cases} \Delta x = (x - x_0)(k_1 r^2 + k_2 r^4 + k_3 r^6 + \dots) \\ \Delta y = (y - y_0)(k_1 r^2 + k_2 r^4 + k_3 r^6 + \dots) \end{cases} \quad (1)$$

The tangential distortion error (Shao Xihui, 1991) is

$$\begin{cases} \Delta x = p_1[r^2 + 2(x - x_0)^2] + 2p_2(x - x_0)(y - y_0) \\ \Delta y = p_2[r^2 + 2(y - y_0)^2] + 2p_1(x - x_0)(y - y_0) \end{cases} \quad (2)$$

where

$$r = \sqrt{(x - x_0)^2 + (y - y_0)^2}$$

x, y = pixel coordinates

x_0, y_0 = principal point of photograph coordinates

k_1, k_2, k_3, \dots = radial distortion coefficients

$p_1, p_2,$ = tangential distortion coefficients

3. CALIBRATION ALGORITHM OF MULTI-IMAGE DLT

The indoor specialized optics check-out facility and the outdoor standardization field are two general methods of calibration. However, this paper has used a standard portable steel cage outdoor, which is approximately 50cm long, 50cm wide and 50cm high. It has six levels of elevation differences altogether

approximately 50cm and altogether 61 control points. This site is presented in Figure 1.



Figure 1 Standard Portable Steel Cage

For the non-metric digital camera, the principal-distance f is unknown and it has not collimating marks. Therefore DLT, which finds the relationship between the photo coordinate system and the ground coordinate system, is direct algorithm without the elements of interior orientation. It is very fit for the calibration of digital camera. However, the traditional DLT is low precision and not easy to converge. So solution is to be difficult. When the control points have small altitude difference, we can not synchronously obtain elements of interior orientation and the lens distortion by solve the DLT equation. So we put forward the adoption of the multi-images iteration method to calculate the coefficients of the DLT and distortion parameters in groups by three-dimensional ground control points (GCP). The precision of camera calibration are confirmed by the experiments of multi-image resection and forward intersection, and the satisfactory effect is obtained.

3.1 Improved DLT with Distortion Error Correction

The DLT equation with distortion error correction is

$$\begin{cases} x - x_0 + \Delta x + \frac{XL_1 + YL_2 + ZL_3 + L_4}{XL_9 + YL_{10} + ZL_{11} + 1} = 0 \\ y - y_0 + \Delta y + \frac{XL_5 + YL_6 + ZL_7 + L_8}{XL_9 + YL_{10} + ZL_{11} + 1} = 0 \end{cases} \quad (3)$$

where X, Y, Z = GCP coordinates

L_1, L_2, L_3, \dots = DLT coefficients

$\Delta x, \Delta y$ = distortion coefficients

It is obvious that we can calculate the DLT coefficients and the distortion parameters with some control points from Eq. (3). If we ignore high order terms of Eq. (1), the distortion parameters are k_1, k_2, k_3, p_1, p_2 . We need 8 control points at least to solve the 11 DLT coefficients and 5 distortion parameters.

3.2 Solution of the DLT Coefficients

Observation equation is

$$\begin{cases} -(L_1 X + L_2 Y + L_3 Z + L_4) / A - L_9 X(x' + \Delta x) / A \\ -L_{10} Y(x' + \Delta x) / A - L_{11} Z(x' + \Delta x) / A - (x' + \Delta x) / A = v_x \\ -(L_5 X + L_6 Y + L_7 Z + L_8) / A - L_9 X(y' + \Delta y) / A \\ -L_{10} Y(y' + \Delta y) / A - L_{11} Z(y' + \Delta y) / A - (y' + \Delta y) / A = v_y \end{cases} \quad (4)$$

Type of Matrix is

$$V = C\Delta + L \quad (5)$$

where $x' = x - x_0, y' = y - y_0$
 $A = L_9X + L_{10}Y + L_{11}Z + I$
 $\Delta = [L_1 \sim L_{11}]^T$
 $V = [v_x v_y]^T$
 $L = -\frac{1}{A} [x' + \Delta x \quad y' + \Delta y]^T$

$$C = -\frac{1}{A} \begin{bmatrix} X & Y & Z & 1 & 0 & 0 & 0 & 0 & (x' + \Delta x)X & (x' + \Delta x)Y & (x' + \Delta x)Z \\ 0 & 0 & 0 & 0 & X & Y & Z & 1 & (y' + \Delta y)X & (y' + \Delta y)Y & (y' + \Delta y)Z \end{bmatrix}$$

Normal equation is

$$C^T C \Delta + C^T L = 0 \tag{6}$$

3.3 Solution of the Distortion Parameters and elements of interior orientation

For weakening the influence of correlation between DLT coefficients and principal point of photograph, we regard x_0 and y_0 as undetermined parameters. From the Eq. (3) and the Eq. (4) we can obtain the following equation

$$\left. \begin{aligned} &-(k_1 r^2 + k_2 r^4 + k_3 r^6) x' - p_1 (r^2 + 2x'^2) - 2p_2 x' y' \\ &+ x_0 - x - L_x / A = v_x \\ &-(k_1 r^2 + k_2 r^4 + k_3 r^6) y' - 2p_1 x' y' - p_2 (r^2 + 2y'^2) \\ &+ y_0 - y - L_y / A = v_y \end{aligned} \right\} \tag{7}$$

Type of Matrix is

$$V = C \Delta + L \tag{8}$$

where

$$C = -\begin{bmatrix} r^2 x' & r^4 x' & r^6 x' & r^2 + 2x'^2 & 2x' y' & -1 & 0 \\ r^2 y' & r^4 y' & r^6 y' & 2x' y' & r^2 + 2y'^2 & 0 & -1 \end{bmatrix}$$

$$\Delta = [k_1 \quad k_2 \quad k_3 \quad p_1 \quad p_2 \quad x_0 \quad y_0]^T$$

$$V = [v_x v_y]^T$$

$$L = -[x + L_x / A \quad y + L_y / A]^T$$

$$L_x = L_1 X + L_2 Y + L_3 Z + L_4$$

$$L_y = L_5 X + L_6 Y + L_7 Z + L_8$$

Normal equation is

$$C^T C \Delta + C^T L = 0 \tag{9}$$

4. CALIBRATION ALGORITHM OF MULTI-IMAGE RESECTION

4.1 Single Image Resection with Distortion Correction

Because the collinear equation is non-linear transformations, the collinear equation can be linearized for solving orientation parameters. The linearization considers the Taylor series first-order expansion of collinear equation collinear equation at the Initial value. The linearized collinear equation with distortion error correction (Chen Xingfeng, 2011b) is

$$\begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & c_{16} \\ c_{21} & c_{22} & c_{23} & c_{24} & c_{25} & c_{26} \end{bmatrix} \begin{bmatrix} dX_s \\ dY_s \\ dZ_s \\ d\varphi_s \\ d\omega_s \\ d\kappa_s \end{bmatrix} + \begin{bmatrix} c_{17} & c_{18} & c_{19} \\ c_{27} & c_{28} & c_{29} \end{bmatrix} \begin{bmatrix} df \\ dx_0 \\ dy_0 \end{bmatrix} \dots \tag{10}$$

$$+ \begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} & d_{15} \\ d_{21} & d_{22} & d_{23} & d_{24} & d_{25} \end{bmatrix} \begin{bmatrix} k_1 \\ k_2 \\ k_3 \\ p_1 \\ p_2 \end{bmatrix} - \begin{bmatrix} l_x \\ l_y \end{bmatrix} = 0$$

where $X_s, Y_s, Z_s, \varphi, \omega, \kappa$ = elements of exterior orientation
 f, x_0, y_0 = elements of interior orientation
 k_1, k_2, k_3, p_1, p_2 = distortion parameters

$$\left. \begin{aligned} d_{11} &= (x - x_0)r^2 \\ d_{12} &= (x - x_0)r^4 \\ d_{13} &= (x - x_0)r^6 \\ d_{14} &= r^2 + 2(x - x_0)^2 \\ d_{15} &= 2(x - x_0)(y - y_0) \end{aligned} \right\}$$

$$\left. \begin{aligned} d_{21} &= (y - y_0)r^2 \\ d_{22} &= (y - y_0)r^4 \\ d_{23} &= (y - y_0)r^6 \\ d_{24} &= 2(x - x_0)(y - y_0) \\ d_{25} &= r^2 + 2(y - y_0)^2 \end{aligned} \right\}$$

$$\left. \begin{aligned} c_{11} &= \frac{1}{Z}(a_1 f + a_3 x) \\ c_{12} &= \frac{1}{Z}(b_1 f + b_3 x) \\ c_{13} &= \frac{1}{Z}(c_1 f + c_3 x) \\ c_{14} &= b_1 \frac{xy}{f} - b_2 (f + \frac{x^2}{f}) - b_3 y \\ c_{15} &= -\frac{x^2}{f} \sin \kappa - \frac{xy}{f} \cos \kappa - f \sin \kappa \\ c_{16} &= y \\ c_{17} &= \frac{x}{f} \\ c_{18} &= 1 \\ c_{19} &= 0 \\ l_x &= x - x' \end{aligned} \right\}$$

$$\left. \begin{aligned} c_{21} &= \frac{1}{Z}(a_2 f + a_3 y) \\ c_{22} &= \frac{1}{Z}(b_2 f + b_3 y) \\ c_{23} &= \frac{1}{Z}(c_2 f + c_3 y) \\ c_{24} &= b_1 (f + \frac{y^2}{f}) - b_2 \frac{xy}{f} + b_3 x \\ c_{25} &= -\frac{xy}{f} \sin \kappa - \frac{y^2}{f} \cos \kappa - f \cos \kappa \\ c_{26} &= -x \\ c_{27} &= \frac{y}{f} \\ c_{28} &= 0 \\ c_{29} &= 1 \\ l_y &= y - y' \end{aligned} \right\}$$

From the Eq. (10) we can obtain the following observation equation

$$\left. \begin{aligned} v_x &= c_{11} dX_s + c_{12} dY_s + c_{13} dZ_s + c_{14} d\varphi + c_{15} d\omega + c_{16} d\kappa + c_{17} df \\ &+ c_{18} dx_0 + c_{19} dy_0 + d_{11} k_1 + d_{12} k_2 + d_{13} k_3 + d_{14} p_1 - d_{15} p_2 - l_x \\ v_y &= c_{21} dX_s + c_{22} dY_s + c_{23} dZ_s + c_{24} d\varphi + c_{25} d\omega + c_{26} d\kappa + c_{27} df \\ &+ c_{28} dx_0 + c_{29} dy_0 + d_{21} k_1 + d_{22} k_2 + d_{23} k_3 + d_{24} p_1 - d_{25} p_2 - l_y \end{aligned} \right\} \tag{11}$$

Type of Matrix is

$$V = C \Delta + L \tag{12}$$

where $V = [v_x v_y]^T, L = [l_x \quad l_y]^T$

$$C = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & c_{16} & c_{17} & c_{18} & c_{19} & d_{11} & d_{12} & d_{13} & d_{14} & d_{15} \\ c_{21} & c_{22} & c_{23} & c_{24} & c_{25} & c_{26} & c_{27} & c_{28} & c_{29} & d_{21} & d_{22} & d_{23} & d_{24} & d_{25} \end{bmatrix}$$

$$\Delta = [dX_s \quad dY_s \quad dZ_s \quad d\varphi \quad d\omega \quad d\kappa \quad f \quad x_0 \quad y_0 \quad k_1 \quad k_2 \quad k_3 \quad p_1 \quad p_2]^T$$

Normal equation is

$$C^T C \Delta + C^T L = 0 \tag{13}$$

The calibration experimental was done in two steps, e.g. Figure 2. The first step, after two cameras and a tripod and a calibration cage were fixed, many multi-angle pictures were taken to solve each camera's interior orientation elements and distortion parameters, with multi-image DLT and resection independently. Table 1 gave the result of calibration and comparison.

	DLT		Resection	
	Camera I <i>mm</i>	Camera II <i>mm</i>	Camera I <i>mm</i>	Camera II <i>mm</i>
f	36.134391	36.074060	36.3144857	36.3802218
x_0	0.377716	-0.029422	0.09867725	0.16534004
y_0	0.132797	0.128374	0.04919723	-0.14494807
k_1	1.209E-004	2.212E-004	1.5803E-04	1.5203E-04
k_2	9.149E-007	-7.742E-007	2.2004E-07	1.1079E-07
k_3	-8.902e-009	5.002e-010	6.7031E-10	2.31E-10
p_1	-7.787e-005	-8.151e-005	4.8981E-06	2.7895E-05
P_2	2.016e-005	-2.450e-005	2.1424E-06	1.7463E-05

Table 1. The Result of Interior Orientation and Distortion Parameters

The second step, a pair of stereoscopic images were used to compare the accuracy of forward intersection. The resection result of this stereoscopic pair was showed in table 2 and the forward intersection's result of stereoscopic pair was showed in Table 3.

	DLT		Resection	
	Camera I <i>mm</i>	Camera II <i>mm</i>	Camera I <i>mm</i>	Camera II <i>mm</i>
X_S	91.0592	439.4953	89.7228	439.5092
Y_S	1917.5416	1918.3010	1914.8721	1918.4376
Z_S	276.7085	265.5823	276.7437	265.7132
φ	0.2568	3.2346	0.2929	3.2381
ω	1.4074	0.1787	1.4107	0.1758
κ	1.8234	2.0439	1.8200	2.0437
MSE x	0.0023	0.0026	0.0037	0.0027
MSE y	0.0024	0.0038	0.0043	0.0040

Table 2. The Result of Multi-Image Resection

GCP		X <i>mm</i>	Y <i>mm</i>	Z <i>mm</i>
DLT				
P1	MV ^{*1}	258.0880	-4.0185	257.3924
	TV ^{*2}	257.8295	-3.3466	257.3611
	error	0.2585	-0.6719	0.0313
P2	MV	250.8088	-485.2394	236.1824
	TV	250.7558	-485.83	236.3143
	error	0.0530	0.5906	0.1319
P3	MV	189.2726	-178.0339	380.8347
	TV	189.0691	-177.5812	380.7502
	error	0.2035	-0.4527	0.0845
Resection				
P1	MV	257.7273	-3.6918	257.3987

P2	TV	257.8295	-3.3466	257.3611
	error	-0.0102	-0.3452	0.0376
	MV	250.5644	-486.8108	236.3273
P3	TV	250.7558	-485.83	236.3143
	error	-0.1914	-0.9808	0.013
	MV	189.0563	-178.4958	380.6049
P3	TV	189.0691	-177.5812	380.7502
	error	-0.0128	-0.9146	-0.1453

*1 measured value

*2 true value

Table 3. The Result of Forward Intersection

6. CONCLUSION

The results of accuracy show that the maximum X error was 0.2585mm, the maximum Y error was 0.6719mm and the maximum Z error was 0.1319mm by using multi-image DLT algorithm. On the other hand, the maximum X error was 0.1914mm, the maximum Y error was 0.9808mm and the maximum Z error was 0.1453mm by using multi-image resection algorithm.

The forward intersection accuracy of the two methods was quite, and the both were less than 1mm. By using multi-image DLT algorithm the planimetric accuracy was less than 0.2585mm and the height accuracy was less than 0.6719mm. On the other hand, by using multi-image resection algorithm the planimetric accuracy was less than 0.1914mm and the height accuracy was less than 0.9808mm. The planimetric accuracy of resection algorithm was the better than DLT algorithm, but the elevation accuracy of DLT algorithm was the better than resection algorithm.

In summary both method can be accepted for non-metric camera calibration. But also the solver accuracy in the inner orientation elements and distortion parameters was not very high has been noted. However for non-metric camera, the true value of inner orientation elements and lens distortion were unknown did not affect the accuracy of photogrammetry.

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