AUAOMATED CALIBRATION OF A ZOOM LENS CCD IMAGE SYSTEM FOR VIDEOGRAMMETRY

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ABSTRACT

This paper presents the automated calibration method and the calibration results of the off-the-shelf zoom lens CCD block camera. The CCD camera interior and exterior parameters with respect to the total-station were determined at every step of the focal length settings. The repeatability of the calibrated parameters against zooming action was assessed at five steps of the focal length settings. Both the accuracy and the repeatability for the automated calibration were analyzed.

1 INSTODUCTION

Zoom lenses have many desirable features but appear to be geometrically unstable and difficult to calibrate. It is common knowledge that the zooming camera parameters change with zoom position. The calibration needs to be performed at various focal settings within the zoom range. If the zoom lenses are used in a measurement application at the setting from which the calibrations had been carried out, the camera parameters need to be derived from the calibrated values.

The problem with the use of zoom lenses is the identification of calibration parameters at every used focal setting. For any vision system, geometric distortions caused by system electronics, focal plane construction, and imperfect lenses, lead to a less than perfect two-dimensional representation. In order to achieve precise three-dimensional positioning of objects, it is necessary to calibrate the vision system and correct for the effects of the above mentioned distortions. Changing the focal length alters the interior geometry of the camera, and consequently changes the magnitude of virtually all of interior orientation parameters.

Calibration of zoom lenses at every used focal length by manual processes is complicated and very time consuming. An auto-calibration method needs to be developed for calibrating zoom lenses for photogrammetric applications. The paper presents an auto-calibration routine for zoom lenses that has been developed from the camera-on-theodolite method by Huang and Harley. The results of auto-calibration using the Sony EVI-371 were presented. The repeatability of auto-calibration results was tested on numerous focal lengths to check the stability of the camera against zoom. The warm-up effect of imaging system was also assessed.

2 THE SYSTEM REQUIREMENTS

The system is comprised of the videotheodolite, an image grabber and a desktop computer. This videotheodolite is set at a number of stations during the research. At each station, the theodolite controlled by the desktop computer can precisely rotate at every angular step for the CCD camera to capture images to cover the designed target. The theodolite angular readings were recorded on capturing of each image to calculate the central position and bias error of the designed target in the image.

The CCD camera of the system is the Sony EVI-371D. It is a 1/3inch CCD image sensor with the 752(H) x 582(V) sensing area and its cell size is 6.35(H) x 7.4(V) microns. The zoom lens has the focal length from 5.4mm to 64.8mm, auto focus and 12 X zoom lens. For this calibration, the focus was fixed at a certain distance and the iris was fixed for the solid exposure.

The frame grabber used for this system is the MRT PCMCIA I imaging card. This card can be directly used with a portable computer or with a desktop computer via an adapter. It digitizes both fields of the composite video input and generates a digital image of 508(H) x 480(V) pixels. Only the luminance signal, which is quantified into 8 bits, was used for processing.

In fact, the theodolite chosen for this system is the Geodimeter System 600, which is a total station and includes the features of the servo-assisted drive, the numeric keyboard, the tracklight and the RS-232C communication. By sending the appropriate commands from the computer, the computer controlled the rotating angle of the total station and the data of the angles of the total station are transferred between the total station and the computer. Therefore, the computer can precisely and quickly control the rotating angles of the videotheodolite.

3 CALIBRATION METHOD AND ITS AUTO-PROCEDURE

In the camera-on-theodolite calibration method, two targets were used and kept the suitable depth of field between them. The telescope of the theodolite was rotated to 25 positions so that the image of each target was captured. There were 25 different positions that cover every part of the image frame. For each image telescope position, the horizontal and vertical angle readings were recorded when every image was captured. The corresponding 25 sets of three dimensional co-ordinates of the targets with the respect to the rotating telescope system were calculated by the following equations:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = D \begin{pmatrix} -\cos \nu_0 \sin (h-h_0) \\ \sin \nu \sin \nu_0 + \cos \nu \cos \nu_0 \cos(h-h_0) \\ \cos \nu \sin \nu_0 - \sin \nu \cos \nu_0 \cos(h-h_0) \end{pmatrix}$$

In the equations, D is the distance between the target and the theodolite; h_0 and ν_0 are the horizontal and vertical readings while the theodolite is initially sighting at the target; h and ν are the readings with the captured image. With these corresponding 2D and 3D co-ordinates for 50 points (both targets), the analytical space resection with lens distortion models was performed to determine the interior and exterior parameters. The exterior parameters are the camera to theodolite parameters. For the detail of the camera-on-theodolite calibration method, see the Huang' s previous paper.

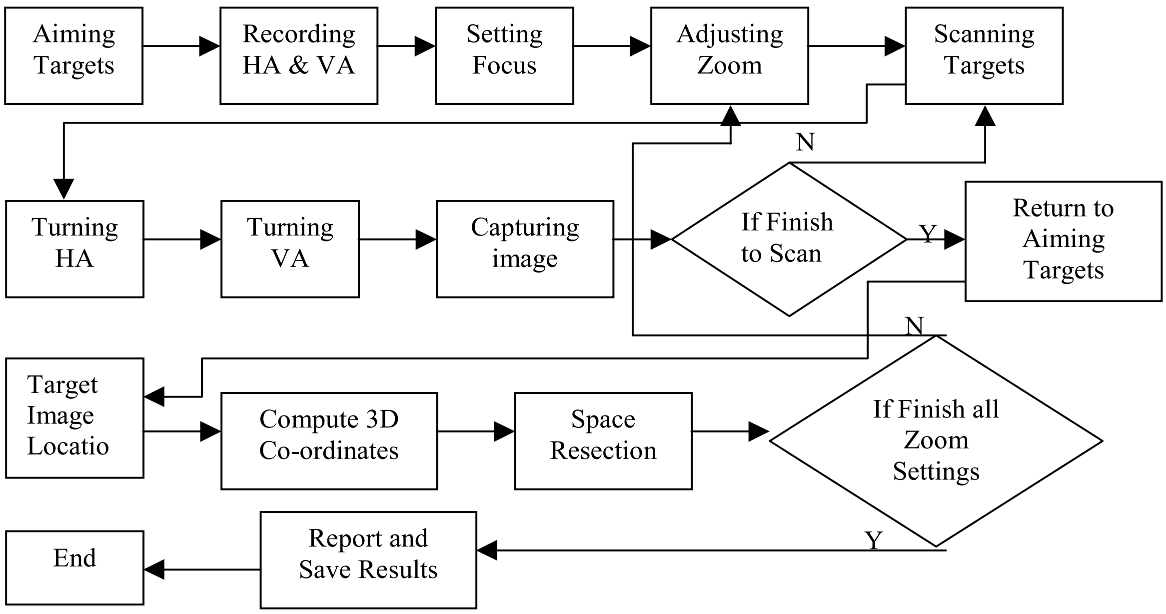

Figure 1. The diagram of auto-calibration procedure

According to this calibration method, the procedure of auto-calibration is shown as the figure 1. The auto-calibration is designed to cover every zoom setting. At every zoom setting, 25 images are captured in 5 X 5 rectangular locations within its field of view so that the targets can cover every part of the zoom lens in 25 images. Besides the camera-on-theodolite parameters, the program can also automatically determine the calibrated interior camera parameters that are the principle point, the principle distance, the affine parameters, three radial lens parameters and two tangential lens parameters at each focal setting.

4 DISTORTION MODEL

The calibrated parameters include the camera exterior orientation parameters with respect to the telescope of the theodolite, the camera interior orientation parameters, and the parameters in the error function model are shown below:

$$\delta x = A*y + x(k_1r^2 + k_2r^4 + k_3r^6) + p_1(r^2 +2x^2) +p_2(2xy)$$
$$\delta y = B*y + y(k_1r^2 + k_2r^4 + k_3r^6) + p_1(2xy) +p_2(r2 +2y^2)$$

Here, A and B are the affine deformation parameters. The ks are the radial lens distortion parameters and the ps are the decentring lens distortion parameters (Brown 1971).

5 WARM-UP EFFECT AND STABILITY TEST

The CCD camera and a target were fitted on two stable pillars. A series of images were automatically captured of the target at a five minutes interval after switch-on. The x and y co-ordinates of captured images were graphed against time as in Fig.2 and Fig. 3. The Fig.2 and the Fig.3 show that the warm-up period is about 4 hours and after 2 hours the x (lines) and y (samples) stayed stable to between 0.01 and 0.02 pixel respectively. In order to minimise the warm-up effect, The CCD camera was always switched on at least two hours before the experiments.

6 AUTO-CALIBRATION RESULTS

The auto-calibration experiments were carried out at twelve identifiable focal length settings. The focal length settings from 5.4mm to 64.8mm were divided into twelve settings. The calibrated values and the root mean squared residuals (RMS) for image co-ordinates are shown in the Table 1 where the symbols are defined as the following:

X_0, Y_0, Z_0	telescope co-ordinates of the camera perspective centre;
x_0,y_0	image co-ordinates of the principle point;
C	principle distance;
A,B	affine deformation parameters;
K_1,K_2,K_3	the radial lens distortion parameters;
P_1,P_2	the tangential distortion parameters;
ω	rotation for the X axis;
ϕ	rotation for the Y axis;
κ	rotation for the Z axis;
RMSx	the root mean squared residuals of image samples for target center;
RMSy	the root mean squared residuals of image lines for target center;
RMSc	the root mean squared residuals for target center;

Table 1. Auto-calibration Results

	Focal	Settings	(mm)			
Parameters	5.4	6.6	7.7	9.4	11.6	14.5
X_0	-1.098	-0.59	1.525	-0.631	-25.954	-944.666
Y_0	30.84	32.04	33.14	34.84	39.966	39.94
Z_0	59.099	58.656	62.645	62.45	49.282	-228.027
ϕ	-1.69812	4.66964	1.5049	2.09242	1.63453	-1.24384
ω	1.55673	1.55904	1.58827	1.58111	1.62226	1.37764
κ	0.12343	-6.24466	-3.07934	-3.66765	-3.21029	-0.33057
C	919.673	1069.289	1223.358	1503.718	1847.431	2200.899
x_0	265.3164	267.1964	266.2999	276.0205	281.0262	520.4202
y_0	247.0998	249.8458	244.162	255.7668	172.4327	-471.451
K_1	4.24E-12	2.27E-12	1.16E-12	1.70E-12	-1.08E-12	4.34E-13
K_2	-4.59E-21	-1.04E-21	4.94E-22	-1.78E-21	3.26E-21	7.25E-24
K_3	3.98E-30	4.36E-31	-6.85E-31	8.71E-31	-1.82E-30	-2.79E-34
P_1	-1.63E-09	-1.29E-09	-1.96E-09	-8.34E-10	1.27E-09	1.18E-09
P_2	-9.84E-10	-4.24E-10	4.35E-11	-2.91E-09	-7.52E-10	-4.16E-09
A	2.82E-06	1.26E-06	9.53E-06	4.09E-06	4.75E-06	4.63E-05

B	-1.78E-05	-1.45E-05	-1.90E-05	-2.61E-05	-8.63E-06	-1.15E-04
RMSx	0.057	0.092	0.052	0.100	0.139	0.122
RMSy	0.127	0.116	0.121	0.167	0.151	0.180
RMSc	0.098	0.105	0.093	0.138	0.145	0.154

	Focal	Settings	(mm)			
parameters	18.4	24.5	32.7	44.2	59.7	64.8
X_0	5.282	1.914	1.173	1.006	-6.069	-582.122
Y_0	43.84	45.74	51.99	58.19	69.72	89.94
Z_0	48.626	48.455	1037.541	45.794	47.46	224.997
ϕ	1.23139	-0.71444	-0.18639	0.83815	1.09493	-6.63511
ω	1.53806	1.52006	1.66582	1.59435	1.58543	1.56287
κ	-2.80636	-0.85959	-1.39357	-2.41422	-2.66987	5.06003
C	2970.936	3011.576	3754.129	5659.798	7663.076	10480.06
x_0	312.6916	396.7678	-330.0771	211.2441	262.3246	338.7931
y_0	385.2845	193.8781	377.5177	232.8796	258.5213	119.4646
K_1	4.09E-12	-6.39E-14	7.91E-13	8.79E-12	6.43E-12	4.57E-13
K_2	-1.05E-20	5.05E-22	3.01E-23	-1.97E-20	-1.24E-20	-5.26E-22
K_3	7.36E-30	-1.78E-31	-2.66E-33	1.37E-29	7.75E-30	1.62E-31
P_1	6.74E-10	2.80E-10	-4.44E-08	0	0	-6.25E-10
P_2	-4.97E-10	-1.70E-10	4.53E-09	0	0	1.88E-10
A	-1.27E-05	9.54E-06	-1.10E-04	-1.22E-05	-1.38E-06	-2.92E-06
B	1.26E-05	-5.71E-06	-5.09E-04	8.75E-07	-3.93E-05	-1.01E-05
RMSx	0.161	0.166	0.113	0.112	0.168	0.082
RMSy	0.177	0.177	0.231	0.195	0.126	0.090
RMSc	0.169	0.171	0.182	0.159	0.148	0.094

In the auto-calibration experiment, the auto-calibration accuracy was between 0.093 pixels and 0.182 pixels. The auto-calibration accuracy in the line direction was from 0.052 pixels to 0.168 pixels. That in the sample direction was from 0.090 pixels to 0.231 pixels. The line direction had higher accuracy of measurement than the sample direction because the sample direction of CCD camera has the random jitters. Fig. 4 shows the distributions of measurement accuracy for all of the calibrated focal settings. There was a high reliability of calibration when the measurement accuracy was high. Generally, the shorter focal length led to the higher accuracy of calibration.

7 REPEATABILITY OF CALIBRATED VALUES

It was expected that the calibrated parameter values of each focal setting retained certain accuracy when the lens returned to the focal setting after zooming in or out. In order to assess this repeatability, the auto-calibration was repeated at some of the calibrated focal settings after sufficient zoom actions. The focusing was fixed at the same distance as the last calibration. The calibrated values for the repetitions are shown in the table 2. Table 3 gives the RMS errors between the detected target image centers and the their corresponding image positions computed from 3D co-ordinates using the calibrated orientation parameter values determined at the first round. Fig. 5 shows the comparison of the measurement accuracy for the target centers in the same focal settings between the calibration values and the reference-calibration values. The repeated focal settings show an ideal consistence of measurement accuracy when the lens is in the wide field of view. When the lens is in the narrow field of view, the RMS values have a large bias because there is a relatively large uncertainty in both calibration and measurement of the lens.

Table 2. Repeated Auto-calibration Results

	Repeat	focal	Settings		
parameters	5.4	6.6	18.4	59.7	64.8
X_0	-1.178	-1.711	5.657	-6.339	-583.493
Y_0	28.366	34.966	46.766	72.566	92.866
Z_0	59.018	58.594	47.619	48.66	225.334
ϕ	1.50528	1.26022	1.91549	1.19263	1.01683
ω	1.58514	1.58701	1.66597	1.5855	1.55539
κ	-3.08034	-2.83522	-3.48937	-2.76762	-2.59121

C	919.17	1068.741	2955.115	7675.3	10319.68
x_0	266.2204	262.6462	377.4435	272.3104	343.9194
y_0	246.6523	245.5286	28.5754	253.7907	284.6795
K_1	2.81E-12	2.19E-12	-2.54E-13	9.47E-12	-6.53E-12
K_2	3.61E-22	-5.71E-22	5.54E-22	-2.09E-20	1.02E-20
K_3	-7.52E-31	-3.68E-32	-1.20E-31	1.43E-29	-5.07E-30
P_1	-2.13E-09	-1.08E-09	0	0	-6.13E-09
P_2	-1.21E-09	-2.91E-10	0	0	9.91E-09
A	-1.01E-07	-2.09E-06	2.20E-05	-3.28E-05	6.33E-06
B	-2.39E-05	-2.08E-05	-3.32E-05	-4.47E-05	3.96E-05
RMSx	0.069	0.086	0.135	0.168	0.087
RMSy	0.129	0.109	0.202	0.105	0.282
RMSc	0.103	0.099	0.172	0.140	0.208

Table 3. The RMS values of the accuracy of target center for reference-calibration parameters

		repeated	focal	settings	
	5.4	6.6	18.4	59.7	64.8
RMSx	0.185	0.152	0.292	0.527	0.25
RMSy	0.227	0.177	0.294	0.526	1.071
RMSc	0.207	0.165	0.293	0.526	0.777

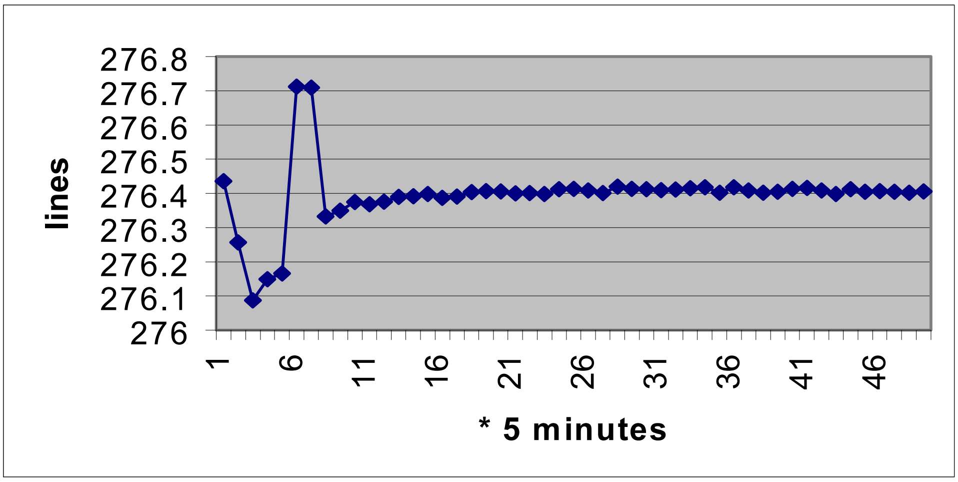

Figure 2. Lines of Warm-up effect

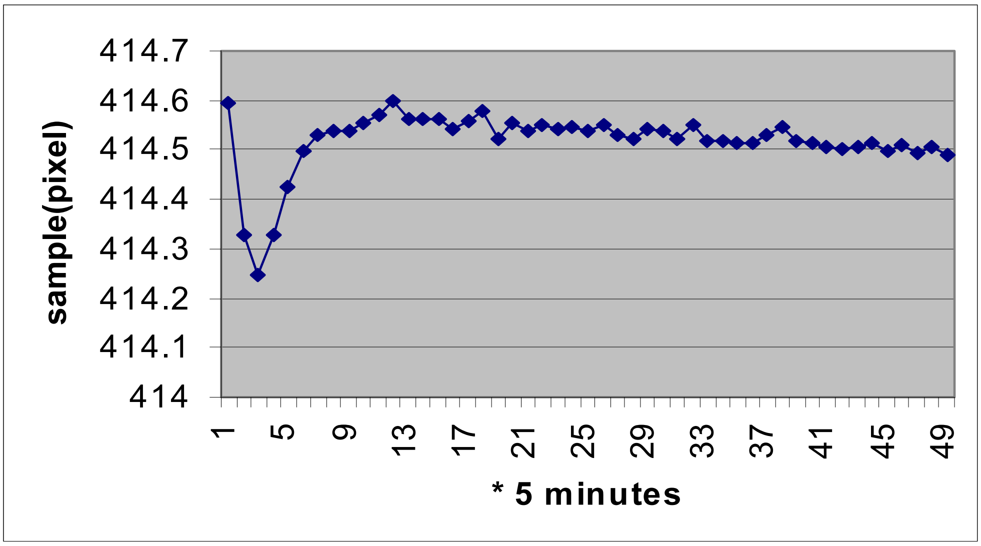

Figure 3. Samples of Warm-up Effect

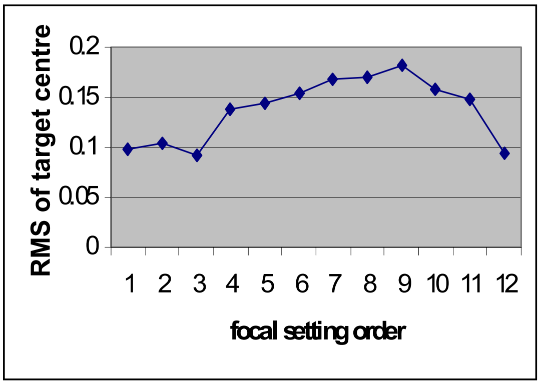

Figure 4. The distributions for the accuracy target center

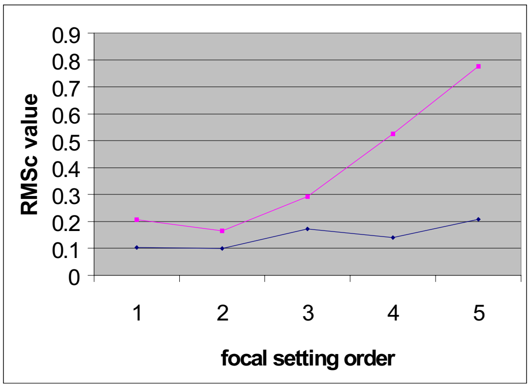

Figure 5. The comparison of two time distributions of for the accuracy of target center

8 CONCLUSIONS

The results of this research prove that automatic calibration of a motorized video-theodolite equipped with a zoom lens is possible and effective using the method and routine proposed. The camera-on-theodolite method demonstrated once again its benefits for frequent camera calibration and video-theodolite calibration. The repeatability of the calibrated zoom camera system against zooming ranges from 0.2 to 0.8 pixel, with the better result at the wide field angles. This accuracy for zoom camera can satisfy many surveying applications, especially when considering the very small angle subtended by a pixel at zoom-in settings.

REFERENCES

Huang, Y.D. & Harley, I.1990, CCD camera calibration without a control field, International Archives of Photogrammetry and Remote Sensing, Zurich, Vol. 28, Part 5/2, pp. 1028-34.

Wiley, A.G. & Wong, K.W., 1990, Metric aspects of zoom vision. International Archives of Photogrammetry and Remote Sensing, Zurich, Vol. 28, Part 5/1, pp.112-118.

Wiley, A.G. & Wong, K.W., 1995. Geometric calibration of zoom lenses for computer vision metrology. Photogrammetric Engineering and Remote Sensing, Vol. 61, No. 1, pp.69-74.