IMAGE ORIENTATION BY
COMBINED BUNDLE ADJUSTMENT WITH FIXED IMAGERIES

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ABSTRACT

According to self-calibration bundle block adjustment, a mathematical model which solutes exterior orientation elements of the new imageries by using fixed imageries in the same area is set up at first. The orientation parameters of the fixed imageries are previously obtained. Several sets of aerial imageries at different scales are simulated based on a piece of DOM (Digital Orthophoto Map) with a scale of 1:50,000 and corresponding DEM (Digital Elevation Model) with the interval of grid being 100 meters of some certain area. Finally, the exterior orientation elements of these new imageries and 3D coordinates of photogrammetric points are calculated by combined bundle block adjustment with the derived mathematical model. The empirical results show that the exterior orientation elements and the coordinates of the photogrammetric points are identical between the mentioned method and the conventional bundle block adjustment for the two periods of imageries at the same scale. However, when the image scales are different the adjusted accuracy has an apparent decrease but can still meet the specification of topographic maps.

The experiment has verified that the determination of the orientation parameters of the new imageries by using the fixed imageries is correct in theory and is feasible in practice. And the accuracy of 3D coordinates of the photogrammetric points, which are purely gained by combined adjustment with two periods of imageries, satisfies the requirement of the specification of topographic maps. That is to say, aerial triangulation without ground control points (GCPs) can be truly realized. It will have glory application future on the map revision, the update of geographic spatial information database and automatic change detection of multi-temporal imageries.

1. INTRODUCTION

As is now well known, the key task for aerial photogrammetry is to determine the orientation parameters of aerial imageries quickly and correctly. For a long time, this goal has been indirectly achieved by aerotriangulation with a lot of GCPs. In order to reduce GCPs in photogrammetry, a combined block adjustment for photogrammetric observations and various auxiliary data was studied since the beginning of 1950s. Despite many attempts, none of these efforts was able to achieve a practical breakthrough because the used instruments were very expensive and the auxiliary data had poorer quality. In the 1970s, the USA developed GPS. It offers new possibilities to extremely precise positioning of airborne cameras and sensors during the photo flights. The technology of combined block adjustment with 3D coordinates of the camera stations, which determined by differential GPS positioning based on carrier phase observations, avoids hard field survey for GCPs and especially provides a topographic map of inaccessible regions of the Earth. This is called GPS-supported aerotriangulation, which has led to a small technological revolution in aerial photogrammetry (*Ackermann, 1994*). However, the superiority of GPS-supported aerotriangulation only lies in photogrammetric procedure of the great field, the medium and small scale, or inaccessible regions of the Earth (*Yuan, 2000*). In the 1990s, combined use of GPS and inertial measurement unit (IMU) was studied to determine the orientation parameters during the photo flights in aerial photography. According to current experiments, this combined system of GPS/IMU is too expensive and the accuracy of exterior orientation elements cannot satisfy the requirements of photogrammetry at large and medium scale (*Cannon, 1996*; *Karsten, 2000*; *Gruen, 2001*; *Helge*, *2002; Yastikli and Jacobsen*, *2002*).

With the development and widely application of the digital photogrammetry, a great count of 4D products (DEM, DOM, DLG, DRG) has been produced and corresponding database have been set up. In these products, DEM database records 3D coordinates of ground objects, and DOM database stores the orthoimages. These data can be conveniently accessed and used. At the same time they need continual update. In addition, the aerial photography with GPS navigation system can take photo at an appointed position. It supplies fast technologies for revision of maps and update of geographic spatial information database. During these operations, if we can use some fixed imageries to get orientation parameters of the new imageries correctly, the aerial photogrammetry will become greatly simplified. Based on this thought, this paper studies how to set up a mathematical model which solutes exterior orientation elements of the new imageries by using fixed imageries in the same area, and how to determine the orientation parameters of the new imageries and the positions of ground objects by combined adjustment with two periods of imageries. The paper aims at using existing data of DEM and DOM in the same area and not using any GCP and data of GPS/IMU to determine orientation parameters of new aerial imageries quickly. It tries to verify the correctness and the feasibility of the theory presented in the paper by simulated experiments, and to realize really aerial triangulation without any GCP.

2. MATHMATIC MODEL OF ADJUSTMENT

Generally, the model of self-calibration bundle block adjustment can be written in matrix form as following:

$$V_x = At + Bx + Cs - l_x, \quad E$$
$$V_s = \quad\quad E_s s - l_s, \quad P_s \quad\quad (1)$$

Where,

V_x is the correction vector of image coordinates;

V_s is the correction vector of virtual observation of additional parameters;

$x = \begin{bmatrix} \Delta X & \Delta Y & \Delta Z \end{bmatrix}^T$ is the vector increment of the unknowns of object point coordinates;

$t = \begin{bmatrix} \Delta\varphi & \Delta\omega & \Delta\kappa & \Delta X_s & \Delta Y_s & \Delta Z_s \end{bmatrix}^T$ is the vector increment of the unknowns of exterior orientation elements;

$s = \begin{bmatrix} a_1 & a_2 & a_3 & \cdots \end{bmatrix}^T$ is the vector of additional parameters;

A, B, C are three coefficient matrices whose elements are the partial derivatives of the collinearity condition equations with respect to the unknowns t, x, c, respectively;

E, E_x, E_s are three unit matrices

$l_x = \begin{bmatrix} x - (x) \\ y - (y) \end{bmatrix}$ is the residual vector of image coordinates. Where, x, y is the image observations; (x), (y) is the approximation of image coordinates calculated by the collinearity condition equation;

l_s is the residual vector of the virtual observations of additional parameters;

P_s is the weight matrix of the virtual observations of additional parameters, and it can be determined by the sign-noise rate of the image observations;

According to equation (1), error equations are formulated for each point in the new imageries and the fixed imageries.
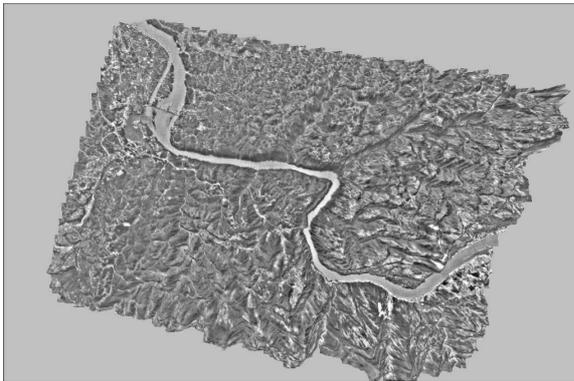
Figure 1. DOM

The empirical block covers a totally mountainous area about 695km^2 extension. The maximum height difference of the terrain is 926m. Because the height difference is so large, the aerial simulated photography are carried out with normal-angle camera at the scales of 1:20,000 and 1:40,000, and at each scale

Additionally, regarding obtained exterior orientation elements as weighted measurements, the equation can be formulated as:

$$V_t = E_t t - l_t, \quad P_t \quad\quad (2)$$

Where,

V_t is the correction vector of observations of exterior orientation elements;

l_t is the residual vector of observations of exterior orientation elements, it is zero when regarding exterior orientation elements of the fixed imageries as approximation;

$P_t = \dfrac{\sigma_0^2}{\sigma_t^2} E$ is the weight matrix of observations of exterior orientation elements. σ_0^2 is the variance of image coordinates, σ_t^2 is the variance of exterior orientation elements.

By combining equation (1) and equation (2), the mathematic model is formulated, which solutes exterior orientation elements of the new imageries by using fixed imageries in the same area. Of course, the orientation parameters of the fixed imageries must be previously obtained. When the same points in the two periods of imageries are measured and the account are enough, it can not only determine the exterior orientation elements of new imageries, but also solute 3D coordinates of all ground objects.

3. SIMULATION OF AERIAL PHOTOGRAPH

To verify the correctness of the mathematic model mentioned above and test the practical accuracy of the combined bundle block adjustment, several sets of aerial imageries at different scales are simulated in this paper. They are acquired based on a piece of DOM with a scale of 1:50,000 and the corresponding DEM with the interval of grid being 100 meters. Figure 1 and figure 2 show the DOM and DEM in the same area, respectively.
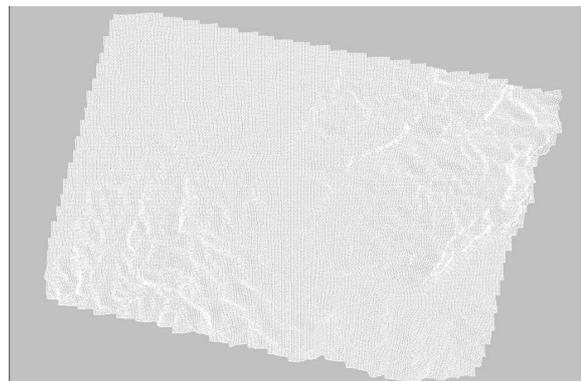
Figure 2. DEM

the testing area is several times covered by imageries with different flight pattern. During the simulated photography, the exterior orientation elements of each image are previously assumed according to aerial photographic specification for 1:5,000 1:10,000 1:25,000 1:50,000 1:100,000 scale

topographic maps (*State Bureau of Technology Supervision, 1996*). Each point in imagery is interpolated and positioned in DEM strictly according to collinearity condition equation. Its gray is given the gray value of corresponding point in DOM based on the ground coordinate. For these simulated imageries, their orientation parameters, image coordinates and ground coordinates are known. It is very convenient to evaluate precisely the practical accuracy of block adjustment. Table 1 shows the main technical data of each set of simulating imageries.

Table 1. Technical data of aerial imageries

Item	Parameters				
	Imagery-1	Imagery-2	Imagery-3	Imagery-4	Imagery-5
strip number	11	10	5	4	5
image number	11×15	10×12	5×7	4×6	5×7
observed point number per image	9~15	10~19	9~15	13~32	36~66
object point number	667	667	143	242	629
average image scale	1:20000		1:40000		
frame	23cm×23cm				
principal length	153.189mm				
resolution of digital imagery	25µm				
heading overlap	60%				
side overlap	40%				

For conveniently adjusting, 9 standard orientation points are extracted in each model of imagery-1 and imagery-3 and transferred to the other imageries of different scale. The orientation points in imagery-2 and imagery-5 are all transferred from imagery-1, and the orientation points in imagery-4 are all transferred from imagery-3. If the transformation of orientation point at the standard position is failure, it must be extracted again in the current image to confirm that the number of orientation points in a model is not less than 9 and there is at least 3 tie points between two neighborhood models. During the experiment, random Gauss noise with zero mean value is added all image observations to simulate the measuring error.

Random noises produce by generator of random number. This experiment adopt fake generator controlled by software. We produce pseuso-random sequence that satisfies the requirement of the experiment at one time. For instance, 4684 random numbers are produced when imagery-1 is simulated. And they are compiled with Gauss distribution. To make the series of random numbers compiled with normal distribution, a series of random numbers are firstly produced by multiplicative congruential method and these numbers are complied with 0-1 distribution. Then these random numbers is standardized to produce a series of random errors. The statistical result shows that the mean value of the series of random errors is zero and the standard variance is $(1 \pm 0.01) \times 5 \mu m$. The series of random errors are added to image coordinates of each orientation point, so we get a set of image observations with measuring errors of 5µm.

Adjustment of imagery-1, imagery-3 and imagery-5 are separately operated by conventional bundle block adjustment software WuCAPS$_{GPS}$ (*Yuan, 2000*). A full ground control points around the perimeter of the area at intervals of two airbases and an elevation ground control points at intervals of four airbases in the center of the area are set up. Table 2 gives the adjustment results.

The data in the table 2 shows that the measuring accuracy of image measurements is not larger than 5.7 m. It accords with the standard variance of the added random errors in image observations. The practical accuracy of adjusted coordinates of photogrammetric points is very close to the theoretic accuracy. It also shows that the program of aerial simulated photography is correct, and produced imageries can be used in the following research.

4. EXPERIMENTS AND RESULT ANALYSIS

The exterior orientation elements of five sets of simulated imageries and 3D coordinates of densification points are calculated by combined bundle block adjustment with the derived mathematical model. The adjustment methods are divided into four ways:

A. Using imagery-1 to calculate the orientation parameters of imagery-2 and the coordinates of densification points;

B. Using imagery-3 to calculate the orientation parameters of imagery-4 and the coordinates of densification points;

C. Using imagery-1 to calculate the orientation parameters of imagery-5 and the coordinates of densification points;

D. Using imagery-5 to calculate the orientation parameters of imagery-1 and the coordinates of densification points.

None of GCPs is used in the above adjustment methods. These bundle block adjustments are accomplished by combine the image observations and the exterior orientation elements of the fixed imageries. According to photogrammetric practice, the exterior orientation elements adopt the ones calculated by the conventional bundle block adjustment in the second section, not the theoretic values of the simulated imageries. And image observations of two periods of imageries have 5µm measuring errors. The adjustment results are shown in table 3.

Table 2. Accuracy of bundle block adjustment

Imagery	GCPs full	GCPs height	σ_0 (μm)	Number	Unconformity	X (m)	Y (m)	Planimetry (m)	Height (m)	φ ( )	ω ( )	κ ( )	X_s (m)	Y_s (m)	Z_s (m)
1	36	30	5.5	631	minimum value	0.000	0.000	0.003	0.001	0	0	0	0.001	-0.007	0.000
					maximum value	-0.410	0.350	0.408	0.945	-56	53	33	0.948	-0.803	0.368
					practical accuracy	0.014	0.090	0.166	0.255	20	19	11	0.341	0.304	0.123
					theoretic accuracy	0.082	0.089	0.121	0.231	20	18	6	0.321	0.310	0.126
3	22	8	5.7	121	minimum value	0.000	0.000	0.012	-0.001	0	0	0	-0.053	-0.029	-0.004
					maximum value	-0.790	0.530	0.822	1.167	-37	-50	-42	1.468	1.560	-0.473
					practical accuracy	0.280	0.160	0.324	0.443	20	16	12	0.648	0.542	0.194
					theoretic accuracy	0.164	0.177	0.242	0.415	18	18	6	0.591	0.619	0.251

Note: 1). Unconformity Δ_i is the difference between computed value and theoretic value.

2). Practical accuracy is $\mu_i = \sqrt{\sum \Delta_i^2 / n}$, $(i = X, Y, Z)$ and $\mu_{pos} = \sqrt{\mu_x^2 + \mu_y^2}$.

3). Theoretic accuracy is $m_i = \sigma_0 \sqrt{\mathrm{tr}(Q_{ii})/n}$, $(i = X, Y, Z)$ and $m_{pos} = \sqrt{m_x^2 + m_y^2}$.

Table 3. Accuracy of bundle block adjustment by using fixed imageries without any GCP

Method	σ_0 (μm)	Number	Unconformity	X (m)	Y (m)	Planimetry (m)	Height (m)	φ ( )	ω ( )	κ ( )	X_s (m)	Y_s (m)	Z_s (m)
A	5.0	667	minimum value	0.000	0.000	0.003	0.000	0	0	0	-0.004	-0.001	0.004
			maximum value	0.440	0.280	0.446	0.946	-47	-57	20	0.784	-0.764	-0.438
			practical accuracy	0.110	0.090	0.143	0.228	17	16	6	0.292	0.266	0.163
B	4.0	242	minimum value	0.000	0.000	0.009	0.006	0	0	0	-0.043	-0.037	-0.019
			maximum value	-0.800	-0.500	0.830	1.144	-37	-34	32	1.803	1.240	0.694
			practical accuracy	0.290	0.170	0.332	0.372	15	13	14	0.688	0.424	0.268
C	5.0	667	minimum value	0.000	0.000	0.008	-0.011	0	0	0	0.004	0.005	0.147
			maximum value	0.470	-0.360	0.474	-1.417	-30	-31	-44	0.876	1.104	0.983
			practical accuracy	0.120	0.090	0.145	0.621	9	11	10	0.2800	0.368	0.605
D	5.3	667	minimum value	0.000	0.000	0.006	1.331	0	0	0	-0.006	-0.002	-1.694
			maximum value	-1.240	0.540	1.238	3.396	69	103	-34	1.290	-2.123	-2.889
			practical accuracy	0.300	0.150	0.335	2.461	22	29	12	0.486	0.561	2.258

From Table 3 the following conclusions can be drawn:

1) Table 3 shows that the accuracy of the orientation parameters of new imageries and 3D coordinates of ground objects is decided by the fixed imageries, the larger the scale, the higher the accuracy; the smaller the scale, the lower the accuracy. And the accuracy of the unknowns relating to planimetry is almost identical between the mentioned adjustment and the conventional bundle block adjustment, but the accuracy of the unknowns relating to height is fluctuated.

2) The results of method A and B shows that the accuracy of the combined bundle block adjustment is highest when the two periods of imageries are at the same scale. Comparing table 3 with table 2, we can learn that the exterior orientation elements of new imageries obtained in this paper are close to the ones calculated by the conventional bundle block adjustment with GCPs. And the accuracy of 3D coordinates of all photogrammetric points is identical between the two methods.

3) The results of method C shows that the accuracy of 3D coordinates of all photogrammetric points is satisfying when a bundle adjustment is conducted by combining a large-scale fixed imageries with a small-scale new imageries in the same area. Comparing to the results of conventional bundle block adjustment in table 2, we can find that the accuracy of the exterior orientation elements of the new imageries and the 3D coordinates of ground objects has no substantial difference.

4) Comparing the results of method D with the adjusted results of imagery-5 in table 2, we can see that the accuracy will decrease apparently when small-scale fixed imageries are used to calculate the exterior orientation elements of large-scale imageries in the same area. The planimetric accuracy of densification points doesn't change much, but the height accuracy decreases terribly. In spite of the fact that the adjusted results still meet the specification for 1:1,000 topographic mapping in mountainous area. The coordinate residuals of check points are less than 5.0m in planimetry and 3.0m in height

(*State Bureau of Technology Supervision, 1991*). This shows that the adjustment method mentioned in this paper has a commendably potential in photogrammetric point determination.

5. SUMMARY

If multi-temporal aerial imageries covering the same area are acquired, this paper has verified theoretic correctness and practical feasibility of the thought that orientation parameters of new imageries can be determined and ground objects can be positioned by measuring the same points between the new imageries and the fixed imageries. It is of great significant to map revision, the update of geographic spatial information database and automatic change detection of imageries, and it shows potential of positioning ground objects by block adjustment without any GCP.

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