THE PRACTICE RESEARCH Of IKONOS-2 POSITIONING AND ITS ACCURACY IN TIBET OF P. R. CHINA

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ABSTRACT:

Tibet is located in the Qinghai-Tibet high plateau in the west of P. R China. In Tibet, the altitude is very high, the weather is extremely bad and few people live there. Especially in the Himalayas area, the terrain undulates frequently and sharply, and its relative height has reached to 3000m. The national foundation control network has not covered the region yet and there is no large scale relief map and high accuracy geospatial data to be used. It is very difficult to survey with the terrestrial method, because of the limitation of the work condition and the traffic condition. Ikonos-2 stereo satellite imagery has the advantages of high ground resolution and wide coverage. It can be used to collect the precise geospatial data and produce the large scale map. As it is different from the aerial photogrammety, the Ikonos-2 RPC, the transform of the datum, the mode of the control point distribution and the method of Ikonos stereo triangulation have been studied by the author. It shows that the precision is under ±0.95m and ±0.55m for plane and height respectively in high mountain area with several ground control points in 1000 square km. These results proof that not only can Ikonos-2 be used in high accuracy spatial position and large scale mapping, but also it need a little field control surveying. Ikonos is very valuable in the Tibet area where the conditions of terrain, traffic and weather are all extremely awful.

1. INTRODUCTION

Photogrammetry or airborne GPS phtogrammetry is a high precision method to obtain the geospatial data, and be used in practice widely. However, it needs a certain Ground Control Points(GCPs) on specifically position. This is a particular difficult thing in Tibet of P.R. China where there is no national foundation control frame and the terrain condition is very horrible.

Ikonos is the commercial high resolution satellite launched in September, 1999. The 1m panchromatic image and 4m color image are produced by Ikonos sensor. Unlike other sensor for mapping, instead of physical sensor model, the RPC model is provide to ultimate users(J. Grodecki, 2001). RPC not only can do the spatial transformation between image space and object space with very high accuracy(M. Kumar, O. T Castro, 2001, E. Baltsavias, M. Pateraki, etc, 2001, C. S. Fraser and H. B. Hanley, 2003), but simplify the physical sensor model and can be implement in various digital photogrammetric system(G.Dial, J. Grodecki, 2002, T., C. Vincent and Y. Hu , 2001). However, the practice researches of Ikonos imagery are limited in WGS-84 system, there is few such researches that transform from image space to national coordinate system, especially in the high altitude, the terrain undulates frequently and sharply area, such as the area of Qinghai-Tibet high plateau and Himalayas in the west of P. R China.

According to the Space imaging estimate, the Ikonos accuracy is the worst in Himalayas area. But the Ikonos image has the advantage of multi-spectrum, the wide coverage, high resolution and the image geometry stabilization, however, it is very high value-added in the area of high altitude and difficulty terrain condition compare to field survey and aerial phtogrammetry for the spatial data can be obtained rapidly and precisely without too much ground control points and the field work can be reduced greatly.

The authors have developed the transform between the Ikonos-2 image space and the national coordinate system based on the RPC, and examined and analysed the results of block adjustment with various control schemes in a practical project near Himalayas mountain, and the encouraging results of high positioning accuracy have been obtained.

2. THE TRANSFORMATION BETWEEN IMAGE SPACE AND THE NATIONAL COORDINATE SYSTEM

2.1 The transformation between the image space and the WGS-84 system

The datum of Ikonos image is WGS-84. The transformation based on rational polynomial coefficient(RPC) is as follow:

$$F_x = x = \frac{\sum_{i=1}^{20} LINE\_NUM\_COEF_i \bullet \rho_i(B,L,H)}{\sum_{i=1}^{20} LINE\_DEN\_COEF_i \bullet \rho_i(B,L,H)}$$

$$F_y = y = \frac{\sum_{i=1}^{20} SAMP\_NUM\_COEF_i \bullet \rho_i(B,L,H)}{\sum_{i=1}^{20} SAMP\_DEN\_COEF_i \bullet \rho_i(B,L,H)}$$

(1)

Where   B,L,H=the normalized coordinate of the object space in WGS-84;
X,Y=the normalized coordinate of the image space;

For the Ikonos camera, the inner orientation elements are known and fixed up among the imaging, but the outer orientation elements consisted of the position and the attitude of the sensor changed from line to line. Because there are orbit

error, attitude error, ephemeris error and drift error, the X,Y in formula (1) should be changed as :

$$x=a_0+a_1x+a_2y$$
$$y=b_0+b_1x+b_2y \qquad (2)$$

The rational polynomial coefficients are regarded as constant, and the error equation of the formula (1) is as follow:

$$V = \begin{bmatrix} B_1 & B_2 \end{bmatrix} \begin{bmatrix} X \\ t \end{bmatrix} - L \qquad (3)$$

where

$$V = \begin{bmatrix} v_x \\ v_y \end{bmatrix} \qquad B_1 = \begin{bmatrix} \dfrac{\partial F_x}{\partial B} & \dfrac{\partial F_x}{\partial L} & \dfrac{\partial F_x}{\partial H} \\ \dfrac{\partial F_y}{\partial B} & \dfrac{\partial F_y}{\partial L} & \dfrac{\partial F_y}{\partial H} \end{bmatrix}$$

$$B_2 = \begin{bmatrix} 1 & x & y & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & x & y \end{bmatrix}$$

$$X = \begin{bmatrix} \delta B & \delta L & \delta H \end{bmatrix}^T$$

$$t = \begin{bmatrix} a_0 & a_1 & a_2 & b_0 & b_1 & b_2 \end{bmatrix}^T$$

$$L = \begin{bmatrix} F_x - F_x^0 \\ F_y - F_y^0 \end{bmatrix}$$

There are two kinds of unknown parameters in formula (3), namely the correction of the image coordinate **t** and the correction of the ground coordinate **X**. After the normal equation is built up and block adjustment is done, the bias a_0 b_0 and the drift a_1 a_2 b_1 b_2 are be calculated. When the strap length is under 20km, the drift b_1 b_2 can be ignored for they are very small.

2.2 The transformation between WGS-84 system and the national coordinate system

The datum of satellite is WGS-84 system, but every country or region owns their geodetic datum. In China, 1954 Beijing coordinate system used the Karassove ellipsoid, and the 1980 national coordinate system adopted the ellipsoid recommended by IUGG in 1975. In order to meet the practice application, the WGS-84 coordinate must be transformed to the national system. The formula Bushar is used for the transformation between the coordinate systems(Zhu Huatong, 1986)

$$\begin{bmatrix} dL \\ dB \\ dH \end{bmatrix} = A \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} + B \begin{bmatrix} \varepsilon_X \\ \varepsilon_Y \\ \varepsilon_Z \end{bmatrix} + CK + D \begin{bmatrix} da \\ d\alpha \end{bmatrix} \qquad (4)$$

Where dL,dB,dH=the coordinate correction between the systems;
X_0,Y_0,Z_0=the offset parameters;
$\varepsilon_x, \varepsilon_y, \varepsilon_z$ =the rotate parameters;
K=the scale factor;
$da, d\alpha$ =the correction of the ellipsoid parameters between the systems;
A,B,C,D=the correspond transform matrix.

When the coordinates of certain system were transformed, they can be projected to the plane coordinate according to a projection, such as the Guass-Krüger projection. To satisfy the engineering design and construction in high altitude area, the coordinate should be further projected to compensate plane of the surveying area.
2.1,2.2 described the relationship from Ikonos image space to the object space of ground points in national system. Contrariwise, the ground coordinate can be transformed to the image coordinate.

3. THE PRACTICE AND THE RESULT

3.1 The project area

The project area of the Ikonos application is located in the southeast of the Tibet, P.R. China, a valley near the Himalayas. It is a mountain area and the terrain undulate sharply. The average height above sea level is 4000m, the lowest altitude is 2730m, and relative height is over 3000m. The snow covers the mountaintop all over the years. There is a river across the area and a road along the river.
There are flourish trees and vegetables in the area. Except the sloping fields assarted by the farmers, the most area is covered by originality forest. The height of some trees is over 40m.
Few people lived there, and the most are Tibetans. The life condition is awful and the civilization and the traffic get more behind.
The area of the Ikonos project is a rectangle block. The length in the east-west is about 35km, and the width in the south-north is about 20km. The area is covered with 3 stereo Ikonos images collected in 3 passes. It is very difficult to collect the Ikonos image for it is rainy and cloudy almost every day. A period of time has been spent to get the qualified Ikonos products. Some data of the Ikonos images are listed in table 1.

Stereo Pair	I(03/05)		II(07/09)		III(12/13)	
Image ID	03	05	07	09	12	13
GSD in Cross Scan(m)	0.87	0.92	0.88	0.96	0.90	0.99
GSD in Along Scan(m)	0.90	0.91	0.89	0.95	0.89	0.96
Scan Azimuth(degrees)	0.03	0.03	0.02	0.02	359.97	359.97
Collection Azimuth(degrees)	331.9226	226.5768	318.5048	229.2133	309.4420	232.9035
Collection Elevation(degrees)	71.10912	67.38771	70.68800	63.52693	69.60148	61.80649
Sun Angle Azimuth(degrees)	162.8567	163.1557	165.1714	165.4367	165.3093	165.5509
Sun Angle Elevation(degrees)	45.39864	45.45548	39.26270	39.31216	37.07084	37.11749
Acquisition Date(Month-Day)	10-29	10-29	11-20	11-20	12-01	12-01

Table 1 The information of the Ikonos-2 data

3.2 The control schemes

It is very hard to do the field survey in the area. Except for the factor of the high altitude and the inconvenience traffic, the visual condition along the surface of the ground is very worse. The GPS receivers were adopted in the field survey so as to obtain the control points and check points of Ikonos images. In order to test the accuracy of the Ikonos stereo image, 58 GCPs for Ikonos block adjustment and 336 check points for examining the production have been collected. All the GCPs and the check points were surveyed by Leica GPS 530 with static or rapid static survey, and its accuracy is ±5cm. Because of the craggedness of the mountain, the GCPs are distributed equably in 3 stereo images among the valley. There are about 20 GCPs in each stereo images(see Fig.1).
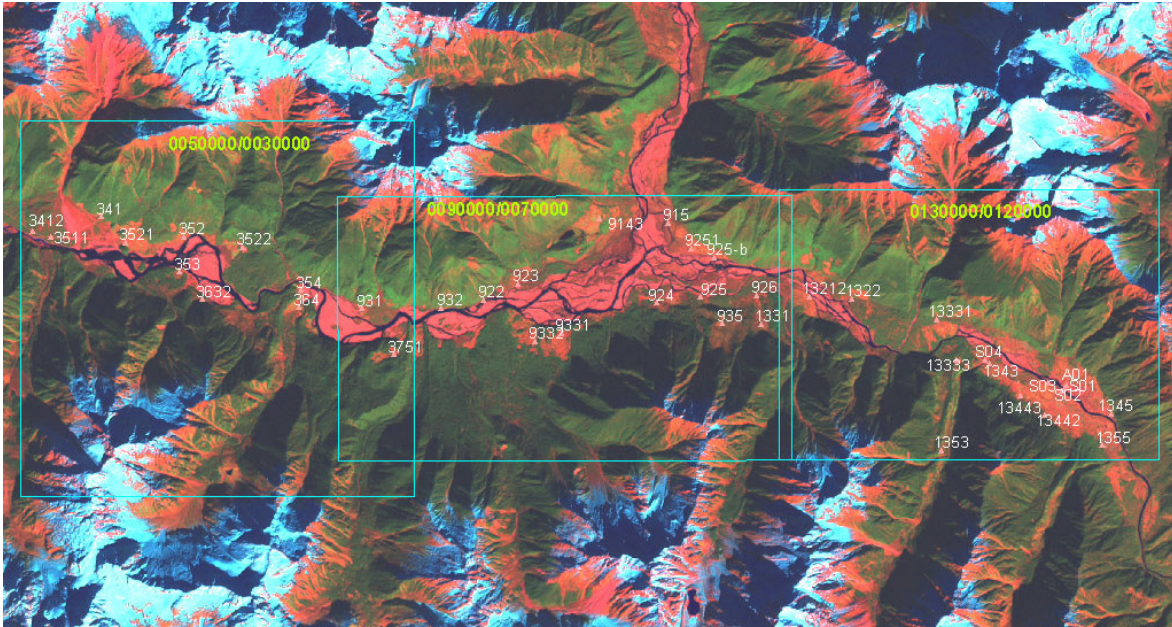

Fig. 1 The project area and the distribution of the GCPs

3.3 The Ikonos accuracy without control

When there is no GCPs, the coordinate and its errors of the image space and the ground space are calculated respectively with the RPC provided by the vender.

● The errors in image space without GCPs

The image coordinates calculated from the RPC model are compared with its measured coordinates, its errors are listed in table 2.

It can be seen obviously from table 2 that there are bias and drift in Ikonos images and they are different from image to image.

● The errors in ground space without GCPs

The errors between the ground coordinates calculated from RPC model and its real ones are listed in table 3.

Image ID	03		05		07		09		12		13	
	l	s	l	s	l	s	l	s	l	s	l	s
Max. error	9.471	-5.618	4.477	-4.723	9.262	-3.975	5.410	-3.143	7.847	-5.145	4.410	-2.558
Min. error	6.748	-7.238	2.295	-6.341	7.038	-6.107	3.519	-5.285	5.919	-7.017	2.606	-4.159
Ave. error	8.207	-6.477	3.293	-5.647	8.333	-5.013	4.586	-4.180	6.759	-6.291	3.476	-3.575
RMS	0.826	0.558	0.749	0.515	0.614	0.662	0.648	0.709	0.654	0.525	0.595	0.481

Table 2 The errors of image space without GCPs(pixel)

Stereo Model	I(03/05)			II(07/09)			III(12/13)		
	X	Y	H	X	Y	H	X	Y	H
Max. error	-6.188	-5.247	8.044	-5.156	-5.383	7.764	-7.164	-3.904	7.709
Min. error	-8.882	-8.129	3.990	-7.960	-7.649	3.600	-8.975	-6.103	5.330
Ave. error	-7.722	-6.399	7.401	-6.980	-6.429	6.253	-8.278	-4.983	6.466
RMS	0.827	0.976	1.071	0.802	0.730	0.964	0.535	0.695	0.622

Table 3 The errors in ground space without GCPs(meters)

When there is no GCPs, the errors in plane is about 10m, and the error in the height is less than 10m.

3.4 The block adjustment test and the result

There is a great challenge in field survey because of the particularity of the project area. Although the GCPs are obtained as much as possible, it is a right method to develop block adjustment based on RPC model to reduce the amount of the GCPs by the greatest extent.

Over 20 schemes of GCP distribution are design for block adjustment. The schemes and their results are listed in table 4.

No.	The GCPs schemes	RMS of IP(pixel)	RMS of GCPs				RMS of CP			
			RMSx	RMSy	RMSz	total	RMSx	RMSy	RMSz	Total
1	All 41 GCPs	0.276	0.474	0.561	0.235	0.771				
2	All SM I GCPs	0.311	0.486	0.658	0.184	0.838	0.564	0.619	1.170	1.439
3	All SM II GCPs	0.307	0.575	0.456	0.286	0.788	0.515	0.711	0.864	1.232
4	All SM III GCPs	0.306	0.373	0.527	0.220	0.682	0.648	0.731	1.290	1.618
5	All SM I & SM III GCPs	0.292	0.419	0.584	0.197	0.745	0.659	0.614	0.667	1.121
6	All SM I & SM II GCPs	0.290	0.529	0.570	0.251	0.817	0.418	0.696	0.580	0.998
7	All SM II & SM III GCPs	0.287	0.417	0.522	0.245	0.745	0.639	0.755	1.251	1.594
8	4 SM I GCPs & 2 SM III GCPs	0.322	0.449	0.169	0.204	0.521	0.552	1.029	0.736	1.381
9	6 SM I GCPs & 2 SM III GCPs	0.318	0.457	0.494	0.199	0.702	0.566	0.940	0.792	1.353
10	All SM I GCPs & 2 SM III GCPs	0.307	0.458	0.626	0.177	0.795	0.554	0.678	0.915	1.266
11	All SM II GCPs & 2 SM I GCPs	0.306	0.558	0.485	0.294	0.795	0.495	0.731	0.576	1.054
12	All SM II GCPs & 2 SM III GCPs	0.303	0.548	0.455	0.274	0.764	0.535	0.757	0.887	1.284
13	4 SM I GCPs	0.326	0.511	0.203	0.125	0.564	0.618	1.026	1.423	1.860
14	6 SM I GCPs	0.321	0.484	0.567	0.149	0.760	0.742	0.898	1.557	1.945
15	1 GCP(middle)	0.333	0.016	0.012	0.001	0.020	0.951	0.733	0.956	1.535
16	2 GCPs(one in each end)	0.330	0.304	0.127	0.256	0.417	0.752	0.818	0.840	1.393
17	4 GCPs(2 GCPs each end)	0.327	0.360	0.086	0.230	0.436	0.602	1.039	0.748	1.415
18	6 GCPs(2 GCPs each SM)	0.322	0.419	0.464	0.208	0.659	0.558	0.774	0.659	1.160
19	7 GCPs(1 middle, 2 each SM)	0.325	0.472	0.421	0.283	0.693	0.556	0.764	0.517	1.076
20	12 GCPs(4 each SM)	0.314	0.409	0.433	0.242	0.643	0.582	0.777	0.510	1.097

Note: SM----Stereo Model; IP----Image point; GCP----Ground Control Point; CP----Check Point.

Table 4 The GCPs schemes and their result of the block adjustment

The block adjustment tests and the results have shown that:
- The Ikonos accuracy is stabilization in anyone control scheme.
- The location of the GCP is at will, but it must be on the object which its image is clear and the character is distinctness.
- The accuracy can be improved greatly even only one GCP.
- The RMS of the ground point is about ±1.5m when the interval of the GCPs is 15km, and ±2.0m at 20km. The longer the interval of GCPs, the worse the accuracy of the height.
- The higher accuracy can be reached when 2 GCPs exist along south-north in each stereo images, but the accuracy is improved little with more GCPs.
- The RMS of production produced with Ikonos image in Himalayas has reached ±0.945m in plane, ±0.510m in height, and ±1.076m in total. The RMS of image point is ±0.3 pixels.

3.5 The accuracy of Digital Line Graph(DLG)

The accuracy of the plane and the height of the DLG produced with Ikonos image was examined on the spot. The errors in the plane and the height were calculated by comparison between the DLG and the survey data (table 5, table 6, table 7).

	Max.	Min	Ave.	RMS
X	2.4	-1.7	0.38	±0.83
Y	2.6	-2.3	-0.43	±0.97
S				±1.28

Table 5 The plane accuracy of the DLG(meters)

Max.	Min.	Ave.	RMS
4.0	-3.2	0.40	±1.14

Table 6 The height accuracy of the DLG(meters)

Max.	Min.	Ave.	RMS
1.9	-1.6	0.26	0.64

Table 7 The accuracy of the height point   meters

It has shown from table 5 to table 7 that the accuracy of the DLG has satisfied the specification of the scale of 1:2000.

3.6 The accuracy of the Digital Elevation Model(DEM)

The DEM was produced from the Ikonos stereo model and its interval was 5m. The height of the check point in DEM was interpolated. The errors of the DEM was calculated by the comparison of difference between the DEM and the survey (table 8).

Max.	Min.	Ave.	RMS
4.222	-3.644	0.346	±1.153

Table 8 The accuracy of the DEM(meters)

3.7 The accuracy of the Digital Ortho Map(DOM)

The check point was overlaid on the DOM produced with the Ikonos stereo image. The distant between the survey point and its image point was measured, and the errors can then be calculated(table 9).

	Max.	Min.	Ave.	RMS
X	1.6	-1.3	0.09	±0.44
Y	1.4	-1.4	-0.03	±0.54
S				±0.70

Table 9 The accuracy of the DOM(meters)

4. CONCLUSION

With the refining of the RPC model, the transformation between coordinate systems and the development of the block adjustment of the Ikonos stereo image, the high accuracy spatial data of wide range in the area where the conditions of terrain, weather and traffic are all awful has been obtained. The application of Ikonos stereo image reduces greatly the field work. It is the best solution to the difficult problem that could not solve by other survey means. Ikonos has great valuable for practice indeed.

The practice research of Ikonos positioning and its accuracy in Tibet proves that:

- With the refining of the RPC model by the correction of the bias and drift and the transformation between the coordinate systems, the relationship between the Ikonos image space and the national coordinate systems has been built up. It meets the need of practice application.
- Without control, the accuracy of Ikonos positioning is about 10m in plane and less than 10m in height.
- The accuracy of Ikonos positioning can be improved greatly by added just one GCP in the area.
- The location of the GCPs is at will. The high positioning accuracy can be achieved when there are two GCPs distributed in south-north. There is little improvement in accuracy to add more GCPs.
- The accuracy of Ikonos positioning has reached to±0.945m in plane ,±0.510m in height, and ±1.076m in total. The RMS of image point is ±0.3 pixels.
- The accuracy of the DOM, DEM produced with Ikonos stereo image has reached to ±0.70m, ±1.153m respectively. The DLG fits the specification of the map of 1:2000.

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