ADJUSTMENT WITH SPARSE GCPS AND THE HIGH-RESOLUTION SATELLITE IMAGERY - FOR THE PROJECT OF WEST CHINA TOPOGRAPHIC MAPPING AT 1:50,000 SCALE

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Special Session SS-17

KEYWORDS: The Project of West China Topographic Mapping (WChTM) at 1:50000 Scale, Rational Function Model (RFM), High-Resolution Satellite Imagery, Block-adjustment with sparse GCPs

ABSTRACT:

High-resolution satellite images (HRSI) at sub-5m footprint such as IKONOS, IRS-P5 (CartoSat-1) and SPOT-5 HRG/HRS images are becoming increasingly available to the earth observation community and their respective clients. HRSI is one of the main data sources for the Project of West China Topographic Mapping (WChTM) which has been approved by the State Council of China in year 2006. In western part of China up to 2.02 million km^2 are not mapped at 1:50,000 scale, it includes Sorthern-XinJiang desert area, Qing-Tibet Plateau area and Heng-duan mountain ranges. This unmapped area covers about 20% of all areas of China; contains total number of about 5,032 sheets of 1:50,000 scale topographic maps. The unmapped area related to the project covers most unmans area of China, the very harsh natural conditions (average terrain elevation is more than 4000m) and difficult transportation conditions provide a very difficult situation for outside field-works such as GCP measurement. In many areas, it's even impossible for collecting enough GCPs, therefore, new advanced technologies in field of photogrammetry and remote sensing, such as the block-adjustment with sparse GCPs and mapping with high-resolution satellite imagery are very necessary.

In this paper, we present an approach for block-adjustment based on Rational Function Model (RFM) with sparse GCPs by using satellite Images. To test the proposed approach, it has been applied to SPOT-5 images over 2 test-fields, one is in Baoji City, Chanxi, China, and another covers eastern part of Tibet Plateau, China. All test-fields are with variable terrain geomorphologic type and several tens of GCPs and check points measured by DGPS. The block-adjustment results show that with SPOT-5 HRS images and small number of GCPs we can achieve 5-9m in planimetric and 2-3m in height direction. In another test we use 23 scenes of IRS-P5 images, the test area covers Beijing area and about 21,000 square kilometers. In this test-field, we used DGPS to measure 66 GCPs and the block-adjustment result shows that only with 5 GCPs we could achieve 2.0 m in planimetric and 2.5m in height direction. From these experiments, it's shown that with the proposed block-adjustment approach, by using SPOT-5 HRS/HRG and IRS-P5 imagery with small number of GCPs, satisfactory image orientation results can be achieved with a little bit better accuracy than those requirements from the Chinese Surveying and Mapping regulations for 1:50000 topographic maps.

1. Introduction

A decade after early 1990s, remote sensing has stepped into a new stage which can supply various high-resolution observation data from space. At present, terrain information extraction, change detection and disaster monitoring, and topographic mapping by using the HRSI (High Resolution Satellite Imagery) in China and abroad is becoming one of research hotspots. Meanwhile, HRSI has more and more applications in photogrammetry. The stereo remote sensing image with spatial resolution of meter-level or even sub-meter level has the capability to replace the aerial images which used for traditional topographic mapping at 1:50,000 and 1:10,000 scale or updating of geo-information (Zhang, et. al., 2004).

SPOT-5 satellite is an earth observation satellite of France which has been launched in 2002, a high-resolution imaging system HRS is mounted on satellite. HRS equipment can acquire stereo image in along-track mode, thus reduce the radiometric differences between these images and facilitating automated measurement processes and convenient for subsequent high-accuracy photogrammetric processing. The size of linear array CCD detector, which works in panchromatic band, for HRS camera is 12,000 pixels and the image resolution is 5m in along-track and 10m in cross-track direction. the largest stereo coverage of SPOT-5 HRS imagery is about 600×120km^2, and the base-to-height ratio of HRS image can reach to 0.8, which ensure the accuracy of target orientation and stereoscopic mapping.

IRS-P5 （also called CartoSat-1）is a remote sensing satellite built by ISRO (Indian Space Research Organization) which is mainly intended for cartographic applications in India. The satellite was launched into a 618 km high polar Sun Synchronous Orbit by PSLV-C6 on May 5, 2005. IRS-P5 carries two panchromatic cameras that are combined in such a way that near simultaneous imaging of the same area from two different angles is possible. The satellite images have a spatial resolution of 2.5 meter and cover a swath of 30 km. This facilitates the generation of accurate Digital Elevation Models (DEM) and other value added products.

SPOT-5 HRS/HRG, IRS-P5 and other HRSI images are main data sources for the project of Western China Topographic Mapping (WChTP) at 1:50,000 scale. At the current time, in western part of China up to 2.02 million km^2 are not mapped at 1:50,000 scale, it includes Sorthern-XinJiang desert area, Qing-Tibet Plateau area and Heng-duan mountain ranges. This unmapped area covers about 20% of all areas of China; contains total number of about 5,032 sheets of 1:50,000 scale topographic maps. This situation greatly hiders the socio-economic development of this region, also posed potential threat to national security. The project has been approved by the State Council of China in year 2006, and is dedicated to complete 1:50,000 scale topographic map and construct the national geo-spatial database for the region within next 5 years through year 2006 to 2010. The unmapped area related to the project covers most unmans area of China, the very harsh natural conditions (average terrain elevation is more than 4000m) and difficult transportation conditions provide a very difficult situation for GCP measurement and other field works. In many areas, it's even impossible for accessing or collecting enough GCPs, therefore, the project of WChTP must across traditional surveying mode, utilize innovative aerial and satellite remote sensing techniques, such as DGPS/IMU assisted aerial photogrammetry, high resolution satellite imagery mapping technique and radar image mapping technique, design and use mapping procedure with sparse GCPs, to achieve surveying for unmapping area in Western China.

The project of WChTP is the importance and complicated project which first uses HRSI cosmically for topographic map generation in China. The imaging principle and geometry investigation of satellite image, block-adjustment with sparse GCPs, 3D processing and stereo mapping of satellite image, automatic DEM and DOM generation, automatic registration and fusion of multiple sensor image information are the key techniques for mapping from HRSI images. Since the related HRSI sensors are all using Linear Array CCD technology for image sensing and equipped with high quality orbit position and attitude determination devices like GPS and IMU systems, we propose and develop a block-adjustment procedure based on Rational Function Model (RFM) for HRSI satellite image (Chapter 2). The procedure has been successfully applied for block-adjustment of large-area SPOT-5 and IRS-P5 satellite imagery with sparse control and production-line for the project of WChTP. The experimental results show that with the proposed approach, by using SPOT-5 HRS/HRG and IRS-P5 imagery, with several GCPs satisfactory image orientation results can be completed with a little bit better accuracy than those requirements from Chinese Surveying and Mapping regulations for 1:50000 topographic maps (Chapter 3).

2. Block-adjustment with HRSI based on Rational Function Model (RFM)

Sensor model is fundamental for image photogrammetric processing. Sensor models are required to establish the precise transformation between the object space and image space, such as the collinear equations used for photogrammetry. They are of particular importance to stereo measurements and image ortho-rectification. Sensor models are typically classified into two categories: the physical and the generalized models. The choice of a sensor model depends primarily on the performance and accuracy required and the camera and control information available.

A physical sensor model represents the physical imaging process. The parameters involved describe the position and orientation of a sensor with respect to an object-space coordinate system. Physical models, such as the collinearity equations, are rigorous, very suitable for adjustment by analytical triangulation and normally yield high modeling accuracy. In physical models parameters are normally uncorrelated because each parameter has a physical significance. Further refinement is also possible by extending the model with the addition of calibration parameters to describe known effects known or effects suspected to be present.

In a generalized sensor model, the transformation between the image and the object space is represented as some general function without modeling the physical imaging process. The function can be of several different forms, such as polynomials or rational functions. Generalized sensor models normally show advantages when real-time computation is required. The Rational Function Models (RFMs) is one of the generalized sensor models and have recently drawn considerable interest in the remote sensing community, especially in light of the trend that some commercial high-resolution satellite imaging systems, such as IKONOS, are only supplied with rational polynomials coefficients (RPCs) instead of physical sensor model parameters.

Being different from the traditional frame-based aerial photography, all the high-resolution satellite cameras use Linear Array CCDs to acquire a single image line at an instant of time, each with its own positional and attitude data. The imaging geometry is characterized by nearly parallel projection in along-track direction and perspective projection in cross-track direction. A physical model can be used to reconstruct the physical imaging geometry and to model transformations between the object space and the image space, and bundle adjustment approach which has been completely developed in aerial photogrammetry, can also be applied for satellite image block-adjustment after appropriate alteration (Qian, et. al., 1990). Due to the dynamic nature of satellite image acquisition, this kind of model is more complicated than in the single frame case. Furthermore, due to very narrow field of view for HRSI images (e.g. SPOT-5 HRS is 8.3°, IKONOS only is 0.7°), many parameters in the sensor models are completely or highly correlated with other parameters so that they cannot be safely estimated through the triangulation procedure (Grodecki and Dial, 2003). According to the researches made by Tao and Hu (2001), The RFM can achieve an approximation accuracy that is extremely high both for aerial frame data and SPOT linear array data. The results support that the RFM can be used as a replacement sensor model for photogrammetric restitution. Therefore in this paper, we try to develop and test a block-adjustment approach with HRSI based on rational polynomial model.

2.1. Rational Function Model (RFM) and parameter estimation

A RFM is generally the ratio of two polynomials with its parameters derived from the physical sensor model and the corresponding terrain information. These models do not describe the physical imaging process but use a general transformation to describe the relationship between image and ground coordinates

In RFM, image pixel coordinates (*x*, *y*) are expressed as the ratios of polynomials of object coordinates (φ, λ, *h*), which in the case of the IKONOS RPCs correspond to latitude, longitude and ellipsoidal height. For reasons primarily due to numerical conditioning of the estimation process involved in computing, the two image and three object coordinates are each offset and scaled to fit the range from -1.0 to 1.0.

For an image, where x_n and y_n are normalised pixel coordinates and φ_n,λ_n,h_n are normalised latitude, longitude and ellipsoidal height, the ratios of polynomials have the following form:

$$\begin{aligned} x_n &= RPC_x(\varphi,\lambda,h) = \frac{f_1(\varphi_n,\lambda_n,h_n)}{f_2(\varphi_n,\lambda_n,h_n)}; \\ y_n &= RPC_y(\varphi,\lambda,h) = \frac{f_3(\varphi_n,\lambda_n,h_n)}{f_4(\varphi_n,\lambda_n,h_n)} \end{aligned} \tag{1}$$

In equation (1), the maximum power of each object coordinate and the total power of all object coordinates are limited to 3.

Some commercial HRSI like IKONOS and IRS-P5, only supply RFM model coefficients to the user, however SPOT-5 HRS/HRG supplies orientation data by the metadata file (DIMAP format file), which contain CCD scanning frequency of image, CCD instantaneous imaging time, position and attitude parameters and some interior orientation parameters. Through these parameters, the physical sensor model (details please refer to SPOTIMAGING, 2002$^{]}$) of SPOT-5 imagery can be established by using these data. Usually, the RFM can be computed based on the SPOT-5 physical sensor model. With the given parameters of the physical sensor model and by projecting evenly distributed image points into the multiple-layered object space, 3D object points can be computed and used as virtual control points. Such control points are created based on the full extent of the image and the range of elevation variation in the object space. The entire range of elevation variation is sliced into several layers. Then, the RPCs are calculated by a least squares adjustment with these virtual control points. Tao and Hu (2001) gave a detailed description of a least squares solution of RPCs and suggested using a Tikhonov regularization for tackling possible oscillations. In our test, this procedure was applied also for SPOT-5 image RPCs estimation and the main steps can be summarized as below:

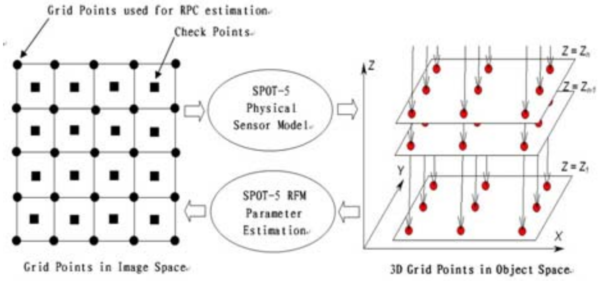

Fig. 1: Procedure for RPC Estimation by using the SPOT-5 physical sensor model

(1) Divide the whole image into a grid mesh with *m* rows and *n* columns, so evenly distributed (*m+1*)×(*n+l*) image point with known coordinates can be obtained (Fig. 1). The values of *m* and *n* can be determined according to the image size, the spacing of row or column usually should be about 200 pixels.

(2) Utilize SPOT-5 orbit or attitude parameters to establish the physical sensor model. Then evenly sliced elevation range (Z_{min}～Z_{max}) in imaging area into *k* layer (normally *k*>5), and obtain (*k+1*) elevation plane with constant elevation.

(3) Utilize physical sensor model of SPOT-5 to compute corresponding ground point of each grid point in image space at every elevation plane, so evenly distributed（*m+1*）×（*n+l*）×（*k+1*）3D virtual grid points in object space can be calculated.

(4) The RPCs are calculated by a least squares adjustment with these virtual control points and their corresponding image coordinates by using a Tikhonov regularization for tackling possible oscillations.

(5) Select checking points (*px,py*) on image to check the fitting accuracy, these checking points usually lie in the center of grid (Fig. 1). Firstly, compute the ground coordinates of every checking point for each elevation plane using SPOT-5 physical sensor model, then compute the corresponding image coordinates (*px',py'*) from the ground coordinate by using RFM, finally the fitting accuracy can be obtained from fitting error (*px-px',py-py'*) for each checking points.

We applied comprehensive testing by using hundreds scene of SPOT-5 HRS/HRG images in order to evaluate the performance of RFM coefficients estimation method, part of the results are shown in Table 1. The results show that: a) For SPOT-5 HRS stereo image, fitting RMSE for physical sensor model usually is about 1/100 pixel, and it seems not related to the image size; for SPOT-5 HRS 5m panchromatic images, fitting accuracy is about 1/40 pixel, for SPOT-5 HRS 2.5m panchromatic images, fitting accuracy is about 1/20 pixel. b) The fitting RMSE for physical sensor model is roughly related to ground resolution of the images, which is roughly equal to 0.1m in ground. c) RFM can replace the physical sensor model in subsequent photogrammetric processing of SPOT-5 image, and the accuracy loss can be ignored in surveying and mapping at 1:50,000 scale.

Image type	Image size（Row×Column）	Fitting RSME（pixel）
HRS 5×10m Pan	50712×12000	0.00854
HRS 5×10m Pan	116264×12000	0.01017
HRS 5×10m Pan	114592×12000	0.01016
HRS 5×10m Pan	81928×12000	0.00978
HRS 5×10m Pan	116864×12000	0.01013
HRG 5m Pan	40208×12000	0.02557
HRG 5m Pan	51984×12000	0.02814
HRG 2.5m Pan	24000×24000	0.05495
HRG 2.5m Pan	24000×24000	0.05518
HRG 10m MS	6000×6000	0.01099
HRG 10m MS	6000×6000	0.01558

Table 1: Accuracy test for SPOT-5 imagery RPC Estimation

2.2. Satellite imagery orientation and block-adjustment based on RFM

Actually, the RFM constitute a re-parameterization of the physical sensor model. Errors in sensor interior and exterior orientation thus give rise to errors in the RPCs. If the RPCs are computed from the a *priori* orientation parameters, e.g. sensor exterior orientation, comprising position and attitude data, which is directly observed using on-board GPS receivers, gyros and star trackers, we have to improve the geo-positioning accuracy of the RFM with a certain number of GCPs. Grodecki and Dial (2003) proposed a practical block-adjustment model for multi-strip blocks of the high-resolution satellite imagery (with a very narrow field of view) described by RPC models and illustrated the method with an IKONOS example. With the supplied RPCs, the mathematical model used is:

$$\begin{aligned} x_k + a_{i,0} + a_{i,1}x_k + a_{i,2}y_k &= RPC^i{}_x(\varphi_k, \lambda_k, h_k) \\ y_k + b_{i,0} + b_{i,1}x_k + b_{i,2}y_k &= RPC^i{}_y(\varphi_k, \lambda_k, h_k) \end{aligned} \tag{2}$$

Where, $a_{i,0}$, $a_{i,1}$, $a_{i,2}$ and $b_{i,0}$, $b_{i,1}$, $b_{i,2}$ are the 6 adjusted parameters for image *i*, and (x_k, y_k) and (φ_k, λ_k, h_k) are pixel and object coordinates of the points *k*. Using this adjustment model, we expect that parameter $b_{i,0}$ is used to absorb all along-track errors causing offsets in the line direction, while parameter $a_{i,0}$ absorbs cross-track errors causing offsets in the image sample direction. Due to the fact that usually the y direction is equivalent to time, parameters $b_{i,1}$ and $a_{i,2}$ absorb the shear effects caused by gyro drift during the image scan. In addition, the parameters $a_{i,1}$ and $b_{i,2}$ are used to absorb parts of the radial ephemeris error, and interior orientation errors such as focal length and a part of lens distortion errors.

In our approach, we first used the RPCs to transform from object to image space and then using these values and the known pixel coordinates we estimated either two shifts $a_{i,0}$, $b_{i,0}$ (model *M_RPC2*) or all 6 parameters $a_{i,0}$, $a_{i,1}$, $a_{i,2}$ and $b_{i,0}$, $b_{i,1}$, $b_{i,2}$ (model *M_RPC6*). The basic least squares observation equations for these 2 models are:

$$\begin{gathered} v = A\Delta + l; \qquad P \\ v = \left[v_x, v_y\right]_k^T; \qquad \Delta = \left[a_{i,0}, a_{i,1}, a_{i,2}, b_{i,0}, b_{i,1}, b_{i,2}, \Delta\varphi_k, \Delta\lambda_k, \Delta h_k\right]^T \\ \textit{where} \quad A = \begin{bmatrix} 1, x_k, y_k, 0,0,0, \dfrac{\partial x_k}{\partial \varphi_k}, \dfrac{\partial x_k}{\partial \lambda_k}, \dfrac{\partial x_k}{\partial h_k} \\ 0,0,0,1, x_k, y_k, \dfrac{\partial y_k}{\partial \varphi_k}, \dfrac{\partial y_k}{\partial \lambda_k}, \dfrac{\partial y_k}{\partial h_k} \end{bmatrix}_i; \qquad l = \begin{bmatrix} x_k - RPC_x^i(\varphi_k, \lambda_k, h_k) \\ y_k - RPC_y^i(\varphi_k, \lambda_k, h_k) \end{bmatrix} \end{gathered} \tag{3}$$

Here, *P* is the weight matrix describing the image measurement precision. For a block of images, the image georeferencing can be performed with the solution of the least squares normal equations resulting from equation (3). From equations (2) and (3) it is apparent that model *M_RPC2* requires a single well-defined GCP, whereas an estimation of all six parameters in model *M_RPC6* would require a minimum of 3 appropriately located GCPs per image. It should be noted is that block-adjustment model based on equation (2) and (3) is only appropriate for HRSI with a narrow imaging field of view. For satellite images with 1m ground resolution as IKONOS, duo to such narrow imaging field of view, for shorter flight strips (about 50-150km), god enough orientation accuracy can be obtained by using orientation method *M_RPC2* and 1-4 well-defined GCPs; for SPOT-5 HRS or longer IKONOS and Quikbird image strips (more than 150km), orientation method *M_RPC6* should be selected and more than 4-6 GCPs are needed for every image (Baltsavias, et. al., 2006; Fraser, et. al., 2002; Poli, et. al., 2004; Grodecki and Dial, 2003)

In principle, RFM can be applied to different object coordinate system, for example, the geocentric coordinate system, geographic coordinate system or any map projection coordinate system. Considering large coverage of satellite image, especially larger coverage of block-adjustment with multiple SPOT-5 stereo images, here we choose the geographic coordinates in WGS84 (longitude, latitude and geodetic height) as the object coordinates for RFM (equation (1)), which has advantages to solve problems such as the earth curvature correction and block-adjustment in multiply map projection zones.

3. Block-adjustment Testing and Accuracy Analysis

In order to evaluate the performance of block-adjustment approach proposed in this paper. Cooperating with several surveying and mapping institutes, we selected several test areas to apply extensively accuracy test, the results show that only using small number of GCPs, we can meet the requirements of topographic mapping at 1:50,000 scale in China for large coverage of SPOT-5 HRS and IRS-P5 stereo images.

3.1 Orientation with SOPT-5 HRS Single Stereo Images and Accuracy Analysis

The testfield is an area around the city of Baoji, China. It consists of a steep mountainous region in the middle-southern part and smooth hilly Loess Plateau regions in the middle and northern parts. The city of Baoji is located in the middle part of the study area. The whole area is about 520 × 180 km^2. The site has an elevation range of more than 2000 m and the land cover is extremely variable.

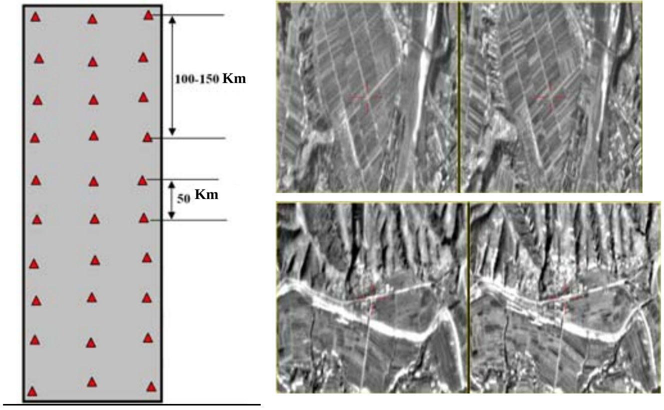

Fig. 2: Left, GCP Distribution of Baoji Test-Field; Right, 2 Examples of GCPs Measured on Images

Over the test area, one stereo pair of level-1A SPOT-5 HRS was acquired. The ground resolution of SPOT-5 HRS images is 10m×5m, and covers about 61,600km^2, the quality of images are fine with only little cloud coverage in the middle part. In order to precisely georeference the SPOT-5 HRS images, with the cooperation of the 3rd Institute of Surveying and Mapping of Shanxi SBSM, about 68 well-distributed GCPs were collected with differential GPS in 2006. The measurement accuracy was better than 1m in planimetry and 1.2m in height. The planimetric coordinates of GCPs is in 1980 Xi'an coordinate system (the 18th projection zone), and the elevation adopt 1985 national elevation standard (China); The GCPs are well-distributed in the test area, their ground intervals are about 30～50km, and most of them lie on the center of road intersection which can be precisely measurement in images (see Fig. 2). These will supply preferable data for evaluation the relationships between the block-adjustment accuracy and number/distribution of the GCPs.

We select different numbers and distribution layout of GCPs for accuracy test, others GCPs will be used as checking points to analyze the relationships between block-adjustment accuracy and number or distribution of GCPs, which includes 0 GCP (without control), 4 GCPs (control points lie on the 4 corner of image), 6 GCPs (4 corner points and 2 points in the middle of image), 10 GCPs, 18 GCPs and all of control points, the results are shown in Table 2. Test results argue that: (a) high systematic errors exist under the condition without control in test area; (b) with the increase of GCPs, there is certain degree of improvement for both planimetry and elevation accuracy, but the improvement is not so significant; (c) adjustment accuracy in teat area can meet the requirement of block-adjustment for hilly terrain and mountainous terrain in surveying criterion at 1:50,000 scale even with only 4 GCPs located at image corners; (d) control points in center of image can be used as checking points. Thereby, considering the factors such as the reliability of block-adjustment results, we concluded that for SPOT-5 HRS stereo images, it is appropriate if the interval of control points is determined with spacing of about 200km in along-track direction and 100km in cross-track direction. According to this, for long-strip SPOT-5 HRS stereo images with the largest coverage of 72,000km^2, only 8-12 GCPs can reach the requirement of topographic map surveying at 1:50,000 scale in China.

Test phase	GCPs +CPs	RMSE -X (m)	RMSE -Y (m)	RMSE -Z (m)	GCP point spacing
0 GCP	0 + 68	9.03	49.43	19.63	--
4 GCPs	4 + 64	5.08	6.03	1.80	520 km
6 GCPs	6 + 62	4.21	4.61	1.77	260 km
10 GCPs	10 + 58	3.65	4.29	1.86	130 km
18 GCPs	18 + 50	3.53	4.00	1.55	65 km
68 GCPs	68 + 0	3.48	3.90	1.40	37 km

Table 2: Accuracy test for block-adjustment in Baoji test-field

3.2 Block-adjustment with SPOT-5 HRS Imagery in Eastern Tibet Plateau and Eastern Talimu Basin

Cooperating with several surveying and mapping institutes, the block-adjustment with multiply SPOT-5 HRS images in areas of eastern Tibet Plateau and eastern Talimu basin for the project of WChTM have been completed in 2006 and 2007. The test area in eastern Tibet Plateau covers 1234 topographic maps at 1:50,000 scale with the area of about 530,000km^2, where contains large-area of seasonally and perennially frozen soil, glacier and perennial snowfield and unman area; The test-field in eastern Talimu Basin and North Slope of Aerjin Mountain ranges covers 325 topographic maps at 1:50,000 scale with the area of about 130,000km^2, where covers large-area of desert with fixed/fluid dunes, arid salt desert, gobi, badland and yardang landforms. Therefore it is quite difficult for surveying field-works with these kinds of harsh nature environment, meanwhile, poor-texture image areas caused by large areas of desert and gobi result in another difficulties for GCP collection and precise measurement in both image and object space..

Field works such as GCPs surveying and image annotation have been completed in the areas of eastern Tibet Plateau and eastern Talimu basin by over 500 surveyors and 120 vehicles from 7 production units including Shanxi, Heilongjiang and Sichuan Surveying and Mapping Bureau, Chongqing Surveying and Mapping department, and Surveying and Mapping Bureau in Qinghai, Xinjiang and Gansu provinces since the project of WChTM started up in 2006. About 700 GCPs and checking points are measured by differential GPS according to the Chinese surveying requirement of GPS D-level point. The measurement accuracy was better than 1m in planimetry and 1.2m in height. The planimetric coordinates of GCPs is in 1980 Xi'an coordinate system, and the elevation adopt 1985 national elevation standard (China); The GCPs are well-distributed in the test area, their ground intervals are about 100-150km (in order to ensure reliable GCP at the in-home designed location, two-point or three-point layout plan would be utilized at the designed location, and all of them would be recorded in the number of GCPs, in addition, considering large-coverage of SPOT-5 image, some of GCPs may located outside of the test area which could reach to over 300km in order to ensure image orientation). According to coverage of the SPOT-5 HRS satellite images and the distribution of GCPs, also considering the terrain type, block-adjustment of the whole test area will be divided into 4 sub-testfields (Fig: 3):

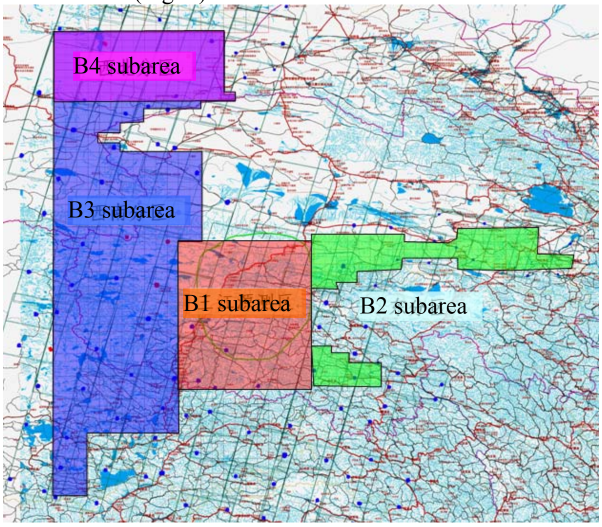

Fig. 3: Overview of test-fields in eastern part of Tibet Plateau, China

(B1) Testfield in zone of headstream of Three rivers, Tibet Plateau, China: In this test area, 13 SPOT-5 HPS stereo image strips which cover about 120,000km^2 are involved. Test-field contains 250 topographic maps at 1:50,000 scale, and across 16 and 17 projection zone (6 degree zone). The GCPs measurement was completed in 2006, there are large number of GCPs because the test area is the first working area of the WChTM project. Finally, there are total 157 points were used in block-adjustment procedure except certain number of necessary tie points, in which contain 59 GCPs and 98 checking points. Sanxi, Sichuan, Heilongjiang and Qinghai Surveying and Mapping Bureaus took part in the work of GCP measurement, point measurement and transfer, and the block-adjustment results are shown in Table 3.

(B2) Test-field of northeast in eastern Tibet Plateau: this test area has 26 SPOT-5 HPS stereo image strips which cover about 200,000km^2. The area contains 200 topographic maps at 1:50,000 scale, and across 16, 17 and 18 projection zone (6 degree zone), the GCPs measurement was completed in 2007. There are 209 points (including some points in test-field of the headstream of Three rivers) were used in block-adjustment for this test-field, in which contain 81 GCPs and 128 checking points. Heilongjiang and Qinghai Surveying and Mapping Bureaus and Chongqing Surveying and Mapping department took part in work of GCP measurement, point measurement and transfer, and the block-adjustment results are shown in Table 3.

(B3) Test-field of southwest in eastern Tibet Plateau: this test area has 26 SPOT-5 HPS stereo image strips with coverage of about 300,000km^2, contains about 700 topographic maps at 1:50,000 scale, and across 15 and 16 projection zone, Finally there are 273 points (including some points in test-field of the headstream of Three rivers) were used in block-adjustment, in which contain 115 GCPs and 158 checking points. Shanxi, Heilongjiang and Sichuan Surveying and Mapping Bureaus took part in work of GCP measurement, point measurement and transfer, and the block-adjustment results are shown in Table 3.

(B4) Test-field of eastern Talimu basin: this test area has 5 SPOT-5 HPS stereo image strips with coverage of about 60,000km^2, contains about 100 topographic maps at 1:50,000 scale, and across 16 and 17 projection zone. There are 92 points were used in block-adjustment, in which contain 51 GCPs and 41 checking points. Xinjiang and Gansu Surveying and Mapping Bureaus took part in work of GCP measurement, point measurement and transfer, and the block-adjustment results are shown in Table 3.

	σ_0 (pixel)	RMSE of GCPs			RMS of CPs			Max error of GCPs		Max error of CPs	
		X	Y	Z	X	Y	Z	X-Y	Z	X-Y	Z
B1	0.79	4.9	5.2	1.4	8.9	6.9	2.1	13.4	4.3	23.2	4.3
B2	0.68	5.3	4.6	2.1	7.8	6.7	2.5	16.2	5.9	17.4	6.1
B3	0.62	5.2	5.6	1.6	8.4	7.2	2.4	15.8	4.1	18.2	5.0
B4	0.54	4.4	4.5	1.2	5.2	6.3	2.1	11.6	2.2	11.7	3.6

Table 3: Accuracy reports for block-adjustment in test-field of eastern part of Tibet Plateau and eastern part of Talimu Basin, China. The unit is in meters

As shown in Table 3, the block-adjustment accuracy of the test areas in eastern Tibet Plateau and eastern Talimu basin are quite good (in sub-pixel level) compared to the resolution of SPOT-5 HRS images, and it can meet the block-adjustment accuracy requirements regulated in mapping standard at 1:50,000 scale with small number of GCPs. Comparing to block-adjustment with the traditional aerial photos, block-adjustment with SPOT-5 HRS stereo image has some different features, also some different difficulties. The most important, the resolution is quite different, the scale of aerial photos used for mapping at 1:50,000 scale normally is 1:35,000-1:50,000, the ground resolution of image usually is in sub-meter or meter level. According to experience of the tests made as above, for block-adjustment with SPOT-5 HRS stereo images, the following problems should be noted specially in GCPs/tie-point measurement, block-adjustment computation and accuracy checking:

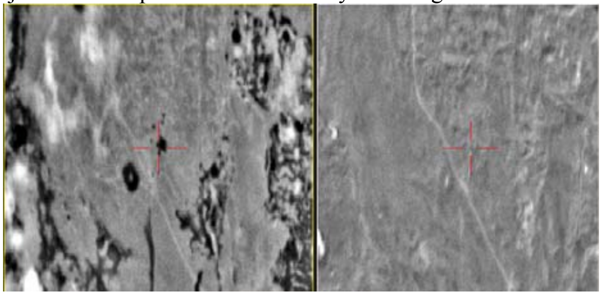

Fig. 4: Example of radiometric difference between adjacent SPOT-5 HRS images caused by different acquisition time

(1) For satellite images, the radiometric differences caused by different imaging time between adjacent stereo images must be considered while making the GCP layout plan and measurement. GCPs should be located and can be measured precisely in all (or as more as possible) satellite images. Radiometric difference may not be a problem for aerial image mapping, but for satellite image, lager temporal difference is usually quite common between adjacent stereo satellite images, sometimes this difference even reach to several years. Take example in Fig. 4 for instance, the GCP in left image will be very hardly or even can not be measured/transferred to the adjacent right image if we do not take the temporal difference into account.

(2) For SOPT-5 HRS stereo images, the image resolution of is 5m in along-track and 10m in cross-track direction, this means that measurement accuracy is different in different direction of SPOT-5 HRS images, thus we have to pay much attention when we make the point measurement in cross-track direction.

(3) The requirement of block-adjustment residual errors for GCPs and checking points in existing Chinese mapping standard of aerial image is regulated for tolerance. Sometimes, it might be very difficult to observe image points and carefully modify point location to reach the tolerance requirement. For example, assume the residual error of an image point is 3.2m or 3.5m, but if the tolerance is 3.0m, this means that the modification of this point is in 1/25 or 1/10 pixel level for SPOT-5 HRS image; Therefore it suggests that precise stereo observation must be applied for SPOT-5 HRS images to insure firstly, the residual error of this point in image space is less than 1.5 pixel, meanwhile, it suggests that the residual errors of 5%-10% GCPs or Check points are allowed over requirement of tolerance but they must be less than 1.5 times of the tolerance.

3.3 Block-adjustment with IRS-P5 Stereo Images and Accuracy Analysis

The test-field is an area around the city of Beijing, China. It consists of a steep mountainous region in the north-western part and flat regions in the middle and southern parts. The city of Beijing is located in the lower part of the study area. The whole area is about 70 × 210 km^2. The site has an average terrain height of 300m and an elevation range of more than 1100 m.

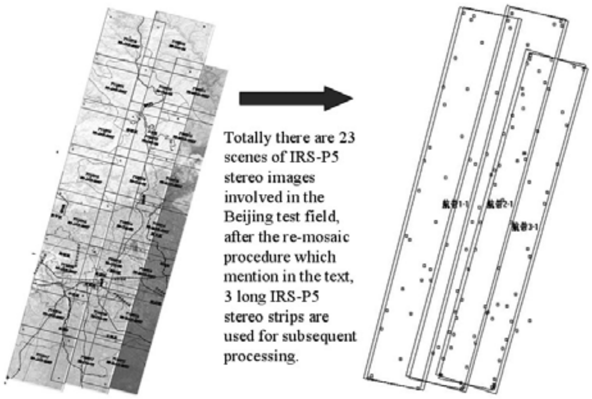
Totally there are 23 scenes of IRS-P5 stereo images involved in the Beijing test field, after the re-mosaic procedure which mention in the text, 3 long IRS-P5 stereo strips are used for subsequent processing.

Fig. 5: In Beijing test-field, there are 23 scenes of IRS-P5 stereo images. In order to facilitate the subsequent processing, we use the re-mosaic procedure based on metadata to combine these 23 stereo images into 3 long stereo strips.

Over the test area, totally 23 scenes of IRS-P5 stereo images were acquired. The ground resolution of IRS-P5 images is 2.5m, and each scene covers about 30 × 30km^2. In order to precisely georeference these images, with the cooperation of the 1rd Institute of Surveying and Mapping of Heilongjiang SBSM, about 66 well-distributed GCPs were collected with differential GPS in 2006. The measurement accuracy was better than 0.5m in planimetry and 1m in height. The planimetric coordinates of GCPs is in 1980 Xi'an coordinate system and the elevation adopt 1985 national elevation standard (China); The GCPs are well-distributed in the test area, their ground intervals are about 30km, and most of them are located at the center of road intersection which can be precisely measurement both in image and object space.

According to works made by Lutes, J. (2006), most orientation errors in IRS-P5 stereo images are either biases or linear in line/sample direction. This suggests that at least 4-6 GCPs are required for orient an IRS-P5 stereo pair (with corresponding RPCs) to achieve good enough results. Other works which made by Jocobsen, et. al (2008) also show that with model *M_RPC2* (RPCs plus biases correction) also can achieve good enough orientation results. However, based on our own test with IRS-P5 images in China, for each scene of stereo image, at least 4 GCPs are necessary to remove all biases and linear trend errors.

Normally, we could commercially get so-called IRS-P5 "standard scene" of images, which have 12000 × 12000 pixels and cover 30 × 30km^2. Basically the standard scenes could be sub-images of a long IRS-P5 strip. They are just subdivided from a long IRS-P5 strip for commercial reason and normally they have 5%-15% overlap between adjacent scenes. This situation will cause difficulties or complicate the sub-sequent processing. For example, in case of block-adjustment, we have to measure necessary tie-points between adjacent standard scenes, the measurement errors can be accumulated if there are not enough GCPs. The most important thing is that points located in overlap areas share the same orientation elements; this could cause big problems in block-adjustment, because the corresponding imaging line will never intersected in object space. To avoid these problems, we develop a procedure to re-mosaic adjacent IRS-P5 standard scenes into a long stereo strip (Fig. 5) in condition that these scenes are sub-images of the original long IRS-P5 strip. After this re-mosaic procedure, 23 IRS-P5 scenes of the Beijing test-field are re-mosaic into only 3 IRS-P5 long stereo strips.

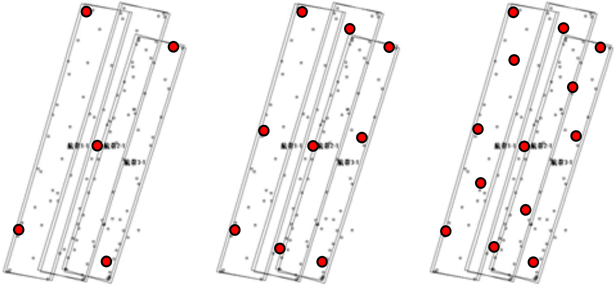

Fig. 6: Different distribution of GCPs for different block-adjustment test phase (with 5, 9, 13 GCPs respectively) with IRS-P5 imagery

We select different numbers and distribution layout of GCPs for accuracy test, which includes 4 GCP, 9 GCPs, 13 GCPs and all of control points (see Fig. 6), the results are shown in Table 4. Test results show that: (a) with the increase number of GCPs, there is certain degree of improvement for both planimetry and elevation accuracy, but the improvement is not so significant; (b) adjustment accuracy in teat area can meet the requirement of block-adjustment in surveying criterion at 1:50,000 scale even with only 5 GCPs located at corners of the test-field. According to this result, the proposed re-mosaic procedure is quite important for both reduce the number of GCPs and reduce the measurement error accumulation. For single long-strip IRS-P5 images, only 4 GCPs at the image corners are enough to achieve good accuracy under the condition that the length of strip is below 150km; for multiply long-strip IRS-P5 stereo images even less GCPs are required to reach the requirement of topographic map surveying at 1:50,000 scale in China.

Test phase	GCPs+CPs	RMSE-X	RMSE-Y	RMSE-Z
5 GCPs	5 + 61	1.70	1.96	2.49
9 GCPs	9 + 57	1.64	1.93	2.50
13 GCPs	13 + 43	1.61	1.86	2.37
66 GCPs	66 + 0	1.43	1.68	1.98

Table 4: Accuracy test for block-adjustment in Beijing test-field, with IRS-P5 stereo images. The unit is in meters

4. Conclusions

In this paper, we present an approach for block-adjustment based on Rational Function Model (RFM) with sparse GCPs by using satellite Images. To test the proposed approach, it has been applied to SPOT-5 images over 2 test-fields, one is in Baoji City, Chanxi, China, and another covers eastern part of Tibet Plateau, China. All test-fields are with variable terrain geomorphologic type and several tens of GCPs and check points measured by DGPS. The block-adjustment results show that with SPOT-5 HRS images and a small number of GCPs we can achieve 5-9m in planimetric and 2-3m in height direction. In another test we use 23 scenes of IRS-P5 images, the test area covers Beijing area and about 21,000 square kilometers. In this test-field, the block-adjustment result shows that only with 5 GCPs we could achieve 2.0 m in planimetric and 2.5m in height direction. From these experiments, it’s shown that with the proposed block-adjustment approach, by using SPOT-5 HRS/HRG and IRS-P5 imagery with several GCPs, satisfactory image orientation results can be completed with a little bit better accuracy than those requirements from Chinese Surveying and Mapping regulations for 1:50000 topographic maps.

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