BLOCK ADJUSTMENT OF MULTISTRIP ALOS/PRISM IMAGES

Chao-Yi Yu [a] *and Tee-Ann Teo* [*b]

[a] *Graduate student, Department of Civil Engineering, National Chiao Tung University, 1001 University Road, Hsinchu, Taiwan 30010; Tel: + 886-3-5712121#54982; E-mail: joyjoy1777.cv99g@g2.nctu.edu.tw*

[b] *Assistant Professor, Department of Civil Engineering, National Chiao Tung University, 1001 University Road, Hsinchu, Taiwan 30010; Tel: + 886-3-5712121#54929; E-mail: tateo@mail.nctu.edu.tw*

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ABSTRACT: ALOS (Advanced Land Observing Satellite) /PRISM (Panchromatic Remote-sensing Instrument for Stereo Mapping) is an optical sensor that is able to acquire forward, nadir and backward images simultaneously. This characteristic is useful for 3-D positioning as it may acquire along-track stereo images. A number of studies have been reported on the block adjustment of PRISM along-track stereo images. However, relatively few studies have discussed the block adjustment of PRISM along-track and across-track stereo images. The purpose of this study is to evaluate the geometric accuracy for the block adjustment of multistrip PRISM images in different combinations. The major works include the automatic tie-point matching, bundle block adjustment and accuracy analysis. First, we use ERDAS LPS to extract the tie points automatically between along-track and across-track images. Then, we perform the bundle block adjustment using ephemeris data and ground control points. Finally, the check points are utilized to assess the geometric accuracy. The test area is located in the northern part of Taiwan. Two strips of PRISM level 1A images with OB1 (forward, nadir and backward images) and OB2 (nadir and backward images) modes are selected in the experiment. The geometric accuracy assessments compare the result of along-track stereo images, cross-track stereo images and all images. The multi-view PRISM images may improve the geometric capability for block adjustment. Therefore, the block adjustment of multi-view images is beneficial to terrain generation.

1. INTRODUCTION

ALOS/PRISM is an optical three lines scanner which is able to take forward, nadir and backward images simultaneously. This characteristic may produces stereo images for 3-D positioning in the way of multi lines scanning. ALOS/PRISM provides different scanning modes which includes stereo pairs and stereo triplets. The images that are scanned in different modes may cause different geometries. As the along-track images of ALOS/PRISM are highly overlapped, we can use the along-track images for 3-D positioning as well as terrain modeling.

There are some sensor models to process linear array satellite images. One of them is the generic model which includes rational function model (RFM) and affine transformation model; and the other is the strict physics model (Gong et al., 2011). Strict physics model is also known as rigorous sensor model which uses 6 exterior orientation parameters to describe the relationship between object points and image points (Kim, 2007).

GPS and IMU on ALOS can provide high precision orbit and attitude data for each PRISM image line, but it is still necessary to build ground control points (GCPs) for eliminating systematic errors (Chen et al., 2004; Poli, 2002). In general, the satellite image has to be related to the national coordinate system. Therefore, ground control points are required for data reliability (Jacobsen, 2008). The GCPs can be obtained by ground surveying, GCP-database or orthoimages. For example, Falala et al. (2009) used Reference3D orthoimages and DSM as a source of GCPs to adjust and validate the sensor model of PRISM images. Since each image row is consecutively recorded while the satellite is moving, each image row also has its own exterior orientation corresponding to acquisition time (Rottensteiner et al., 2009; Takaku and Tadono, 2009). Hence, the bundle block adjustment of linear array satellite images is usually a time-dependent model. Besides, the three lines scanner usually needs additional interior parameters in the self-calibration procedure, for example, two translate for each CCD array. These interior parameters may compensate systematic error and produce better results (Kocaman and Gruen, 2008).

Many studies have discussed the block adjustment of PRISM along-track stereo images (Kocaman and Gruen, 2008; McNeill and Belliss, 2009; Rottensteiner et al., 2009). But relatively few studies have discussed the combination of along-track and across-track stereo images. Therefore, the objective of this study is to evaluate the geometric accuracy for the block adjustment of multistrip PRISM images in different combinations. The 3-D positioning accuracy is improved while the intersection angle is increased. Besides, the intersection angle has more significant impact on Y and Z coordinates than on the X coordinate (Li, 2007). We use rigorous sensor model of bundle adjustment to evaluate the orientation parameters. We also analyze the 3-D positioning accuracy of check points for different intersection angles. The control points and check points are measured manually, and the tie points are generated automatically through ERDAS LPS. The suitable compensatory order for exterior orientation parameters is also analyzed.

2. METHODOLOGY

The input data for this study include two sets of PRISM OB1 images and two sets of PRISM OB2 images. The total number of test images is ten. The reference data are a SPOT orthoimage and 40m DEM. We use the orthoimage and DEM to measure the control points and check points. We analyze the bundle block adjustment result in four different aspects. The first part is bundle block adjustment of multi-images. The second part analyzes the accuracy of block adjustment when different number of tie points is applied. The third part compares the accuracy between OB1 and OB2 modes, and the last part compares the accuracy of check points in different intersect angles.

We use bundle block adjustment of rigorous sensor model to evaluate the exterior orientation parameters. The collinearity equations of satellite image are shown in equation 1. The collinearity condition equations state that the exposure station, an object point, and its image point all lie along a straight line. This is a time-dependent sensor model. In other words, sensor position and rotation matrix are dynamically changed with time. The compensation parameters include position and attitude parameters as shown in equation (2). The compensation parameters are time-dependent polynomial function. The order of polynomial can be zero-order, first-order and second-order. For example, 0-order in X direction is $\Delta X(t) = X_0$, 1-order in X direction is $\Delta X(t) = X_0 + X_1 t$, and 2-order in X direction is $\Delta X(t) = X_0 + X_1 t + X_2 t^2$. The observation for collinearity equations are control points and tie points. The unknown parameters are the coefficients for compensation function.

$$x_{jk} = -f\frac{m_{11i}(t)\big(X_{jk} - X_j(t)\big) + m_{12i}(t)\big(Y_{jk} - Y_j(t)\big) + m_{13i}(t)\big(Z_{jk} - Z_j(t)\big)}{m_{31i}(t)\big(X_{jk} - X_j(t)\big) + m_{32i}(t)\big(Y_{jk} - Y_j(t)\big) + m_{33i}(t)\big(Z_{jk} - Z_j(t)\big)}$$
$$y_{jk}S = -f\frac{m_{21i}(t)\big(X_{jk} - X_j(t)\big) + m_{22i}(t)\big(Y_{jk} - Y_j(t)\big) + m_{23i}(t)\big(Z_{jk} - Z_j(t)\big)}{m_{31i}(t)\big(X_{jk} - X_j(t)\big) + m_{32i}(t)\big(Y_{jk} - Y_j(t)\big) + m_{33i}(t)\big(Z_{jk} - Z_j(t)\big)} \quad (1)$$

$$X_j(t) = X_{0t} + \Delta X(t)\ ;\ Y_j(t) = Y_{0t} + \Delta Y(t)\ ;\ Z_j(t) = Z_{0t} + \Delta Z(t)\ ;$$
$$\omega_{jt} = \omega_{0t} + \Delta\omega(t)\ ;\ \varphi_{jt} = \varphi_{0t} + \Delta\varphi(t)\ ;\ \kappa_{jt} = \kappa_{0t} + \Delta\kappa(t)\ ; \quad (2)$$

Where,

x_{jk}, y_{jk} : image coordinate
X_{jk}, Y_{jk}, Z_{jk} : object space coordinate
$X_j(t)$, $Y_j(t)$, $Z_j(t)$: sensor position at time t
X_{0t}, Y_{0t}, Z_{0t} : sensor position from metadata
$\Delta X(t)$, $\Delta Y(t)$, $\Delta Z(t)$: compensation function for sensor position
$m_{11i}(t)$, $m_{12i}(t) \ldots m_{33i}(t)$: rotation matrix from rotation angles
ω_{0t}, φ_{0t}, k_{0t} : attitude angles from metadata
$\Delta\omega(t)$, $\Delta\varphi(t)$, $\Delta\kappa(t)$: compensation function for attitude angles
j ,k : image and point numbers
f : focal length
S : CCD scalar
t : scan time

3. EXPERIMENTAL RESULTS

3.1 Test data

Test data include 10 PRISM images, six of them are OB1 mode and the others are OB2 mode. OB1 is in triplet scan mode including forward, nadir and backward directions. OB2 is in stereo pair scan mode including nadir and backward directions. The control points are measured from a 2.5m SPOT orthoimage and 40m DEM. The planimetric accuracy of SPOT orthoimage is about 5m at 1 sigma. The related parameters of ALOS/PRISM are shown in table 1.

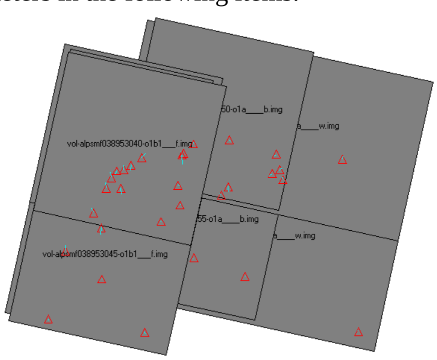
Table 1. Parameters of ALOS/PRISM

Items	ALOS/PRISM	
Scan mode	OB1	OB2
Image width	Forward 35km; Nadir 35km; Backward 35km	Nadir 70km; Backward 35km
Date	2006/10/18	2010/02/24
Image number	2 sets, total 6	2 sets, total 4
Spectrum resolution	Panchromatic	Panchromatic
Spatial resolution	2.5 m	2.5 m
Image size (pixel)	14496x16000	29024x16000 (Nadir) 14496x16000 (Backward)

3.2 Experimental results

3.2.1 Bundle block adjustment using different polynomial orders

We used all of the PRISM images to evaluate the suitable polynomial orders for exterior orientation parameters. The configuration of control points is shown in figure 1. The red triangles are control points. The accuracies of check points are shown in table 4. From the table, we found that the accuracy of check points is improved when the polynomial orders of position and attitude parameters are 1. Therefore, we selected this polynomial order for exterior orientation parameters in the following items.



Items	Multistrip PRISM images
Number of image	10 images
Control point	10 points for each image, total 40
Check point	10 points for each image, total 40
Tie point	Total 57

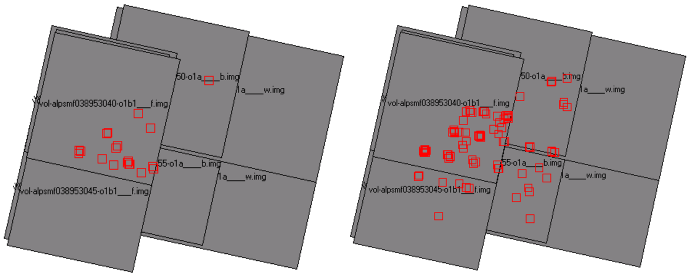
Figure 1. The configuration of control points

Table 4. Accuracies of check points in different polynomial functions

Compensation function for position	0-order	0-order	0-order	1-order	1-order	1-order	2-order	2-order	2-order
Compensation function for attitude	0-order	1-order	2-order	0-order	1-order	2-order	0-order	1-order	2-order
Ground X (meter)	3.199	2.662	2.780	2.646	2.754	3.012	2.894	2.881	2.987
Ground Y (meter)	7.159	6.357	7.587	6.339	6.269	7.554	7.271	7.671	7.696
Ground Z (meter)	12.698	12.028	11.240	11.969	11.847	11.384	13.553	13.457	11.339
Image X (pixel)	1.061	1.054	1.080	1.026	1.072	1.095	1.056	1.110	1.149
Image Y (pixel)	3.422	2.596	2.903	2.596	2.580	2.915	2.779	2.805	2.922

3.2.2 Bundle block adjustment using different number of tie points

This part analyzes the accuracy of check points using different number of tie points. The distribution of tie points is shown in figure 2. The red rectangles are tie points. The accuracy of check points is shown in table 5. From the table, we found that the accuracy of check points is improved when the number of tie points is increased. The improvement is not significant. As the tie points are generated automatically, the incorrect tie points may effects the accuracies.



Items	Different number of tie points	
Number of image	10 images	
Control point	10 points for each image, total 40	
Check point	10 points for each image, total 40	
Tie point	Total 20	Total 100

(a) (b)

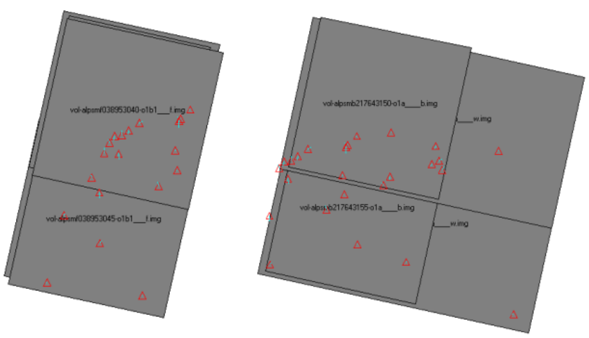
Figure 2. The diagram and parameters of project, (a) 20 tie points and (b) 100 tie points

Table 5. Accuracies of check points

Check point	20 tie points	100 tie points
Ground X (meter)	2.709	2.632
Ground Y (meter)	6.713	6.480
Ground Z (meter)	12.318	12.285
Image X (pixel)	1.069	1.022
Image Y (pixel)	2.710	2.681

3.2.3 Bundle block adjustment using OB1 mode and OB2 mode

The purpose of this stage is to compare the accuracy of images taken with different modes. The test images include OB1 and OB2 modes. The OB1 acquires triple images and OB2 acquires stereo images. There are 6 images in OB1 and 4 images in OB2 mode. The project diagram and parameters are shown in figure 3. The accuracy of check points is shown in table 6. From the table, we found that the accuracy of OB1 is better than OB2 especially in Z direction as the base-to-height ratio of OB1 is better than OB2.



Items	Different modes	
Mode	OB1	OB2
Number of image	6 images	4 images
Control point	10 for each image, total 19	10 for each image, total 21
Check point	10 for each image, total 20	10 for each image, total 20
Tie point	Total 26	Total 26

(a) (b)

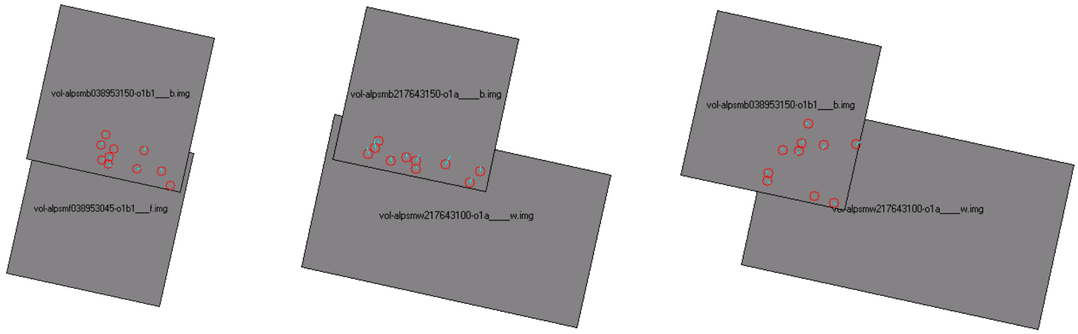
Figure 3. The diagram and parameters of project, (a) OB1 mode and (b) OB2 mode

Table 6. Accuracies of check points

Check point	OB1 mode	OB2 mode
Ground X (meter)	2.484	2.574
Ground Y (meter)	6.648	6.500
Ground Z (meter)	10.908	14.004
Image X (pixel)	1.024	1.045
Image Y (pixel)	3.164	2.058

3.2.4 Different intersection angles

The purpose of this experiment is to compare the accuracy of images with different intersection angles. We evaluate three combinations with different intersection angles. The first one includes 2 images in OB1 mode, the second one includes 2 images in OB2 mode, and the last one includes 1 image in OB1 and 1 image in OB2 modes. Three combinations are shown in figure 4. The accuracy of check points is shown in table 7. From the table, we found that the large intersection may produce better results. Notice that the quality of control and check points also effect the results. As the number of check pint is 10 points the results of 3-D positioning were underestimated.



(a) (b) (c)

Items	Different intersect angles		
Mode	OB1	OB2	OB1 with OB2
Intersect angle	48 degree	24 degree	35 degree
Number of Image	2 images		
Control point	10 for each image, total 19	10 for each image, total 19	10 for each image, total 20
Check point	10 for each image, total 10		
Tie point	Total 10		

Figure 4. The diagram and parameters of project, (a) 48 degrees, (b) 24 degrees and (c) 35 degrees

Table 7. Accuracies of check points

Mode	OB1	OB2	OB1 with OB2
Check point	48 degrees	24 degrees	35 degrees
Ground X (meter)	2.953	2.192	3.060
Ground Y (meter)	2.898	6.692	3.128
Ground Z (meter)	2.451	12.228	4.066
Image X (pixel)	1.126	1.120	1.426
Image Y (pixel)	1.194	2.066	1.884

4. CONCLUSIONS

This study evaluated the geometric accuracy of multiple strips ALOS/PRISM using bundle block adjustment. The experimental results indicate that: (1) the bundle block adjustment of multi-images shows that the accuracy of check points can reach 1.1, 2.5, and 4.5 pixels in X, Y and Z direction, respectively. Notice that, the quality of control points may influence the result. The first order polynomial function for position and attitude parameters may obtain the highest accuracy in this study area. (2) The results of different number of tie points show that when the number of tie point is increased, the accuracy of check points would become better. However, wrong matched tie points may impact the result. (3) The results of different modes show that the accuracy of OB1 is better than OB2 while the geometry of OB1 is better than OB2 mode. (4) The results of different intersection angles show that the accuracy of check points is improved when the intersection angle is increased. The accuracy of check points with cross-track image can reach 1.2, 1.3, and 1.6 pixels in X, Y and Z direction, respectively.

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