Orbit Adjustment for EROS A1 High Resolution Satellite Images

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ABSTRACT: As the resolution of satellite images is improving, the applications of satellite images become widespread. Orientation modeling is an indispensable step in the processing for satellite. EROS A1 is a high resolution imaging satellite. Its linear array pushbroom imager is with 1.8meter resolution on ground. EROS A1 is a sun-synchronous satellite and sampling with asynchronous mode. The main purpose of this investigation is to build up an orientation model for EROS A1 satellite images. The major works of the proposed scheme are:(1) to set up the transformation model between on-board data and respective coordinate systems, (2) to perform correction for on-board parameters with polynomial functions, (3) to adjust satellite's orbit accurately using a small number of ground control points and (4) to fine tune the orbit using the Least Squares Filtering technique. The experiment includes validation for positioning accuracy using check points.

1. INTRODUCTION

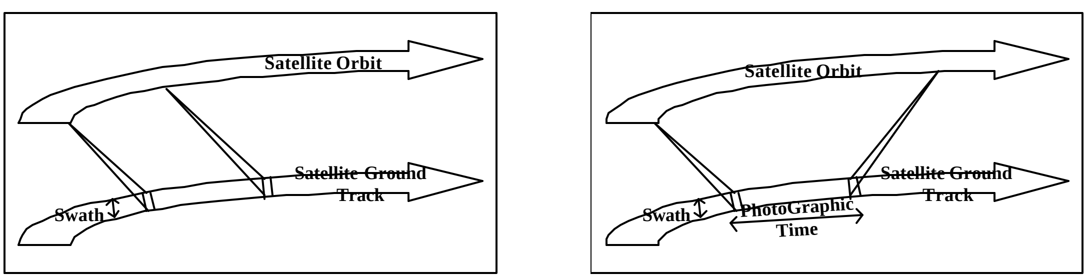
The generation of orthoimages from remote sensing images is an important task for various remote sensing applications. Orbit adjustment is the first step of geometric correction. Nowadays, most of the high resolution satellites are using linear pushbroom array, for example, IKONOS, Orbview, EROS and others. From the photogrammetric point of view, base on the collinearity condition equations, a bundle adjustment may be applied to model the satellite orientaion (Guanand and Dowman 1988, Chen and Lee 1993). This approach needs a large number of ground control points (GCPs). Chen and Chang (1998) used on-board data and a small number of GCPs to build up a geometric correction model for SPOT satellite images. This paper proposes to use the on-board orbital parameters and GCPs to calibrate the satellite orbit. The central tasks include (1) calculation of the orbital parameters and attitude data from on-board data, (2) modeling of the orbital parameters with low order polynomial functions, (3) to adjust satellite's orbit accurately using a small number of ground control points and (4) to fine tune the orbit using the Least Squares Filtering technique.

2. CHARACTERISTICS OF EROS A1 SATELLITE

EROS A1 was launched by ImageSat International(ISI) on the 5th of December, 2000. It is expected to have at least four years of lifetime. Its orbit altitude is 480km with 97.3 degrees orbit inclination. EROS A1 is a sun-synchronous satellite. Using its body rotation, the satellite can turn up to 45 degrees in any direction. Its linear array push broom imager is with 1.8meter resolution on ground and 1.5degree of FOV. EROS A1 satellite is sampling with asynchronous mode. it allows the satellite to move at a faster ground speed than its rate of imaging. The satellites actually bend backwards to take its images at an almost constant, predetermined angular speed, enabling its detectors to dwell longer time over each area. In this way it will be able to get lighter, and improve contrast and conditions for optimal imaging. Referring to figure 1, the satellite orbit is longer than the sampling area. In the best condition, the ratio of satellite orbit to sampling area is about 1 to 5. Table 1 shows the comparison of EROS A1 and SPOT 1 to 4 satellites.

Table 1. Comparison of EROS A1 and SPOT1~4 satellites

ITEM	EROS A1	SPOT1~4
Mode of Operation	Push Broom Scanning	Push Broom Scanning
Orbit Altitude	480km	832km
Ground Sampling Distance	1.8m (PAN)	10m(PAN) 20m(XS)
Swath Width	12.5km	60km
Scanning	Asynchronous mode(up to 750 lines/sec)	Synchronous mode(665 lines/sec)
Sensor Type	CCD	CCD
Spectral Band	0.5 to 0.9 microns	PAN:0.51-0.73microns Multispectral：0.50-0.59;0.61-0.68;0.79-0.89micron
Sampling Depth Transmitted	11BITS	8BITS
Pixels-in-line	7800	6000
Field of View	1.5 Deg	4.125 Deg
Slant Angles	45 Deg	27 Deg
Focal Length	3.5 m	1.082 m
Orbit Inclination	97.3 Deg	98.77 Deg
Orbit Pass rate	15.3 orbits/day	14 5/26 orbits/day
Body Rotation	YES	NO
Stereo pairs	In Track, Cross Track	Cross Track



(a) (b)

Figure 1. Illustration for Scanning modes (a) Synchronous (b) Asynchronous

EROS A1's on-board data includes its general condition during sampling as well as other related data. Its position data is defined in Inertial Frame (True date, Mean Equinox). For every 1000 scan lines, it records one data that includes location vector and velocity vector. Its altitude data is defined in Orbital Reference Frame with respect to EROS A1 Body Frame. In the Orbital Reference Frame, Z-axis is pointing to the earth, Y-axis is perpendicular to the orbital plane and X-axis is thus complete to a right hand system. In the EROS A1 Body Frame, Z-axis is pointing to camera axis, X-axis is perpendicular to the sensitive side of the solar panels and Y-axis is complete to a right hand system. It records one data in 15 seconds, which includes 3rd order polynomial functions for 3 direction angles (phi, theta, psi).

3. METHODOLOGY OF ORBIT ADJUSTMENT

3.1 Coordinate Transformation

The on-board data and GCPs are in the different coordinate systems. Before the orbit adjustment, it is essential to built up the coordinate transformation, so that the orbit adjustment will be using the WGS84 as the consistent coordinate systems. Those coordinate systems include inertial frame, WGS84, GRS67, Geodetic Coordinate System, TWD67, Orbital Reference Frame and EROS A1 Body Frame. When using the on-board data to calculate the satellite orbit position, inertial frame will be projected into WGS84 coordinate system. Likewise, when using the on-board data to calculate the satellite orbit attitude, the Orbital Reference Frame to EROS A1 Body Frame angle will be projected into WGS84 ray direction. There will be three steps in between TWD67 and WGS84 transformation. First, we project TWD67 into the geodetic coordinate system, then the geodetic coordinate system is projected into GRS67. Finally, the GRS67 system is projected into WGS84.

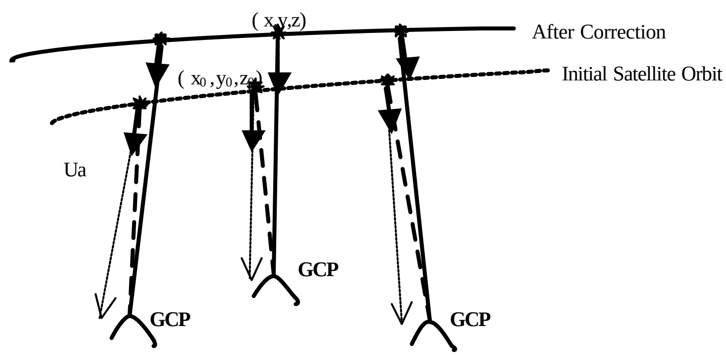


Figure 2. Correction of Satellite Orbit

3.2 Least Squares Adjustment

Because the on-board data include errors to a certain degree, GCPs are needed to adjust the orbit parameters. Referring to figure 2, the observation vector(Ua) provided by the satellite will not pass through the corresponding GCP due to errors in the on-board data. Thus, correction of the orbit data from (x0, y0, z0) to (x, y, z) may be performed under conditions where

$$X_i = x(t_i) + S_i u_{xi} \quad (1a)$$

$$Y_i = y(t_i) + S_i u_{Yi} \quad (1b)$$

$$Z_i = z(t_i) + S_i u_{Zi} \quad (1c)$$

$$x(t_i) = x_0 + a_0 + a_1 \cdot t_i + a_2 \cdot t_i^2 \quad (2a)$$

$$y(t_i) = y_0 + b_0 + b_1 \cdot t_i + b_2 \cdot t_i^2 \quad (2b)$$

$$z(t_i) = z_0 + c_0 + c_1 \cdot t_i + c_2 \cdot t_i^2 \quad (2c)$$

Where X, Y and Z are object coordinates of GCP; ux, uy and uz are components of the observation vector; x(t), y(t) and z(t) are satellite position after correction; x_0, y_0 and z_0 are satellite position before correction; and a_i, b_i and c_i (i=0,1,2) are coefficients for orbit corrections, t represents sampling time and Si is the scale factor.

3.3 Least Squares Filtering

Because the least squares adjustment is a global treatment, it cannot correct the local errors. Therefore, the least squares filtering(Mikhail and Ackermann, 1982) has to be used to fine tune the orbit. By doing this, we assume that the x, y, z-axis are independent. Using three one dimension's function to adjust the orbit. The model of least squares filtering is shown as below:

$$\Delta_k = \sigma_k^{T} [S_k]^{-1} e_k \qquad \text{k=x,y,z axis} \qquad (3)$$

Where ? $_k$ is the correction value of intersection point after least squares filtering;? $_k$ is the covariance matrix of intersection point with respect to each GCPs; S_k is the covariance matrix for each pair of GCPs; e_k is the residuals of GCPs

The basic consideration in this investigation is to minimize the number of required GCPs. Thus, using a large amount of GCPs to characterize the covariance matrix is not practical. In this paper, we use a Gaussian function with some empirical values as the covariance function. The Gaussion function is shown as below:

$$Covariance = \begin{cases} c e^{-(2.146 \frac{d}{d_{max}})^2} & , \quad if \quad d \neq 0 \\ \mu_k & , \quad if \quad d = 0 \end{cases} \qquad (4)$$

$$c = (1 - r_n)\mu_k$$

Where d is the distance between an intersection points and a GCP, d_{max} is maximum distance of intersection point, μ_k is variance of GCPs' residual, r_n is filtering ratio. In which we use r_n =0.1 in experiment. This empirical value 2.146 is selected so that the covariance limit is 1% of 0.01(1-rn)μ_k when d=dmax.

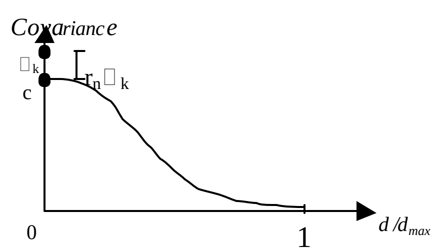


Figure 3, Covariance matrix of least squares filtering

4. EXPERIMENTS

4.1 Test Data

The test data include MBT1-e1001493 and TAW1-e1019903 images, which were sampled on Dec. 15, 2000 and Apr. 15, 2001, respectively. The ratios of the two satellite orbits to sampling area are 1:15 and 1:13 respectively. For MBT1-e1001493 image, GCPs and CHKPs were taken by using GPS surveying. The position accuracy is in centimeter level. The total number of GCPs and CHKPs are 52. As for the TAW1-e1019903 image, GCPs and

CHKPs were selected by using 1:1000 scale topographic map. The position accuracy is better than 50 centimeter. The total number of GCPs and CHKPs are 53. Other related information is shown in table 2.

Table 2 Related Information of Test Images

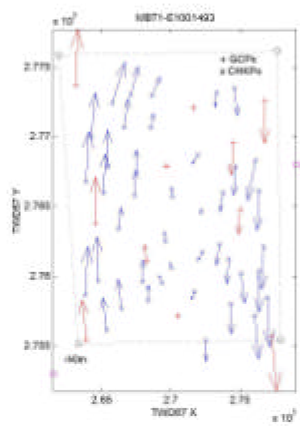
	Case I	Case II
Scene ID	MBT1-e1001493	TAW1-e1019903
Date	2000/12/15	2001/04/15
Integration Time	3.9msec	3.7msec
Ground Sampling Distance	2.10m	1.90m
Test Area	14.79 km *20.96 km	13.38km * 12.48km
Image size	7043*9981 pixel	7043* 6572 pixel
Place	TaoYuan, Taiwan	KaoHsiung, Taiwan
Pointing Angle	18 Deg	11.60 Deg
Orbit Arc	300KM(about 1:15)	170KM(about 1:13)

4.2 Accuracy Evaluation

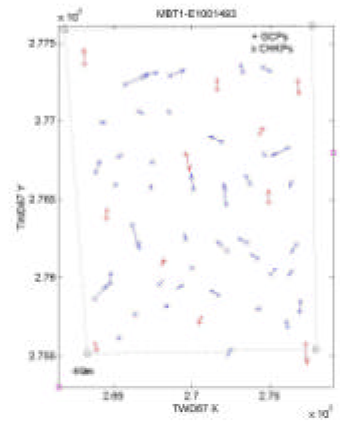
The Ray-Tracing method is applied to evaluate the orbit accuracy. Given the satellite position and ray direction, we calculate the intersection point of DTM and ray direction. Table 3 illustrates the accuracy performance of GCPs and CHKPs. The number of GCPs of case I is eleven. Using least squares adjustment, the RMSE of CHKPs is about 10meter and 43meter in two directions. After least squares filtering, the RMSE of CHKPs are reduce to 4meter and 5meter respectively. In case II, after least squares filtering, the RMSE of CHKPs is about 3meter. The error vectors are illustrated in Figure 4. In figures 4a and 4c, using least squares adjustment one, could see that the system errors are obvious. In figure 4b and 4d, after using least squares filtering the major system errors have been compensated.

Table 3. Root-Mean-Square Error (RMSE) of Orbit Adjustment

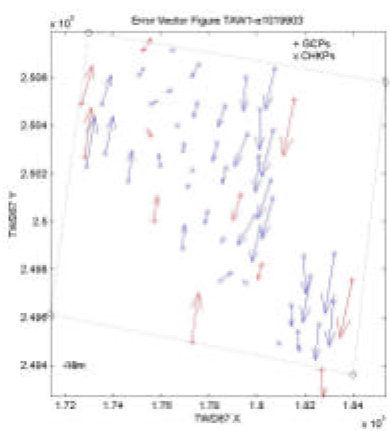
Coordinate system:	Least Squares Adjustment		Least Squares Filtering	
TWD67	RMSE E (meter)	RMSE N (meter)	RMSE E (meter)	RMSE N (meter)
Case I				
GCPs(11)	3.43	50.77	1.23	5.99
CHKPs(41)	5.75	43.36	4.70	5.43
Case II				
GCPs (11)	5.61	31.22	1.64	3.58
CHKPs (42)	5.93	24.54	3.34	3.43



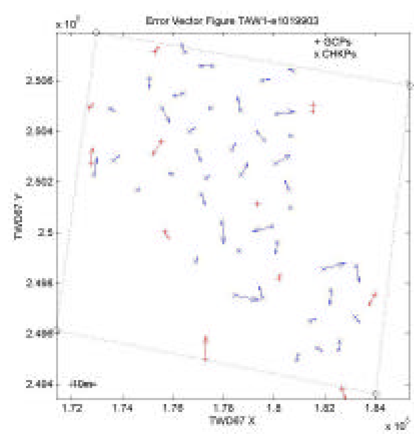
(a) Least Squares Adjustment Error Vectors of Case I



(b) Least Squares Filtering Error Vectors of Case I



(c) Least Squares Adjustment Error Vectors of Case II



(d) Least Squares Filtering Error Vectors of Case II

Figure 4.Error Vectors for GCPs and Check Points

5. CONCLUSIONS

This paper investigates geometric correction for EROS A1 using the satellite on-board orbital data as initial values. The correction for orbital data is modeled as functions of time. The GCPs are then applied to correct the on-board data to maintain the geometrical relationship between image space and object space. After that, we use least squares prediction to fine tune the orbit. Experimental results indicate that using the on-board data and GCPs to do the orbit adjustment, the RMSE of CHKPs may reach about 4meter. This is a preliminary result more investigations are needed to verify the geometric precision for EROS A1 images.

6. REFERNENCES

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