THE SIMPLE METHOD OF GEOMETRIC RECONSTRUCTION FOR SPOT IMAGES

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Abstract: The simple method of the geometric reconstruction of satellite linear pushbroom images is investigated. The model of the sensor used is based on the SPOT model that is developed by Kraiky. The satellite trajectory is a Keplerian trajectory in the approximation. Four orbital parameters, longitude of the ascending node(ω), inclination of the orbit plan(I), latitude argument of the satellite(W) and distance between earth center and satellite, are used for the camera modeling. We suppose that four orbital parameters and satellite attitude angles are exactly acquired. Then, in order to refine model, the given attitude angles and orbital parameters is not changed, but time-independent four parameters associated with LOS(Line Of Sight) vector is updated. A pair of SPOT-5 images has been used for validation of proposed method. Two GCPs acquired by GPS survey is used to controlling the LOS vector. The results are that the RMSE of 16 checking points are about 4.5m. Because the ground resolution of SPOT-5 is 2.5m, the result obtained in this study has a good accuracy. It demonstrates that the sensor model developed by this study can be used to reconstruct the geometry of satellite image taken by pushbroom camera.
Keywords: Camera modeling, Pushbroom, SPOT-5

1. Introduction

Nowadays the images acquired by satellite bring many benefits. One can find the changed region using two satellite images acquired in different times, generate the DTM (Digital Terrain Model) from the geometry of the stereo image, and acquire the military intelligence about the world.

In order to use this satellite image, it is important to study the geometry of satellite images. Because current commercial satellites such as IRS-1C/1D, SPOT, IKONOS, and QuickBird generally use linear arrays in pushbroom mode, most of researchers are interested in the geometric reconstruction of linear pushbroom images. A variety of approach including direct linear transformation (DLT)[1], method based on extended collinear equations[2], and orbital parameter model[3-5], are used for geometric reconstruction.

In our study, the sensor model is based on a SPOT model developed by Kraiky [6]. The satellite trajectory is a Keplerian trajectory in the approximation. Four orbit parameters including longitude of the ascending node(ω), inclination of the orbit plan(I), latitude argument of the satellite(W), and distance between earth center and satellite, were used for the camera modeling. These parameters are expressed by quadratic polynomials over time and supposed that those are exactly calculated. Also We naturally use satellite attitude angles. Otherwise in order to refine model, time-independent parameters associated with LOS vector are updated using two ground control points (GCPs).

Theory of sensor model is presented in section 2. In Section 3 and 4, we show the test data and results. Conclusions follow them in section 5.

2. Theory

Generally, the satellite used to acquire the image is moving along a well-defined close-to-circular elliptical orbit. Fig. 1 represents the relationships between satellite position in orbit and ground position on the earth to explain position vectors. The position vector **p** is the distance from earth center to a point P on earth, **u** is LOS (line-of-sight) vector, and satellite position vector **s** is the distance between satellite position S and earth center. They satisfy the following equation.

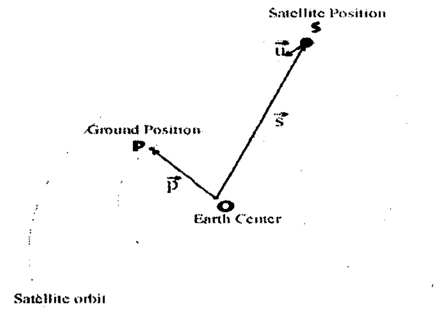

Fig. 1. The relationship between the ground point and satellite position.

$$\mathbf{p} - \mathbf{s} = \mu \mathbf{u} \quad (1)$$

where, μ is arbitrary factor.

1) Coordinate Systems

In order to reconstruct the geometry of satellite image, several coordinate systems must be defined. We follow the convention below:

Earth Centered Interval (ECI) coordinate system – ECI coordinate system has its origin at the center of mass of the earth but has a fixed inertial direction along the intersection of the Earth equatorial plane and the ecliptic plane.

Earth Centered Fixed (ECF) coordinate system – ECF coordinate system has its origin at the center of mass of the Earth but is fixed in the Earth with its axis through the Greenwich meridian (zero longitude).

Local Orbital Reference (LOR) coordinate system – LOR coordinate system has its origin at the center of mass of the satellite. Z is zenith direction, X is the direction of satellite velocity and Y form a right handed reference coordinate.

Attitude Reference (AR) coordinate system – AR coordinate system is identical to the LOR coordinate system when the satellite attitude angle are all zero. So, this coordinate is linked to the satellite.

Imaging Reference (IR) coordinate system – IR coordinate system is given by pixel (j) and scanline (i) position.

2) Geometric Reconstruction

Position vectors represented by Fig. 1 are transformed into LOR coordinate system using a rotation matrix **M** and **A**[5]. Therefore, equation (1) can be written as

$$\begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix}\begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \\ \rho \end{bmatrix} = \mu \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}\begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix} \quad (2)$$

where m_{11}, m_{12}, ..., m_{33} are the elements of rotation matrix **M** of transforming ECI into LOR, a_{11}, a_{12}, ..., a_{33} are the elements of rotation matrix A of transforming AR into LOR, p_x, p_y, p_z and u_x, u_y, u_z are the element of vector $\mathbf{p}$ and $\mathbf{u}$, and ρ is the distance between satellite position S and earth center.

Rotation matrix **M** is represented by three orbital parameters of longitude of the ascending node (ω), inclination of the orbit plan (I), and latitude argument of the satellite(W) calculated from model developed by Kraiky[5]. Fig. 2 represents these parameters.

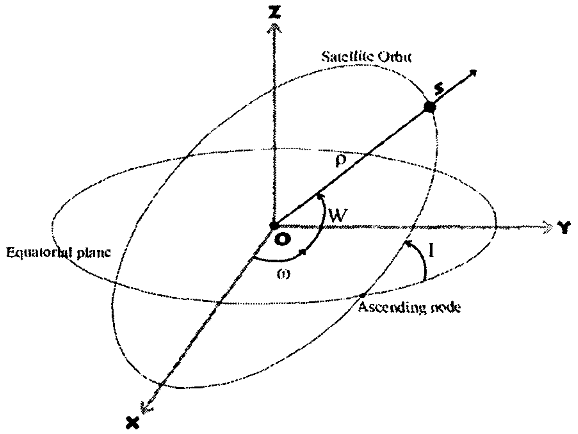

Fig. 2. Orbit parameters definition; longitude of the ascending node(ω), inclination of the orbit plan(I), latitude argument of the satellite(W).

Rotation matrix **A** is acquired by satellite attitude angles of yaw angle, pitch angle and roll angle.

And, u_x, u_y and u_z can be expressed as

$$u_x = \tan\left[\left(\psi_{x_2} - \frac{p_l - j}{p_l - 1}(\psi_{x_2} - \psi_{x_1})\right)\times\frac{\pi}{180}\right] \quad (3)$$

$$u_y = \tan\left[\left(\psi_{y_2} - \frac{p_l - j}{p_l - 1}(\psi_{y_2} - \psi_{y_1})\right)\times\frac{\pi}{180}\right] \quad (4)$$

$$u_z = -1 \quad (5)$$

where ψ_{x_1}, ψ_{x_2}, ψ_{y_1} and ψ_{y_2} are look angles of first and last point in x and y direction respectively, and j and p_l is each other pixel count and number of pixel in IR.

Matrix **B** and **R** is defined as

$$\mathbf{B} = \mathbf{A}^{-1} \quad (6)$$

$$\mathbf{R} = \mathbf{BM} \quad (7)$$

And, We can rewrite Eq. (3) and (4) as

$$u_x = \tan(a_0 + b_0 j) \quad (8)$$

$$u_y = \tan(a_1 + b_1 j) \quad (9)$$

where a_0, a_1, b_0 and b_1 are arbitrary factors associated with LOS vector.

Using Eq. (2), (6), (7), (8) and (9), we can represent as

$$F_1 = \tan^{-1}\left[\frac{r_{11}p_x + r_{12}p_y + r_{13}p_z - b_{13}\rho}{r_{31}p_x + r_{32}p_y + r_{33}p_z - b_{33}\rho}\right] + a_0 + b_0 j = 0 \quad (10)$$

$$F_2 = \tan^{-1}\left[\frac{r_{21}p_x + r_{22}p_y + r_{23}p_z - b_{23}\rho}{r_{31}p_x + r_{32}p_y + r_{33}p_z - b_{33}\rho}\right] + a_1 + b_1 j = 0 \quad (11)$$

where r_{11}, r_{12}, ..., r_{33} and b_{11}, b_{12}, ..., b_{33} are each other the elements of matrix **R** and **B**.

In order to reconstruct geometry of satellite images, these four parameters are calculated by LMS(Least Mean Square) algorithm using two more GCPs.

Because we suppose that the position, velocity, and attitude angles of satellite are right, the result acquired by controlling LOS vector must be including the systematic error. But, the difference between true satellite's position and predicted and corrected satellite's position that has an important effect upon the result of geometric reconstruction is 50m below in SPOT-5 and 500m below in SPOT-1 to 4, so that systematic error taken by controlling LOS vector has about 50cm in SPOT-5 and about 5m in SPOT-1 to 4 about 8 Km high.(Fig.3) Therefore, this method of controlling LOS vector must be a good result.

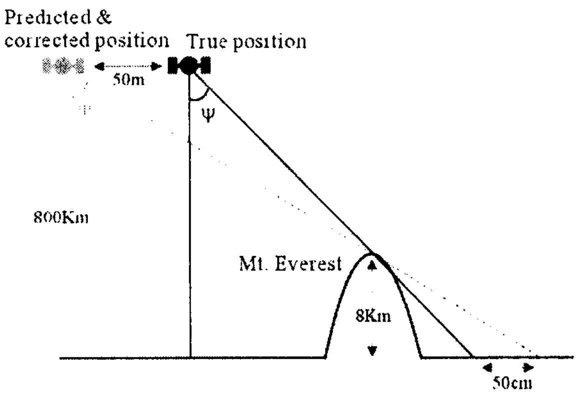

Fig. 3. The systematic error taken by the difference between true position and predicted & corrected position; in SPOT-5

3. Test Data

We use stereo pair of SPOT-5 images. SPOT imaging parameters are summarized in Table1.

Table 1. The imaging parameter of stereo pair SPOT-5 data.

Parameter	Left Image	Right Image
Center Time	9330.202640 (sec)	8407.947218 (sec)
Look Angle (x)	0.517 ~ 0.512 (deg)	0.533 ~ 0.546 (deg)
Look Angle (y)	-3.978 ~ -8.106 (deg)	15.813 ~ 19.941 (deg)

4. Result

In order to analyze LOS vector control method, the values of a_0, a_1, b_0 and b_1 using all ground points are calculated. Fig.4 shows lines taken by given look angle and lines calculated by ground points. The fit result using LMS algorithm is R^2=0.997 and 1 in left images and R^2=0.996 and 1 in right image.

And, We test this method using 2 GCPs (Ground Control Points) and 16 checking points about stereo pair images. The RMSE of checking point acquired from left images and right are 4.565m and 4.451m. Table2 display the result about RMSE.

The results obtained the applicability of the LOS vector control method for accurate geopositioning from

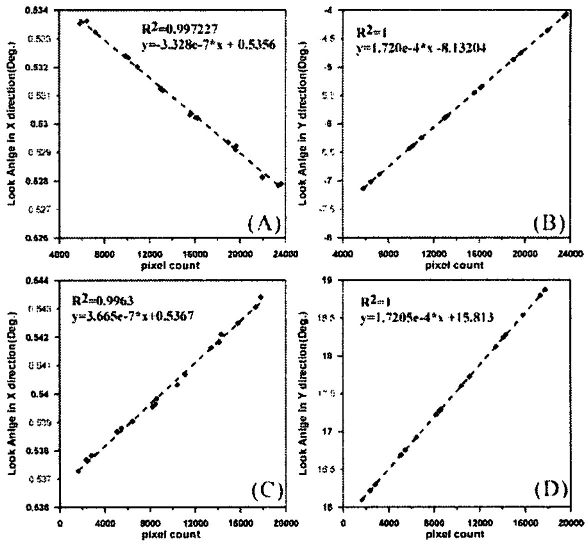

Fig. 4. The result calculated by LMS algorithm. (A) and (B) is the result from left image, (C) and (D) is the result from right image.

SPOT-5 image.

Table 2. RMSE of checking points. Ex is RMSE in direction of pixel, Ey is RMSE in line direction and Et means Total RMSE.: L means left image, R means right image.

	No	Ex	Ey	Et
Check points(L)	16	3.33m	3.12m	4.565m
Check points(R)	16	2.34m	3.79m	4.451m

5. Conclusions

We formulated the LOS vector control method for satellite linear pushbroom images. The results obtained the applicability of this method for accurate geopositioning from SPOT-5 image.

References

[1] Rajiv. G., and Richard, I. H., 1997, Linear pushbroom camera, IEEE trans. pattern anal. mach. Intell, 19(9): 963-975.

[2] Orun, A. B. and K. Natarajan, 1994, A modified bundle adjustment software for SPOT imagery and photography: Tradeoff, PE&RS, 60(12): 1431-1437.

[3] Gugan, D. and I. J. Dowman, 1988, Topographic mapping from SPOT imagery, PE&RS, 54(10): 1409-1414.

[4] Radhadevi, P. V., R. Ramachandran and A. S. R. K. V. Murali Mohan, 1998, Restitution of IRS-1C PAN data using an orbit attitude model and minimum control, ISPRS J. Photogramm. Remote Sensing, 53: 262-271.

[5] Jung H.S., Kang M. H., Lee Y. W. and Won J. S., 2003, A new approach of camera modeling for linear pushbroom images, ASRS2003ISRS, In Pusan.

[6] Kratky, V. 1989, Rigorous photogrammetric processing of SPOT images at CCM Canada, ISPRS Journal of Photogrammetry and Remote Sensing, 44: pp. 53-71.