

Direct Epipolar Image Generation From IKONOS Stereo Imagery Based On RPC and Parallel Projection Model

Jaehong Oh[†], SungWoong Shin and Kyungok Kim

Spatial Information Research Team, ETRI

Abstract : Epipolar images have to be generated to stereo display aerial images or satellite images. Pushbroom sensor is used to acquire high resolution satellite images. These satellite images have curvilinear epipolar lines unlike the epipolar lines of frame images, which are straight lines. The aforementioned fact makes it difficult to generate epipolar images for pushbroom satellite images. If we assume a linear transition of the sensor having constant speed and attitude during image acquisition, we can generate epipolar images based on parallel projection model (2D Affine model). Recent high resolution images are provided with RPC values so that we can exploit these values to generate epipolar images without using ground control points and tie point. This paper provides a procedure based on the parallel projection model for generating epipolar images directly from a stereo IKONOS images, and experimental results.

Key Words : Epipolar, Parallel Projection, RPC, IKONOS, Stereo.

1. Introduction

The epipolar resampling is a prerequisite for a variety of photogrammetric tasks such as image matching, stereoscopic viewing and DEM (Digital Elevation Model) generation. Epipolar resampling of images captured by frame camera has been established and implemented. However, the projection geometry of satellite imagery, which is imaged with a CCD line sensor, is quite different from that of conventional frame images. The shape of epipolar curves is not linear but rather is hyperbola-like (Kim, 2000). This leads to failure of application of well-known epipolar geometry. It is already

reported that strict epipolar images cannot be generated from SPOT imagery without DTM (Digital Terrain Model) (Otto, 1988). The same applies to high-resolution satellite imagery with CCD line scanner such as IKONOS, Quickbird and Kompsat-2.

There was a study on epipolar image generation using affine model (Ono, 1999). Affine model have 8 parameters for each image and require some tie points to normalize images. There's also a study on parallel projection model for epipolar resampling which is almost similar to 2D affine model (Morgan, 2004). Parallel projection model has physical parameters such as attitude and scale. This characteristic set it apart from 2D affine model. However, parallel projection model also requires

Received 15 September 2006; Accepted 20 October 2006.

[†] Corresponding Author: J. - H. Oh (ojh@etri.re.kr)

GCP (Ground Control Points) for computing parameters. Fortunately, high resolution imagery such as IKONOS and Quickbird provide RPC (Rational Polynomial Coefficient) parameters, this can give virtual GCP and image points.

In this paper, we proposed a direct epipolar image generation procedure using RPC and parallel projection model, and analyzed the accuracy.

2. Methodology

1) Overview

This study starts with the assumption that a pair of stereo images are provided with RPC information. RPC let us generate virtual GCP to compute parallel projection model for left and right image. Using parallel projection parameters, epipolar images are generated. In the end, RPC for epipolar images are created using virtual GCP and corresponding image points on the epipolar images for next photogrammetric processing.

When only basic RPC are available, we need to improve RPC parameters with more than 1 GCP, because the accuracy of basic RPC is somewhat low. For example, the positional accuracy of IKONOS Geo level imagery (Level-2) is 50m (CE90, RMSE = 23.3m), and the 1m Stereo Imagery (Level-2 stereo) has horizontal error of 25m (CE90), vertical error of 22m (LE90).

2) Exploitation of RPC

RFM(Rational Function Model) is a ratio of two cubic polynomials of object space coordinates, and as such provides a functional relationship between the object space coordinates and the image space coordinates as shown equation (1). RPC can be generated not only by fitting the RPC to the physical camera model, but also by GCP. An iterative least squares solution was derived to compute the

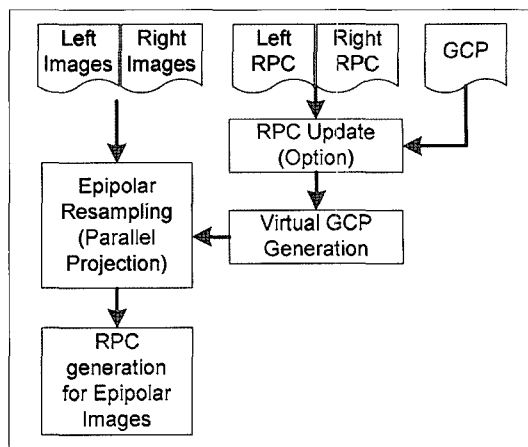


Figure 1. Overview of the study.

coefficients using GCP (Tao, 2001).

$$Y = \frac{N_L(U, V, W)}{D_L(U, V, W)} = \frac{a^T u}{b^T u} \tag{1}$$

$$Y = \frac{N_S(U, V, W)}{D_S(U, V, W)} = \frac{c^T u}{d^T u}$$

where, X, Y = normalized image space coordinates

U, V, W = normalized object space coordinates

$$u = [1 \ V \ U \ W \ VU \ VW \ UW \ V^2 \ U^2 \ W^2 \ UVW \ V^3 \ VU^2 \ VW^2 \ V^2W \ U^2W \ W^3]^T$$

$$a = [a_1 \ a_2 \ \dots \ a_{20}]^T, \ b = [b_1 \ b_2 \ \dots \ b_{20}]^T$$

$$c = [c_1 \ c_2 \ \dots \ c_{20}]^T, \ d = [d_1 \ d_2 \ \dots \ d_{20}]^T$$

In equation (1), each coordinates are normalized to $<-1, +1>$ range by applying the offsets and the scale factors as shown equation (2). This normalization is for improving numerical precision.

$$U = \frac{\phi - \phi_0}{\phi_s}, \ V = \frac{\lambda - \lambda_0}{\lambda_s}, \ W = \frac{h - h_0}{h_s} \tag{2}$$

$$Y = \frac{L - L_0}{L_s}, \ X = \frac{S - S_0}{S_s}$$

where, ϕ, λ, h = the geodetic latitude, longitude, and ellipsoidal height,

L, S = the image line and sample coordinates, $\phi_0, \lambda_0, h_0, S_0, L_0, \phi_s, \lambda_s, h_s, S_s, L_s$ = offset and scale factors for the latitude, longitude,

height, sample and line.

RPC involve typical error due to camera position and attitude errors such as ephemeris error and drift error, etc. Therefore, RPC have to be adjusted for accurate photogrammetric processing. Dial (2002) proposed a polynomial model defined on the domain of image coordinates to represent the adjustable functions as shown equation (3).

$$L + a_0 + a_s S + a_L L = \frac{N_L(U, V, W)}{D_L(U, V, W)} \times L_s + L_0 \quad (3)$$

$$S + b_0 + b_s S + b_L L = \frac{N_s(U, V, W)}{D_s(U, V, W)} \times S_s + S_0$$

where, $a_0, a_L, a_s, b_0, b_L, b_s$ = the adjustment parameters.

3) Parallel Projection Model

The very narrow AFOV(Angular Field Of View) of some sensors can result in having almost parallel projection in the scanning direction. The constant attitude and constant velocity of the scanner during image capture leads to parallel scan lines (Fraser, 2000; Morgan, 2004). For example, AFOV of IKONOS is less than 1 degree and altitude above ground is 680 km (Gruen, 2000).

The mathematical model of parallel projection between the image (2D) and the object space surface (3D) is expressed as equation (4).

$$\begin{bmatrix} x \\ y \\ 0 \end{bmatrix} = sR \begin{bmatrix} L \\ M \\ N \end{bmatrix} + sR \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \\ 0 \end{bmatrix} \quad (4)$$

where, x, y = image coordinates

X, Y, Z = object space coordinate

s = scale value

λ = the distance between object point and its image point

L, M, N = parallel projection unit vector

$R = R_k R_\phi R_w$ = rotation matrix

$\Delta x, \Delta y$ = shift values

Equation (4) is simplified as 2-D affine as shown

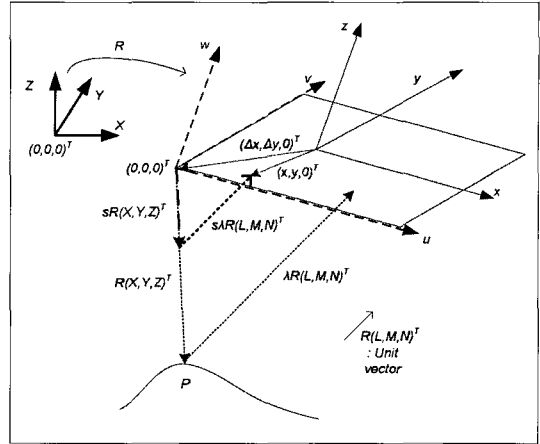


Figure 2. Parallel projection model.

equation (5).

$$x = A_1 X + A_2 Y + A_3 Z + A_4 \quad (5)$$

$$y = A_3 X + A_6 Y + A_7 Z + A_8$$

For more details including the transformation between parallel projection parameters and 2-D affine parameters, please refer (Morgan, 2004).

Very narrow AFOV is similar to parallel projection, but they are not identical. Therefore, the transformation from perspective to parallel projection has to be applied before modelling as equation (6).

$$y_{parallel} = \frac{y_{perspective}}{1 - (\tan \omega) \frac{y_{perspective}}{c}} \quad (6)$$

where, ω = roll angle

c = focal length

4) Epipolar Resampling

After determining the parallel projection parameters for each image, the parallel projection parameters of the epipolar images can be selected as equation (7). (n denotes epipolar image, single quotation mark means right image)

$$\omega_n = \phi_n = 0$$

$$\kappa_n = \arctan \left[\frac{NM' - MN'}{NL' - LN'} \right] \quad (7)$$

$$\Delta x_n = \frac{(\Delta x + \Delta x')}{2}, \Delta y_n = \frac{(\Delta y + \Delta y')}{2}, s_n = \frac{(s + s')}{2}$$

$$L_n = L, M_n = M, L'_n = L', M'_n = M$$

Once parallel projection parameters of epipolar image are determined, the transformation parameters between original image and epipolar image can be established as equation (8).

$$\begin{aligned} x_n &= B_1x + B_2y + B_3 \\ y_n &= B_4x + B_5y + B_6 \end{aligned} \tag{8}$$

where, $B_1 = S(M_{11} - M_{31}U)$

$$B_2 = S(M_{12} - M_{32}U)$$

$$B_3 = \Delta x_n + S((M_{31}\Delta x + M_{32}\Delta y)U - M_{11}\Delta x - M_{12}\Delta y)$$

$$B_4 = S(M_{21} - M_{31}V)$$

$$B_5 = S(M_{22} - M_{32}V)$$

$$B_6 = \Delta y + S((M_{31}\Delta x + M_{32}\Delta y)V - M_{21}\Delta x - M_{22}\Delta y)$$

$$B_1 = S(M_{11} - M_{31}U)$$

$$B_2 = S(M_{12} - M_{32}U)$$

$$B_3 = \Delta x_n + S((M_{31}\Delta x + M_{32}\Delta y)U - M_{11}\Delta x - M_{12}\Delta y)$$

$$B_4 = S(M_{21} - M_{31}V)$$

$$B_5 = S(M_{22} - M_{32}V)$$

$$B_6 = \Delta y + S((M_{31}\Delta x + M_{32}\Delta y)V - M_{21}\Delta x - M_{22}\Delta y)$$

$$B_1 = S(M_{11} - M_{31}U)$$

$$B_2 = S(M_{12} - M_{32}U)$$

$$B_3 = \Delta x_n + S((M_{31}\Delta x + M_{32}\Delta y)U - M_{11}\Delta x - M_{12}\Delta y)$$

$$B_4 = S(M_{21} - M_{31}V)$$

$$B_5 = S(M_{22} - M_{32}V)$$

$$B_6 = \Delta y + S((M_{31}\Delta x + M_{32}\Delta y)V - M_{21}\Delta x - M_{22}\Delta y)$$

$$B_1 = S(M_{11} - M_{31}U)$$

$$B_2 = S(M_{12} - M_{32}U)$$

$$B_3 = \Delta x_n + S((M_{31}\Delta x + M_{32}\Delta y)U - M_{11}\Delta x - M_{12}\Delta y)$$

$$B_4 = S(M_{21} - M_{31}V)$$

$$B_5 = S(M_{22} - M_{32}V)$$

$$B_6 = \Delta y + S((M_{31}\Delta x + M_{32}\Delta y)V - M_{21}\Delta x - M_{22}\Delta y)$$

3. Experimental Results

1) Data

We tested with a stereo pair of IKONOS panchromatic images. Table 1 shows the information

Table 1. Test data description.

Satellite	IKONOS	
Site	Daejeon, Korea	
Product level	Level 2 Stereo Geo	
	Left Image	Right Image
Acquisition date	2001-11-19 / 02:18 GMT	2001-11-19 / 02:19 GMT
Row size in pixel	13824	14336
Col size in pixel	13816	13816



Figure 3. Overview of IKONOS imagery (Green: 3 GCP, Red: 20 Check points).

Table 2. Result of RPC update.

Error in pixel	Left RPC		Right RPC	
	row	col	row	col
Before Update	3.83	4.37	2.42	15.5
After Update	1.10	1.02	0.89	1.83

on the test images.

2) RPC Update

First of all, RPC were improved using 3 ground control points. Therefore, 6 adjustment parameters were computed using equation (3). The accuracy, which was calculated using 20 check points, was improved as shown Table 2.

When IKONOS stereo imagery (Level-3 stereo) is available or high positional accuracy is not needed, this procedure would not be required.

3) Epipolar Resampling

After RPC were improved, 125 virtual GCP (5 points for each ϕ, λ, h) were generated within normalized coordinate range $\langle -1, +1 \rangle$ and projected to image points via improved RPC. We estimated the



Figure 4. Result epipolar image.

Table 3. The accuracy of RPC of epipolar image.

Average of 20 checkpoints	X	Y	Z
	0.92 m	1.33 m	1.02 m

roll angle indirectly from virtual GCP to correct each image coordinate from perspective projection to parallel projection. Estimated roll angle was -22.87 and -12.62 in degree.

Virtual ground points and corresponding corrected image points were used to compute 2D affine parameters for each image as equation (5) and then, affine parameters were transformed to parallel projection parameters. Parallel projection parameters for epipolar image were computed as equation (7).

The transformation parameters between original image and epipolar image were computed as equation (8). Based on these parameters, epipolar images were generated. The result images are as follows. Average y parallax of 20 check points was 3.43 pixels. This result was poor than expected, it seems that the accuracy of RPC and the test area size effected the result. When we tested with small images such as 7000 by 7000 size, we got a result less than 1 pixel.

Epipolar images must have sensor model information for next photogrammetric processing such as matching. Therefore, RPC for epipolar images were regenerated using virtual GCP and corresponding image points on epipolar images. The accuracy calculated using regenerated RPC and 20 check points is as shown Table 3.

4. Conclusion

The epipolar resampling is a prerequisite for a variety of photogrammetric tasks. However, pushbroom sensor has curve-shaped epipolar line that makes it difficult to generate epipolar image.

In this paper, we proposed a procedure for directly generating epipolar images using RPC and parallel projection model. RPC play an important role for generating virtual GCP. As the result, we found that we can get epipolar images with high accuracy using this procedure.

In the future, we will apply this procedure to various satellite images with broad swath width such as Quickbird and Kompsat2 and analyze accuracy.

Acknowledgements

This work was supported by the grant from Korea Ministry of Information and Communication (Project title: Development of Integrated Processing Technology for Multi-Sensor Spatial Imagery Information).

References

- Dial, G., and Grodecki, J., 2002. Block adjustment with rational polynomial camera models, *ASPRS*.
- Fraser, C., 2000. High-resolution satellite imagery : a review of metric aspects, *International Archives of Photogrammetry and Remote Sensing*, 33(B7): 452-459.
- Gruen, A., 2000. Potential and limitations of high resolution satellite imagery, *21st Asian Conference on Remote Sensing*, Taipei, 4-8

December.

- Kim, T., 2000. A study on the epipolarity of linear pushbroom images, *Journal of Photogrammetric Engineering & Remote Sensing*, 66(8):961-966.
- Morgan, M., 2004. *Epipolar resampling of linear array scanner scenes*, Doctoral Dissertation in University of Calgary, Calgary, Alberta.
- Ono, T., 1999. Epipolar resampling of high resolution satellite imagery, *International Archives of Photogrammetry and Remote Sensing*.

- Otto, G. P., 1988. Rectification of SPOT data for stereo image matching, *International Archives of Photogrammetry and Remote Sensing*, 27(B3): 635-645.
- Tao, C. and Yong, H., 2001. A comprehensive study of the rational function model for photogrammetric processing, processing. *Journal of Photogrammetric Engineering & Remote Sensing*, 67(12): 1347-1357.