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

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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 Kompas-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

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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 coefficients using GCP (Tao, 2001).

\[
Y = \frac{N_d(U, V, W)}{D_d(U, V, W)} = \frac{a^T u}{b^T u}
\]

(1)

where, \(X, Y\) = normalized image space coordinates
\(U, V, W\) = normalized object space coordinates
\(a = [a_1 a_2 \ldots a_{20}]^T, b = [1 b_2 \ldots b_{20}]^T\)
\(c = [c_1 c_2 \ldots c_{20}]^T, d = [1 d_2 \ldots d_{20}]^T\)

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.

\[
U = \frac{\phi - \phi_0}{\phi_s}, V = \frac{\lambda - \lambda_0}{\lambda_s}, W = \frac{h - h_0}{h_s}
\]

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

(2)

where, \(\phi, \lambda, h\) = the geodetic latitude, longitude, and ellipsoidal height,
\(L, S\) = the image line and sample coordinates,
\(\phi_0, \lambda_0, h_0, S_0, L_0, \phi_s, \lambda_s, h_s, S_s\) = 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).

\[
L + a_0 + a_tS + a_tL = \frac{N_t(U, V, W)}{D_t(U, V, W)} \times L_s + L_0
\]

\[
S + b_0 + b_tS + b_tL = \frac{N_t(U, V, W)}{D_t(U, V, W)} \times S_s + S_0
\]

(3)

where, \(a_0, a_t, a_s, b_0, b_t, b_s\) = 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).

\[
\begin{bmatrix}
  x \\
  y \\
  0
\end{bmatrix} = s R \begin{bmatrix}
  L \\
  M \\
  N
\end{bmatrix} + s R \begin{bmatrix}
  X \\
  Y \\
  Z
\end{bmatrix} + \frac{\Delta x}{\Delta y} \begin{bmatrix}
  \Delta x \\
  \Delta y \\
  0
\end{bmatrix}
\]

(4)

where, \(x, y\) = image coordinates

\(X, Y, Z\) = object space coordinate

\(s\) = scale value

\(\lambda\) = the distance between object point and its image point

\(L, M, N\) = parallel projection unit vector

\(R = R_x R_y R_z\) = rotation matrix

\(\Delta x, \Delta y\) = shift values

Equation (4) is simplified as 2-D affine as shown equation (5).

\[
x = A_1X + A_2Y + A_3Z + A_4
\]

\[
y = A_5X + A_6Y + A_7Z + A_8
\]

(5)

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 parallel projection has to be applied before modelling as equation (6).

\[
y_{\text{parallel}} = \frac{y_{\text{perspective}}}{1 - (\tan(\omega))}\frac{y_{\text{perspective}}}{c}
\]

(6)

where, \(\omega\) = 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)

\[\omega_n = \varphi_n = 0\]

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

(7)
\[
\Delta x_n = \frac{(\Delta x + \Delta x')}{2}, \quad \Delta y_n = \frac{(\Delta y + \Delta y')}{2}, \quad s_n = \frac{(s + s')}{2}
\]

\[
L_n = L, M_n = M, L' = L', M' = M
\]

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

\[
x_n = B_1x + B_2y + B_3
\]

\[
y_n = B_4x + B_5y + B_6
\]

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

\[
B_2 = S(M_{12} - M_{32}U)
\]

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

\[
B_4 = S(M_{21} - M_{31}V)
\]

\[
B_5 = S(M_{22} - M_{32}V)
\]

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

\[
R_n = R_nB_nB_n^T
\]

\[
M = R_n^T
\]

\[
S = S_n / S
\]

\[
U = \frac{R_{n11}L + R_{n12}M + R_{n13}N}{R_{n31}L + R_{n32}M + R_{n33}N}
\]

\[
V = \frac{R_{n21}L + R_{n22}M + R_{n23}N}{R_{n31}L + R_{n32}M + R_{n33}N}
\]

3. Experimental Results

1) Data

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

<table>
<thead>
<tr>
<th>Satellite</th>
<th>IKONOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>Daejeon, Korea</td>
</tr>
<tr>
<td>Product level</td>
<td>Level 2 Stereo Geo</td>
</tr>
<tr>
<td>Acquisition date</td>
<td>2001-11-19 / 02:18 GMT</td>
</tr>
<tr>
<td>Row size in pixel</td>
<td>13824</td>
</tr>
<tr>
<td>Col size in pixel</td>
<td>13816</td>
</tr>
</tbody>
</table>

Table 2. Result of RPC update.

<table>
<thead>
<tr>
<th>Error in pixel</th>
<th>Left RPC</th>
<th>Right RPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>col</td>
<td>row</td>
<td>col</td>
</tr>
<tr>
<td>Before Update</td>
<td>3.83</td>
<td>4.37</td>
</tr>
<tr>
<td>After Update</td>
<td>1.10</td>
<td>1.02</td>
</tr>
</tbody>
</table>

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 \(\phi, \lambda, h\)) were generated within normalized coordinate range <-1,1> and projected to image points via improved RPC. We estimated the
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.

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References


December.


