RATIONAL POLYNOMIAL MODELLING FOR CARTOSAT-1 DATA

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Commission I, WG I/5

KEY WORDS: Cartosat-1, RPC, Stereo image, Stereo Orthokit, Geo Orthokit

ABSTRACT:

Cartosat-1, ISRO's first satellite with along track stereo capability was launched in May 2005 providing high-resolution stereo imagery of earth's surface for cartographic applications. Providing relevant ancillary information along with the data product is the general practice followed by satellite data providers. Rational Polynomial Camera (RPC) model is used to represent the imaging geometry of Cartosat-1 which is expressed as a ratio of two cubic polynomials which are functions of ground coordinates. One of the important products realised for Cartosat-1 is Stereo Orthokit. Cartosat-1 Orthokit products are already in demand among global users who are able to perform the required geometric processing including DEM generation, ortho-rectfication at their end with the help of any standard COTS Package.Orthokit product consists of radiometrically corrected image in GeoTIFF format, corresponding RPCs and a metadata file, which gives the information about the data. In Stereo Orthokit product, image data from both cameras i.e. FORE and AFT is provided along with their corresponding RPCs. Another product under consideration for Cartosat-1 is Geo Orthokit, where geometrically corrected image is planned to be supplied along with associated RPCs. One of the advantages of this product is user can directly use the product for their applications since the image supplied is already geometrically corrected with mean height. The other advantage is that it will ease the DEM generation process by properly utilizing the reconstruction of epipolar geometry. This paper provides the technical details of RPC generation process and geometric accuracy assessment of the Orthokit products in comparison with georeferenced image generated using Cartosat-1 rigorous imaging sensor model. Both quantitative and qualitative verifications have been conducted over a number of stereo pairs. This paper also addresses the problems observed in RPC during initial phase of the mission and the remedial actions taken to resolve them. From the exercises and analysis carried out, it is clear that Cartosat-1 Orthokit products are meeting the accuracy requirements of global users for various photogrammetric applications. This paper also deals with the approach considered and results achieved for realisation of Geo Orthokit product.

1. INTRODUCTION

Cartosat-1, ISRO's first satellite with along track stereo capability was launched in May 2005 providing high-resolution stereo imagery of earth's surface for cartographic applications. Providing relevant ancillary information along with the data product is the general practice followed by satellite data providers. Rational Polynomial Camera (RPC) model in general is used to represent the imaging geometry of Cartosat-1 which is expressed as a ratio of two cubic polynomials which are functions of ground coordinates. Stereo Orthokit is one of the important products realised for Cartosat-1. Orthokit products are already in demand among global users of Cartosat-1, who are able to perform the required geometric processing including DEM generation, ortho-rectfication at their end with the help of any standard COTS Package.

Orthokit product basically consists of radiometrically corrected image in GeoTIFF format, corresponding RPCs in a file and a metadata file, which gives the description of the data. In Stereo Orthokit product, image data from both cameras i.e. FORE and AFT is provided along with their corresponding RPCs, whereas in the other product Geo Orthokit which is under consideration for Cartosat-1 geometrically corrected image is planned to be supplied along with associated RPCs. One of the advantages of this product is user can directly use the product for their applications since the image supplied is already corrected for mean height. The other advantage is that it will ease the DEM generation process by properly utilizing the reconstruction of epipolar geometry.

This paper discusses about the approaches which are adopted for generation of Orthokit (both mono as well as stereo) and Geo Orthokit products for Cartosat-1. Many improvements were done for Orthokit products since launch of Cartosat-1. Users had reported the denominator zero crossing problem in RPC. The details of the analysis and exercises done towards taking care of problems are also furnished in this paper.

2. RATIONAL POLYNOMIAL MODEL

In general the rigorous sensor model of an image is used for transformations between the 3D object space and the 2D image space. It includes the physical parameters about the camera, such as focal length, principal point location, pixel size, lens distortions, and orientation parameters of the image such as position and attitude. Since satellite imagery consists of both parallel as well as perspective projection, each image scanline is taken at different instance of time. The exterior orientation parameters i.e the attitude angles viz. roll, pitch and yaw and state vectors of the perspective center changes from one scanline to another. The Rational Function Model (RFM) is a general version of the polynomial model that can describe more

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complex image-to-ground transformations. It is otherwise called Rational Polynomial Coefficients (RPC) model that is used as an alternative solution for the rigorous physical sensor model . The RPC model forms the co-ordinates of the image point as ratios of the cubic polynomials in the co-ordinates of the world or object space or ground point. A set of images is given to determine the set of polynomial coefficients in the RPC model to minimise the error.

2.1 Mathematical Formulation

Each scanline number can be expressed as a function of ground coordinates in terms of ratio of cubic polynomials (*Grodecki, J. et al)*. The constant term in the denominator is taken as 1. So for a given scanline number, we have

$$s = \frac{P_1(X,Y,Z)}{P_2(X,Y,Z)} \qquad (1)$$

where,

$$\begin{aligned} P_1(X,Y,Z) = {} & a_1 + a_2 Y + a_3 X + a_4 Z + a_5 YX \\ & + a_6 YZ + a_7 XZ + a_8 Y^2 + a_9 X^2 \\ & + a_{10} Z^2 + a_{11} XYZ + a_{12} Y^3 + a_{13} YX^2 \\ & + a_{14} YZ^2 + a_{15} Y^2 X + a_{16} X^3 + a_{17} XZ^2 \\ & + a_{18} Y^2 Z + a_{19} X^2 Z + a_{20} Z^3 \end{aligned}$$

$$\begin{aligned} P_2(X,Y,Z) = {} & b_1 + b_2 Y + b_3 X + b_4 Z + b_5 YX \\ & + b_6 YZ + b_7 XZ + b_8 Y^2 + b_9 X^2 \\ & + b_{10} Z^2 + b_{11} XYZ + b_{12} Y^3 + b_{13} YX^2 \\ & + b_{14} YZ^2 + b_{15} Y^2 X + b_{16} X^3 + b_{17} XZ^2 \\ & + b_{18} Y^2 Z + b_{19} X^2 Z + b_{20} Z^3 \end{aligned}$$

$$b_1 = 1$$

Similarly each pixel number can also be expressed as a function of ground coordinates in terms of ratio of cubic polynomials. Here also we take the constant term in the denominator as 1. So for a given pixel number, we have

$$p = \frac{P_3(X,Y,Z)}{P_4(X,Y,Z)} \qquad (2)$$

where,

$$\begin{aligned} P_3(X,Y,Z) = {} & c_1 + c_2 Y + c_3 X + c_4 Z + c_5 YX \\ & + c_6 YZ + c_7 XZ + c_8 Y^2 + c_9 X^2 \\ & + c_{10} Z^2 + c_{11} XYZ + c_{12} Y^3 + c_{13} YX^2 \\ & + c_{14} YZ^2 + c_{15} Y^2 X + c_{16} X^3 + c_{17} XZ^2 \\ & + c_{18} Y^2 Z + c_{19} X^2 Z + c_{20} Z^3 \end{aligned}$$

$$\begin{aligned} P_4(X,Y,Z) = {} & d_1 + d_2 Y + d_3 X + d_4 Z + d_5 YX \\ & + d_6 YZ + d_7 XZ + d_8 Y^2 + d_9 X^2 \\ & + d_{10} Z^2 + d_{11} XYZ + d_{12} Y^3 + d_{13} YX^2 \\ & + d_{14} YZ^2 + d_{15} Y^2 X + d_{16} X^3 + d_{17} XZ^2 \\ & + d_{18} Y^2 Z + d_{19} X^2 Z + d_{20} Z^3 \end{aligned}$$

$$d_1 = 1$$

X, Y, Z are the normalized object space coordinates i.e normalized latitude, longitude and height respectively. s and p are the normalized scanline number and pixel number between (-1,+1). The normalization of the coordinates can be done as follows

$$X = (\phi - O_\phi)/S_\phi,\ Y = (\lambda - O_\lambda)/S_\lambda,\ Z = (h - O_h)/S_h,$$
$$s = (S - O_s)/S_s,\ p = (P - O_p)/S_p \qquad (3)$$

$O_\phi, O_\lambda, O_h, O_s, O_p$ are the mean values for latitude, longitude, height, scanline number and pixel number respectively. They are calculated as follows

$$O_\phi = \frac{1}{n}\sum \phi,\ O_\lambda = \frac{1}{n}\sum \lambda,\ O_h = \frac{1}{n}\sum h$$
$$O_s = \frac{1}{n}\sum S,\ O_p = \frac{1}{n}\sum P \qquad (4)$$

while $S_\phi, S_\lambda, S_h, S_s, S_p$ are the scale factor values for latitude, longitude, height, scanline number and pixel number respectively. They are calculated as follows

$$\begin{aligned} S_\phi &= \max\left(|\phi_{\max} - O_\phi|,\ |\phi_{\min} - O_\phi| \right) \\ S_\lambda &= \max\left(|\lambda_{\max} - O_\lambda|,\ |\lambda_{\min} - O_\lambda| \right) \\ S_h &= \max\left(|h_{\max} - O_h|,\ |h_{\min} - O_h| \right) \qquad (5) \\ S_s &= \max\left(|S_{\max} - O_s|,\ |S_{\min} - O_s| \right) \\ S_p &= \max\left(|P_{\max} - O_p|,\ |P_{\min} - O_p| \right) \end{aligned}$$

Where max and min represents the maximum and minimum values.

3. RPC GENERATION

The RPC generation methodology for Orthokit and Geo Orthokit products are different and the steps for the same are described as follows

3.1 RPC Generation methodology for Orthokit

The steps involved in RPC generation(*Tao, V. et al, Fraser, C. et al, Dial, G. et al*) for Orthokit products for Cartosat-1 are as follows:

1. Computation of ground coordinates for every scan line and pixel number using the rigorous image to ground model. Hence determining the corner coordinates for the given area.
2. Based on the input grid interval, computation of ground coordinates at regular interval.
3. Extracting the Minimum and Maximum heights for the particular area from the Global GTOPO DEM to get the estimation of the height of the area under consideration.
4. Based on Minimum and Maximum heights, formation of various constant elevation layers.
5. Generation of multiple grids corresponding to each height using the ground to image transformation along with rigorous sensor model, which uses interior orientation parameters consisting of principal point coordinate as well as focal length, exterior orientation parameters consisting of state vectors as well as attitude.
6. Estimation of RPCs using the grid of object points and the corresponding image points by least square technique.

3.2 RPC Generation methodology for Geo Orthokit

The steps involved in RPC generation for Geo Orthokit products are as follows:

1. Same as steps 1 to 3 from previous section (3.1).
2. Generation of object-space grid using the extents of the area of interest.
3. Performing ground to image transformation using rigorous sensor model for each object point.
4. Computation of ground coordinates in radiometrically corrected image for every scan line and pixel number (image points obtained in previous step) using rigorous image to ground model for mean height.
5. Conversion of geo image coordinates into projected map coordinates (Easting, Northing).
6. Derivation of geo image coordinates from projected map coordinates, which is obtained from previous step.
7. Computation of Rational Polynomial Coefficients using the mappings between ground coordinates and geo image coordinates obtained in previous step by least square technique.

4. EVALUATION PROCEDURE

The RPCs generated are evaluated in the following manner:

- Generation of Rational Polynomial Coefficients using the set of grid points (derived from multiple grids) obtained with different elevation layers.
- Thus obtained coefficients along with scale and offset parameters are used to compute image coordinates.
- The difference between original image coordinates and the coordinates computed using the RPCs are used for the analysis of the fit.

Quantitative evaluation of Geo Orthokit product is also done where the geometrically corrected image is generated with constant elevation using the rigorous sensor model and is compared with the corrected image generated using the RPCs. The difference between the ground coordinates is checked visually by displaying both the images using the COTS package.

5. RESULTS AND DISCUSSIONS

Five datasets were chosen for the analysis of Orthokit product which included two stereo Orthokits and one mono Orthokit. One dataset(mono) was used for analysis of Geo Orthokit product. During evaluation of these products, it was found that there is a possibility of denominator zero cross over in the RPCs in some cases. On deeper analysis of these cases, it was observed that there were jumps in the attitude samples. When these wild points were removed and the attitude values were refitted to smooth them, the regenerated RPCs did not show denominator zero crossovers. Irregular grid as input for RPC generation also caused zero cross over anomaly which was rectified by taking extra attitude samples in the top and bottom of the scene. After rectification of the above problems, RPCs were regenerated and following are the observations:

- RPC fitting residuals are within +/-0.06 pixels (from max to min) both in along-track as well as across-track direction for FORE datasets (**Figure 1, 3 and 5**). RMS of RPC fitting residuals for FORE dataset is around 0.01 pixels in scanline direction and 0.008 in pixel direction (**Table 1**)
- RPC fitting residuals are within +/-0.008 pixels (from max to min) both in along-track as well as across-track direction for AFT datasets (**Figure 2 and 4**). RMS of RPC fitting residuals for AFT dataset is around 0.0015 pixels in scanline direction and 0.004 pixels in pixel direction(**Table 1**).
- Image was geo corrected using sensor model and was compared with the corrected image generated using the Geo Orthokit product with fixed elevation in both cases
- Differences in the coordinates (latitude and longitude) are less than 0.00002 degrees (~2 meters) for one particular dataset which is well within a pixel (**Table 2**)

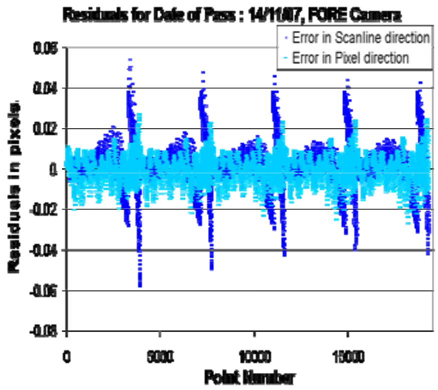

Figure 1

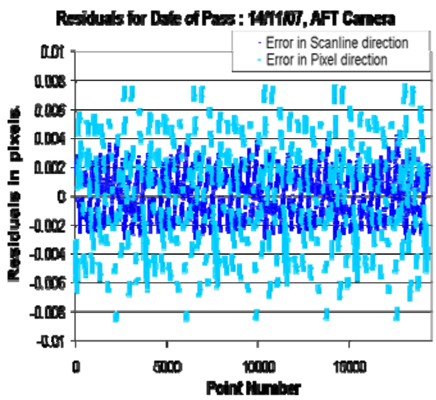

Figure 2

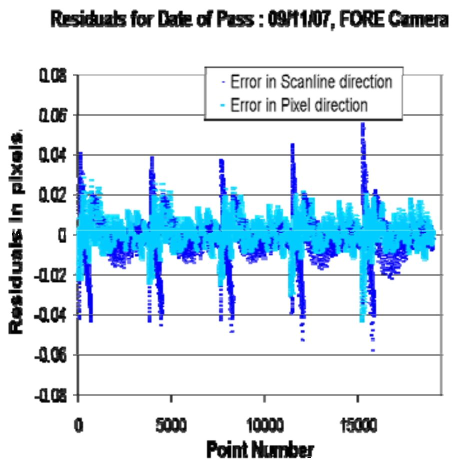

Figure 3

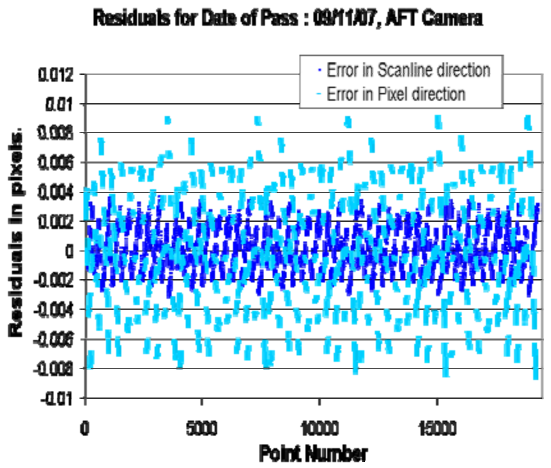

Figure 4

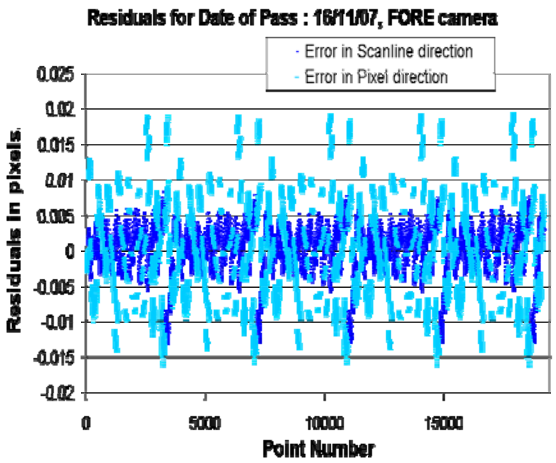

Figure 5

Date of Pass	Camera	RMS Scan	RMS Pixel
14/11/2007	FORE	0.011	0.006
14/11/2007	AFT	0.001	0.004
9/11/2007	FORE	0.010	0.006
9/11/2007	AFT	0.001	0.004
16/11/2007	FORE	0.003	0.007

Table 1: Residual Error for RPC fitting

Standard Corrected		RPC Corrected		Difference in degrees	
Longitude	Latitude	Longitude	Latitude	Longitude	Latitude
130.52392	31.71640	130.52390	31.71641	0.00002	-0.00001
130.61888	31.70757	130.61887	31.70758	0.00001	-0.00001
130.72203	31.62179	130.72202	31.62179	0.00001	-0.00000
130.82592	31.65884	130.82592	31.65885	0.00000	-0.00001
130.80521	31.55389	130.80520	31.55390	0.00001	-0.00001
130.76868	31.40433	130.76867	31.40434	0.00001	-0.00001
130.53104	31.48118	130.53103	31.48118	0.00001	-0.00000
130.46587	31.49833	130.46586	31.49834	0.00001	0.000001

Table 2: Geo Orthokit product vs normal product

6. CONCLUSIONS

Approaches for Cartosat-1 Orthokit product generation are presented including the test results on five datasets. From the tests performed on the given datasets, it can be inferred that RPCs can be provided to the users for photogrammetric processing at their end without compromise on the accuracy. For solving denominator zero crossovers problems, studies showed that more attitude samples are required in order to make the area regular. Further attitude filtering is required to weed out wild points or attitude jumps in samples which is also one of the causes for denominator zero crossing. With the above mentioned improvements, the study showed the rational polynomial model is able to model all the distortions in the image. Also RPCs for georeferenced image could be generated successfully for Geo Orthokit products.

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ACKNOWLEDGEMENT

The authors are grateful to Dr. R.R.Navalgund, Director, Space Applications Centre, Ahmedabad for encouraging and allowing us to take up this work. Authors are thankful to Shri Amit Gupta, Dr. Arvind Kumar Singh, Ms. Medha Alurkar and other members of SPDCG/SIPA, Space Applications Centre for their constant support during the activity. Authors also wish to thank the internal reviewers for their critical comments.