A STUDY OF THE RPC MODEL OF TERRASAR-X AND COSMO-SKYMED SAR IMAGERY

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ABSTRACT:

The rational polynomial coefficient (RPC) model has recently raised considerable interest in the photogrammetry and remote sensing community. This model is a generalized sensor model that is capable of achieving high approximation accuracy. Unfortunately, in all previous literature, the computation of the parameters of the RPC model depends on initial values for the parameters. In this paper, an algorithm for the computation of the parameters without these initial values is presented. Finally, the algorithm is tested on TerraSAR-X and COSMO-SkyMed SAR imagery. Based on numerous tests, the following conclusion can be drawn. This study found that the RPC model is suitable for high resolution SAR imagery.

1. INTRODUCTION

The rational polynomial camera (RPC) model is a generalized sensor model that is capable of achieving high approximation accuracy. It can be solved with or without knowledge of the rigorous physical sensor model. If this model is available, a terrain-independent solution can be developed. Otherwise, the RPC solution will be highly dependent on the input of control points from the terrain surface (Tao et al., 2001; Chen et al., 2006).

When the RPC model is solved using the terrain-independent solution, the important question is whether the over-parameterization of the RPC has led to the design matrix becoming ill conditioned and the normal matrix being singular in a row (Dolloff, 2004). This happens often when there are high order polynomials in the RPC model. In order to improve the condition number of the normal matrix, Tao applied the ridge estimate in which a small multiplication of the identity matrix is added (Tao et al., 2001). Tao determines the ridge parameter by the ridge mark method; other researchers all cite this paper (Gong et al., 2003; Zhang, 2005; Chen et al., 2006). But the ridge estimate raises two problems: the first is that the ridge estimate changes the isometric relation in the normal matrix leading to the estimated result being a biased estimator. The second is that the determination of the ridge parameter is difficult and can be selected over a wide range. So if the RPC is solved using a terrain-independent solution, an algorithm must be found that can improve the status of the normal matrix and does not change the isometric relation of the normal matrix. To overcome the two problems of the ridge estimate, we can use 3D-grid control points to obtain an unbiased RPC estimator that is the base of the geometric processing of satellite imagery.

The numerical properties and accuracy assessment of the use of RPC to replace the rigorous sensor model are reported. But only studies of push-broom imagery and aerial photographs have been undertakem, with no one yet studying TerraSAR-X SAR and COSMO-SkyMed SAR SAR imagery.

TerraSAR-X is a new German radar satellite that has been launched in 2007. The scheduled lifetime is 5 years. It's high frequency X-band SAR sensor can be operated in different modes and polarisation. The SpotLight- (1.3 m), StripMap- (3.3 m) and ScanSAR-modes (14.8 m) provide high resolution SAR images for detailed analysis as well as wide swath data whenever a larger coverage is required. Imaging will be possible in single, dual and quad-polarisation. Beam steering enables observation in different incidence angles and double side access can be realized by satellite roll maneuvers. The satellite will be positioned in an 11 days repeat orbit. The solar panel is mounted on top of the satellite bus. The SAR antenna is visible on the bottom side. The X-band downlink antenna is mounted on a small boom in order to avoid interference with the SAR-antenna.

COSMO-SkyMed is an Earth observation satellite system funded by the Italian Ministry of Research and Ministry of Defence and conducted by the Italian Space Agency (ASI), intended for both military and civilian use. The space segment of the system will include four medium-sized satellites equipped with synthetic aperture radar (SAR) sensors with global coverage of the planet. Observations of an area of interest will be repeated several times a day in all-weather conditions. The four satellites are planned for sun-synchronous polar orbits, phased at 90° and at an altitude of 619 km with an orbit of 97 minutes. The expected operating life of each satellite is estimate in 5 years. COSMO SkyMed is equipped with a polarimetric X-band SAR. COSMO SAR is a multi-mode sensor, a programmable system which is able to operate providing different performance in terms of swath dimension, spatial resolution and polarization. The COSMO-SkyMed SAR instrument can be operated in different beam which include: Spotlight, Stripmap (himage and pingpong), Scansar

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(wideregion or hugeregion), SPOTLIGHT, allowing SAR images with spot extension of 10x10 km^2 and spatial resolution equal to 1x1 m^2 single look; STRIPMAP (HIMAGE achieving medium resolution, wide swath imaging, with swath extension 340 km and spatial resolution of 3x3 m^2 single look; STRIPMAP (PINGPONG), achieving medium resolution, medium swath imaging with two radar polarization's selectable among HH, HV, VH and VV, a spatial resolution of 15 meters on a swath 330 km; SCANSAR (WIDE and HUGE region), achieving radar imaging with swath extension selectable from 100x 100 km^2 (WIDE REGION) to 200x 200 km^2 (HUGE REGION), and a spatial resolution selectable from 30x30 m^2 to 100x100 m^2.

This paper aims to generate a RPC with an unbiased estimator for TerraSAR-X and COSMO-SkyMed SAR imagery.

2. RPC MODEL

In the RPC model, image pixel coordinates d(line, sample) are expressed as the ratios of polynomials of ground coordinates D(Latitude, Longitude, Height). In order to improve the numerical stability of equations, the 2D image coordinates and 3D ground coordinates are each offset and scaled to fit the range from –1.0 to 1.0. The RPC model between the image coordinates d and the ground coordinates D for an image can be presented as below (OGC, 1999),

$$Y = \frac{Num_L(P,L,H)}{Den_L(P,L,H)}$$
$$X = \frac{Num_s(P,L,H)}{Den_s(P,L,H)} \tag{1}$$

Where, $Num_L(P,L,H)$, $Den_L(P,L,H)$, $Num_s(P,L,H)$, $Den_s(P,L,H)$ are the terms of the third order polynomial of (P,L,H), Y and X are the normalized row and column index of pixels in the image, and P, L and H are normalized coordinate values of object points in the ground.

In order to fit the RPC using the rigorous sensor model, we can rewrite Equ. (1) as (Zhang, 2005),

$$F_X = Num_s(P,L,H) - X * Den_s(P,L,H) = 0$$
$$F_Y = Num_L(P,L,H) - Y * Den_L(P,L,H) = 0 \tag{2}$$

The observation error equations can then be formed as,

$$V = Bx - l \tag{3}$$

Where,

$$B = \begin{bmatrix} \frac{\partial F_X}{\partial a_i} & \frac{\partial F_X}{\partial b_j} & \frac{\partial F_X}{\partial c_i} & \frac{\partial F_X}{\partial d_j} \\ \frac{\partial F_Y}{\partial a_i} & \frac{\partial F_Y}{\partial b_j} & \frac{\partial F_Y}{\partial c_i} & \frac{\partial F_Y}{\partial d_j} \end{bmatrix}, \quad (i = 1,20,\ j = 2,20)$$

$$l = \begin{bmatrix} -F_X^0 \\ -F_Y^0 \end{bmatrix}$$

$$x = \begin{bmatrix} a_i & b_j & c_i & d_j \end{bmatrix}^{\mathrm{T}}$$

Based on the least squares method, the RPC are

$$\left(B^T B\right) x = B^T l \tag{4}$$

Wang presents a new iteration for normal equation. The iteration is suitable for common normal equation, morbidity normal equations and rank-defect normal equations and its unbiased and convergent properties have been proved (Wang et al., 2001).

We solve the Equ(4), based on Wang's method, as follows:
Add the x onto Equ(4):

$$\left(B^T B + E\right) x = B^T l + x \tag{5}$$

The x can be estimated:

$$x^{(k)} = (B^T B + E)^{-1} (B^T l + x^{(k-1)}) \tag{6}$$

According to Wang et al., (2001), the estimator is unbiased.

3. TEST DATA

In this study, the TerraSAR-X and COSMO-SkyMed SAR image are used for the test.

TerraSAR-X Data
The test image of TerraSAR-X is a full scene of Beijing; basic information about the scene is listed below.

Image Size	8104* 9042pixels
Resolution	1.6 m
Topography	Flat
imaging mode	SL
Time of Acquisition	2008/03/29/22:17:23.9
Product Type	SSC

Table 1. Basic information on the Beijing TerraSAR-X imagery.

COSMO-SkyMed Data
The test image of COSMO-SkyMed is a full scene of Shang hai ; basic information about the scene is listed below.

Image Size	18427 * 23136 pixels
Resolution	0.9*1.8 m
Topography	Flat
imaging mode	HIMAGE
Time of Acquisition	2008/03/15/11:05:03.5
Product Type	SSC

Table 2. Basic information on the Shanghai COSMO-SkyMed imagery.

4. THE TEST OF THE UNBIASED RPC ESTIMATOR

Based on the RPC conclusions of Tao, the third order RPC model cases with an unequal denominator achieve the best accuracy when the rigorous sensor model is available (Tao et al., 2001). This paper will only test the fitting of a third order RPC with an unequal denominator.

According to the thinking explained above, RPC fitting based on the rigorous sensor model was performed (Kampes, 2005). These results are based on an established 3D Grid GCPs consisting of 15 elevation layers, each with 200 pixel * 200 pixel grid points. The results are listed below.

5. CONCLUSIONS

The RPC model has recently raised considerable interest in the photogrammetry and remote sensing community. The RPC is a generalized sensor model that is capable of achieving high approximation accuracy in comparison to the rigorous sensor models. In this paper, the unbiased RPC estimator is derived.
The unbiased estimator is proposed to strengthen the solutions when the condition of the normal equations is poor. Based on numerous tests with terrain-independent scenarios, the following conclusions can be draw.

The RPC model can achieve an approximation accuracy (1% pixel RMS) that is extremely high for satellite data. The results support the view that the the RPC model, can be used as a replacement for sensor models for photogrammetric restitution.

The RPC model is suited not only for push-broom imagery but also for high resolution SAR imagery.

Check points						Control points					
Y		X		planarity		Y		X		planarity	
max	RMS	max	RMS	max	RMS	max	RMS	max	RMS	max	RMS
0.4	0.1	2.6	1.6	2.6	1.6	0.5	0.1	2.2	1.2	2.2	1.2

Table 3. The accuracy of the 3rd order RPC with unequal denominator on the Beijing TerraSAR-X imagery (10^{-4}pixel).

Check points						Control points					
Y		X		planarity		Y		X		planarity	
max	RMS	max	RMS	max	RMS	max	RMS	max	RMS	max	RMS
1.5	0.4	-8.5	2.9	8.5	3.0	1.8	0.4	-9.6	3.0	9.7	3.1

Table 4. The accuracy of the 3rd order RPC with unequal denominator on the Shanghai COSMO-SkyMed imagery (10^{-4}pixel).

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