Evaluating Modified IKONOS RPC Using Pseudo GCP Data Set and Sequential Solution

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Abstract

RFM is the sensor model of IKONOS imagery for end-users. IKONOS imagery vendors provide RPC (Rational Polynomial Coefficients), Ration Function Model coefficients for IKONOS, for end-users with imagery. So it is possible that end-users obtain geospatial information in their IKONOS imagery without additional any effort. But there are requirements still for rigorous 3D positions on RPC user. Provided RPC can not satisfy user and company to generate precision 3D terrain model. In IKONOS imagery, physical sensor modeling is difficult because IKONOS vendors do not provide satellite ephemeris data and abstract sensor modeling requires many GCP well distributed in the whole image as well as other satellite imagery. Therefore RPC modification is better choice. If a few GCP are available, RPC can be modified by method which is introduced in this paper. Study on evaluation modified RPC in IKONOS reports reasonable result. Pseudo GCP generated with vendor's RPC and additional GCP make it possible through sequential solution.

1. Introduction

Physical and abstract, mathematics sensor models are used for pushbroom satellite imagery. For IKONOS, which don't produce ephemeris data (or ancillary data) for end-user, abstract and mathematics sensor models, such as DLT and RFM, are used to extract 3D geospatial information. Among of them, RFM is generic sensor model used for IKONOS imagery and recommended as image transfer standards by OGC (Open GIS Consortium). IKONOS vendors provide RPC which is 'Rational Polynomial Coefficient' for IKONOS imagery. It is easy way to extract geospatial information by RFM/RPC in IKONOS if end-users don't want more accurate position data. There is need to modify RPC to generate DEM or vector information using IKONOS. But it is difficult for end-users to generate model parameters themselves, because RFM has too many coefficients, so it is necessary to acquire a lot of ground control to solve the sensor model function. For these reasons, it is attractive theme and hot issue updating RPC with a few additional GCPs.

2. RFM sensor model

RFM is one of the image transfer standards for earth image as well as polynomial model, grid interpolation model, universal real-time image geometry model which are recommended by OGC. It is possible to get imagery transfer solution by RFM without satellite ephemeris data and orientation information of sensor if sufficient GCPs are available. RFM is defined ratios of polynomials and image coordinates and 3D object coordinates are normalized by each offset and scale factor to fit the range form -1.0 ~ +1.0 over an image or image section in order to minimize the introductions of errors during the computation (NIMA, 2000).

$$x = \frac{f_1(u,v,w)}{f_2(u,v,w)} \qquad y = \frac{f_3(u,v,w)}{f_4(u,v,w)} \tag{1}$$

$$\begin{aligned} u &= (Lat - O_{Lat})/S_{Lat} \\ v &= (Lon - O_{Lon})/S_{Lon} \\ w &= (H - O_H)/S_H \\ y &= (Row - O_{Row})/S_{Row} \\ x &= (Col - O_{Col})/S_{Col} \end{aligned} \tag{2}$$

Equation (1), (2) is generic form of RFM and offset, scale. Where x and y are the normalized image coordinates and X, Y, Z are the normalized object coordinates.

$$\begin{aligned} f(u,v,w) &= \sum_{i=0}^{3}\sum_{j=0}^{3}\sum_{k=0}^{3} a_n u^i v^j w^k \\ &= a_0 + a_1 v + a_2 u + a_3 w + \\ & a_4 uv + a_5 vw + a_6 uw + \\ & a_7 v^2 + a_8 u^2 + a_9 w^2 + \\ & a_{10} uvw + a_{11} v^3 + a_{12} vu^2 + \\ & a_{13} vw^2 + a_{14} uv^2 + a_{15} u^3 + a_{16} uw^2 \\ & + a_{17} v^2 w + a_{18} u^2 w + \\ & a_{19} w^3 \\ & (i+j+k) \le 3 \\ & (n = 0 \sim 19) \end{aligned} \tag{3}$$

Polynomials (f_1, f_2, f_3, f_4) are expressed detailed in equation (3). For the third order case, the numerators and denominators are 20-term polynomials. Maximum powers of object coordinates are typically limited to 3.

3. IKONOS RPC data

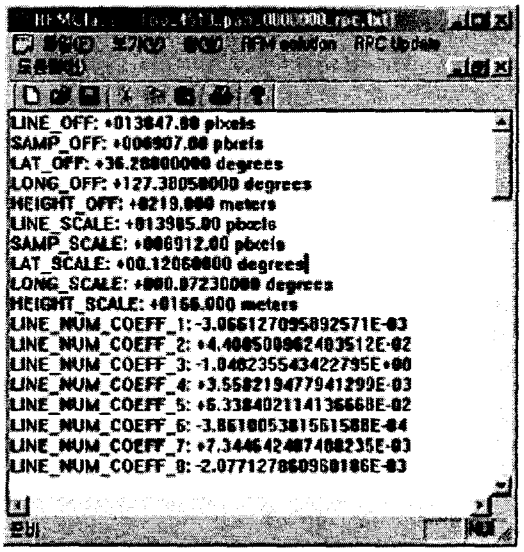

Fig. 1. IKONOS RPC File

It is not provided to end-users orientation or orbit information of IKONOS. It is available only RPC (rational polynomial coefficients). Table 1, Fig. 1 shows the contents of IKONOS RPC file.

RFM used in IKONOS imagery consist of third order polynomials and RPC has 80 terms of polynomials and 10 terms of offset/scale factor. Practically 59 terms are available because each denominators of RFM are equal in both of imagery sample (exactly $f_2 = f_4$) and line term and denominator has constant term (=1.0). Therefore 30 GCPs are essential for RFM modeling at least without the physical sensor model.

Table 1. Contents of IKONOS RPC

Name	Description
LINE_OFF	image row coordinate offset value
SAMP_OFF	image column coordinate offset value
LAT_OFF	ground latitude offset value
LONG_OFF	ground longitude offset value
HEIGHT_OFF	ground height offset value
LINE_SCALE	image row coordinate offset scale
SAMP_SCALE	image column coordinate offset scale
LAT_SCALE	ground latitude offset scale
LONG_SCALE	ground longitude offset scale
HEIGHT_SCALE	ground height offset scale
LINE_NUM_COEFF	numerator of row term
LINE_DEN_COEFF	denominator of row term
SAMP_NUM_COEFF	numerator of column term
SAMP_DEN_COEFF	denominator of column term

4. Modification of RPC

In many cases, additional a few GCPs are available, and end-users want to improve IKONOS RPC for better solution. If GCPs less than 10 are available, it is impossible to generate 59 RFM parameters again with GCPs without physical sensor model. In this paper four methods are tested and proposed for update IKONOS RPC with additional a small number of GCPs.

4.1. Method 1 : Using Pseudo GCPs in Normalized Cubic

First method uses pseudo GCPs in normalized cubic and additional GCPs by GPS observation. Because of number of additional GCPs is not enough to solve the RFM parameters, pseudo GCPs are be generated in normalized cubic to solve RFM sensor model. Fig. (2). Shows the pseudo GCPs are generated normalized cubic. Normalized cubic is the space that each axis range is limited from -1.0 to +1.0.

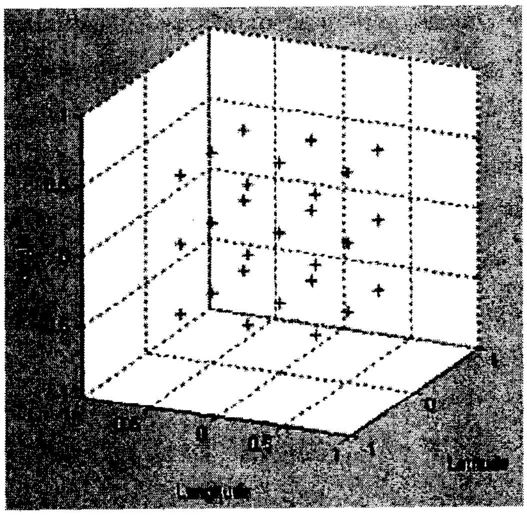

Fig. 2. Pseudo GCPs in Normalized Cubic.

Equation (4), (5) expresses the matrix solution for linearized RFM. Initial values are RPC given by IKONOS vendor. Watchfulness is the weight determination. Pseudo GCPs' weight is to be different from additional GCPs. Additional GCPs are assigned enough larger weight than pseudo GCPs to modify original RPC.

$$\begin{bmatrix} \frac{\partial F}{\partial a_i} & \cdots & \frac{\partial F}{\partial b_i} & \cdots \\ \frac{\partial G}{\partial c_i} & \cdots & \frac{\partial G}{\partial d_i} & \cdots \\ \vdots & & \vdots & \end{bmatrix} \begin{bmatrix} da_i \\ \vdots \\ db_i \\ \vdots \\ dc_i \\ \vdots \\ dd_i \\ \vdots \end{bmatrix} = \begin{bmatrix} x - F_o \\ y - G_o \\ \vdots \end{bmatrix} + \begin{bmatrix} V_x \\ V_y \\ \vdots \end{bmatrix} \quad (4)$$

$$\begin{aligned} F = x = F_0 + \sum_{0}^{19} \frac{\partial F}{\partial a_i} da_i + \sum_{1}^{19} \frac{\partial F}{\partial b_i} db_i \\ G = y = G_0 + \sum_{0}^{19} \frac{\partial G}{\partial c_i} dc_i + \sum_{1}^{19} \frac{\partial G}{\partial d_i} dd_i \end{aligned} \quad (5)$$

4.2. Method 2 : Adding Parameters Observation Equations

In this method RFM parameters (RPC) observation are used instead of pseudo GCPs. Number of additional GCPs observation equations is not enough to solve the RFM. Therefore 59 additional equations are used for re-calculating modified parameters. Observation values of parameters are determined by RPC IKONOS vendor provides. Equation (6) expresses the matrix form of parameters and GCPs observation equations.

$$\begin{bmatrix} 1 & & & & \\ & \ddots & & & \\ & & \ddots & & \\ & & & 1 & \\ \frac{\partial F}{\partial a_i} & \cdots & \frac{\partial F}{\partial b_i} & \cdots & \\ \frac{\partial G}{\partial c_i} & \cdots & \frac{\partial G}{\partial d_i} & \cdots & \\ \vdots & & \vdots & & \end{bmatrix} \begin{bmatrix} \frac{\partial F}{\partial a_i} \\ \vdots \\ \frac{\partial F}{\partial b_i} \\ \vdots \\ \frac{\partial G}{\partial c_i} \\ \vdots \\ \frac{\partial G}{\partial d_i} \\ \vdots \end{bmatrix} = \begin{bmatrix} a_{1o} - da_1 \\ \vdots \\ x - F_o \\ y - G_o \\ \vdots \end{bmatrix} + \begin{bmatrix} V_{a_1} \\ \vdots \\ V_x \\ V_y \\ \vdots \end{bmatrix} \quad (6)$$

4.3. Method 3 : Sequential Least Square Solution

This method is sequential solution using additional GCPs observation. Sequential least square is expressed in equation (7). " $N_1, \hat{X}^*$ " are existing solution term and " A_2, N_2, L_2 " are additional solution term. Sequential LS provides advantage that quality of each additional point is checked instantly.

$$\hat{X} = \hat{X}^* + N_1^{-1} A_2^T (A_2 N_1^{-1} A_2^T + P_2^{-1})^{-1} (L_2 - A_2 \hat{X}^*) \quad (7)$$

4.4. Method 4 : Integrating Affine Transformation

This method proposes extended RFM solution. Addition GCPs are used for calculating parameters of 2D transformation equations. Equation (8) shows integration of affine transformation and RFM. There is disadvantage that this solution can not be called pure RFM solution and is not cooperable with existing solution.

$$\begin{aligned} x' = a_1 x + a_2 y + a_3 = \frac{f_1(u,v,w)}{f_2(u,v,w)} \\ y' = b_1 x + b_2 y + b_3 = \frac{f_3(u,v,w)}{f_4(u,v,w)} \end{aligned} \quad (8)$$

5. Conclusion

Maximum 5 additional GCPs are used for testing proposed methods and 42 check points are used for checking the accuracy of modified RPC solution. Each method is tested with 1 to 5 additional GCPs. Result, Table (2) ~ (5), shows possibility of modification of RPC when additional a few GCPs are available. The accuracy of IKONOS RPC can be improved 50% or more using these methods.

Table 2. Image Coordinates Residuals at Check Points (Unit: Pixel)

(A) Method 1: Using Pseudo GCPs in Normalized Cubic

num GCPs	RMSE (po_pan_000)		RMSE (po_pan_001)	
	Column	Row	Column	Row
0	3.89	5.36	3.09	16.42
1	2.37	2.34	2.43	5.12
2	2.38	2.35	1.99	5.07
3	2.00	2.09	2.01	4.74
4	1.68	2.21	1.94	3.82
5	1.55	2.29	1.85	3.71

(B) Method 2: Adding Parameters Observation Equations

num GCPs	RMSE (po_pan_000)		RMSE (po_pan_001)	
	Column	Row	Column	Row
0	3.89	5.36	3.09	16.42
1	3.89	3.62	2.88	8.74
2	2.63	3.30	2.47	7.71
3	2.11	3.26	2.10	7.21
4	1.94	3.13	2.02	5.65
5	1.65	2.62	1.99	4.16

(C) Method 3: Sequential Least Square Solution

num GCPs	RMSE (po_pan_000)		RMSE (po_pan_001)	
	Column	Row	Column	Row
0	3.89	5.36	3.09	16.42
1	2.39	2.34	2.43	5.12
2	2.33	2.42	2.05	5.11
3	1.92	2.15	1.88	4.51
4	1.59	2.36	1.85	3.73
5	1.54	2.30	1.79	3.66

Method 4: Integrating 2D Affine Transformation to RFM

num GCPs	RMSE (po_pan_000)		RMSE (po_pan_001)	
	Column	Row	Column	Row
0	3.89	5.36	3.09	16.42
1	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A
3	1.74	2.08	1.98	3.25
4	1.73	2.70	1.72	2.34
5	1.58	1.74	1.72	2.33

6. Reference

1. Gene Dial, Jacek Grodecki, "Block Adjustment with Rational Polynomial Camera Models" ACSM-ASPRS, 2002, Proceeding CD.

2. C.S. Fraser, H.B. Hanley, T. Yamakawa, "High-Precision Geopositioning from IKONOS Satellite Imagery", ACSM-ASPRS, 2002, Proceeding CD.

3. C. Vincent TAO, Yong HU, "Image Rectification Using A Generic Sensor Model - Rational Function Model", International Archives of Photogrammetry and Remote Sensing. Vol. XXXIII, Part B3. Amsterdam, 2000, pp. 874-881

4. Ki-In Bang, "Abstract Sensor Model for IKONOS Level 2 Images", ISRS, 2001, pp. 49-52.

5. Ki_In Bang, "Analysis of EOC Sensor Model" FIG WORKING WEEK, 2001, pp. 57-65.

6. Ki-In Bang, "Pseudo Image Composition and Sensor Models Analysis of SPOT Satellite Imagery for Inaccessible Area", Korean Society of Remote Sensing", 2001, Vol. 17, pp. 33-34.

7. NIMA, The Compendium of Controlled Extensions for the National Imagery Transmission Format (NITF), Version 2.1, URL:

http://www.ismc.nima.mil/ntb/superceded/STDI-2002 v2.1.pdf

8. OpenGIS Consortium, "The OpenGIS Abstract Specification, Topic 7 : The Earth Imagery Case Ver 4.0", 1999, pp. 2-23.

9. Yong Hu, C. Vincent Tao, "Updating Solutions of The Ratioanl Function Model Using Additional Control Information" PE&RS, Vol. 68, No. 7, July 2002, pp. 715~723.

10. Lee, Dong Gu, “"Study on Sensor Models of Pushbroom Satellite Imagery Using Rational Function Model”, Inha University, 2002.

11. Lee, Jae Bin “Study on Extracting 3D Geospatial Information with High Spatial Resolution Satellite Imagery by RPC”, Seoul National University, 2002.

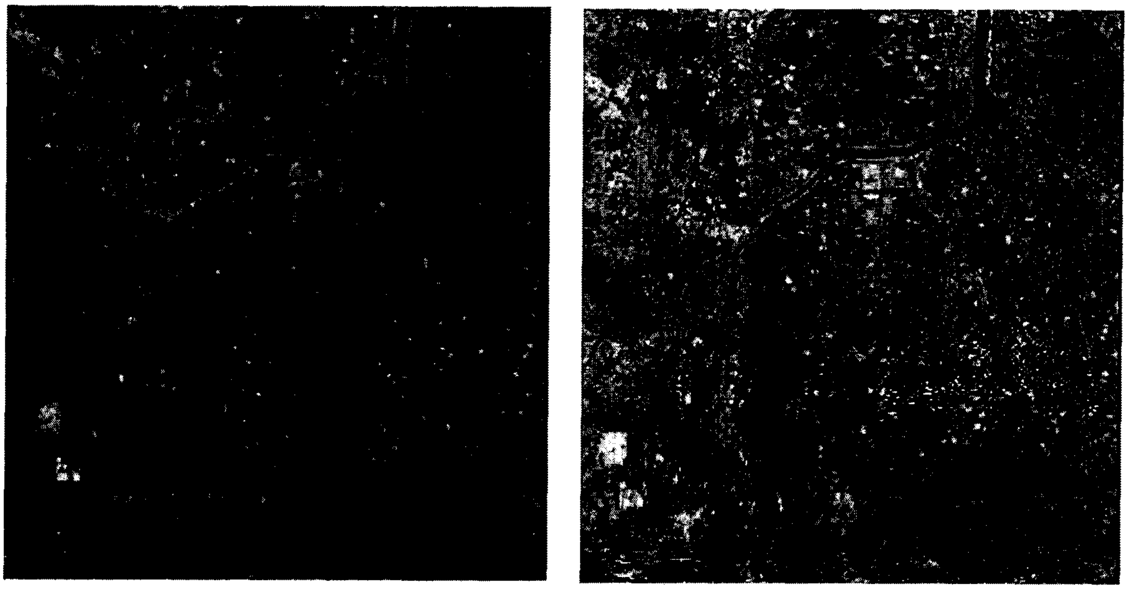

Fig. 3. Tested IKONOS Image 1 and 2 (Nov. 2001, Daejeon)