The Improvement of RFM RPC Using Ground Control Points and 3D Cube

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Abstract: Some of satellites such as IKONOS don't provide the orbital elements so that we can't utilize the physical sensor model. Therefore, Rational Function Model(RFM) which is one of mathematical models could be a feasible solution. In order to improve 3D geopositioning accuracy of IKONOS stereo imagery, Rational Polynomial Coefficients(RPCs) of the RFM need to be updated with Ground Control Points(GCPs). In this paper, a method to improve RPCs of RFM using GCPs and 3D cube is proposed. Firstly, the image coordinates of GCPs are observed. And then, using offset values and scale values of RPC provided, the image coordinates and ground coordinates of 3D cube are initially determined and updated RPCs are computed by the iterative least square method. The proposed method was implemented and analyzed in several cases: different numbers of 3D cube layers and GCPs. The experimental results showed that the proposed method improved the accuracy of RPCs in great amount.
Keywords: IKONOS, RFM, RPC, Sensor Modeling, High Resolution Satellite

1. Introduction

A well-defined sensor model for satellite imagery is prerequisite for obtaining 3D positional data. The sensor models are in general categorized into physical sensor models and mathematical sensor models. While physical sensor models(rigorous sensor models) are based on the physical and geometric condition of satellites, mathematical sensor models establish the mathematical relationship between image and object space.

The RFM is one of the mathematical sensor models and Image Transfer Standard proposed by OpenGIS Consortium(OGC). The RFM, which is independent of the orbital elements, is a generalized sensor model because the RFM can be applied to various sensors such as pushbroom, frame, SAR and so on. Particularly, in order to obtain geospatial information from IKONOS imagery provided by Space Imaging(SI), the RFM is used instead of the physical sensor model. In case users are not satisfied with the accuracy of the existing RFM RPCs, the existing RPCs can be updated using GCPs.

In recent years, many researches have been performed on the upgrade of RFM RPC(Hu and Tao, 2002; Fraser, Hanley and Yamakawa, 2002; Di, Ma and Li, 2003). This study presents the method of RPC upgrade using GCPs and 3D Cube. Figure 1 illustrates the diagram of the proposed approach for updating IKONOS RPCs.

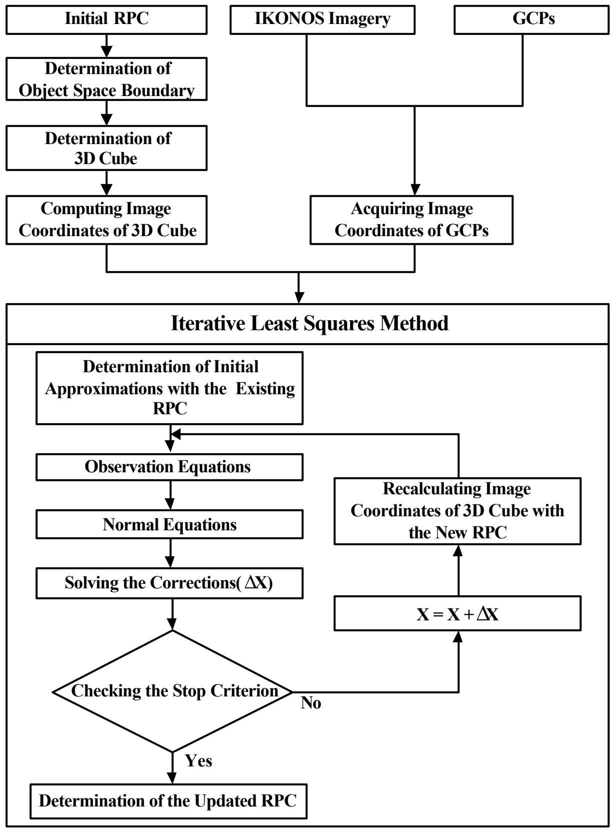

Fig. 1. The diagram of proposed method for upgrading IKONOS RFM RPCs.

2. Improvement of RFM RPC

1) Two existing methods of the RPC upgrade

In order to improve 3D geopositioning accuracy using RFM, RPCs need to be updated with GCPs. The existing methods for the RPC upgrade are classified into two categories: with and without satellite orbital elements (Fraser and Hanley, 2003; Hu and Tao, 2002; Tao and Hu, 2001).

2) The proposed method for RPC upgrade

It is well known that the IKONOS satellite doesn't release orbital parameters to public so that the users can't utilize the physical sensor model. Instead, IKONOS provides RFM RPCs for geospatial community. The proposed method for updating IKONOS RFM RPCs aimed at utilizing small number of GPCs and 3D Cube. The final RFM RPCs could be computed through iterative least squares method with regularization.

1. The RFM of IKONOS

In the basic RFM function for IKONOS satellite image, image space coordinates (line, sample) are expressed as the ratios of polynomials of object space coordinates.

The RFM function for IKONOS satellite image is given by the following Equation (1).

$$line = \frac{NUM_L(U,V,W)}{DEN_L(U,V,W)} \qquad sample = \frac{NUM_S(U,V,W)}{DEN_S(U,V,W)} \tag{1}$$

The line and sample in IKONOS RFM function are the normalized image coordinates, and U,V, and W are the normalized ground coordinates. In general U, V and W are latitude, longitude and height respectively. The detailed representation for numerator of the line in RFM function can be rewritten as

$$\begin{aligned} NUM_L(U,V,W) = & a_0 + a_1 V + a_2 U + a_3 W + a_4 VU + a_5 VW \\ & + a_6 UW + a_7 V^2 + a_8 U^2 + a_9 W^2 + a_{10} UVW \\ & + a_{11} V^3 + a_{12} VU^2 + a_{13} VW^2 + a_{14} V^2 U + a_{15} U^3 \\ & + a_{16} UW^2 + a_{17} V^2 W + a_{18} U^2 W + a_{19} W^3 \end{aligned} \tag{2}$$

where $a_0 \sim a_{19}$ are the RPCs and the power of each term is limited to 3 in Equation (2). The denominator of the line in RFM and the numerator and denominator of the sample in RFM are expressed in similar fashion.

2. 3D Cube determination

The total number of RFM RPCs is 78, which should be recomputed for upgrade. Since total RPCs need to be updated with small number of GPCs, pseudo observation such as 3D Cube points is introduced. The 3D Cube points are evenly well distributed in object space.

The determination of 3D Cube is divided into three steps. First, the object space boundary is determined by offset and scale values of RPC file. Secondly, the 3D Cube points are formed at regular interval in the object space boundary. Thirdly, the image coordinates of 3D Cube points are computed by RFM RPCs provided. The process of 3D Cube determination is shown in Figure 2.

3. Iterative least squares method with regularization

Using the initial approximations determined by the existing RPCs, GCPs and 3D Cube, the RPCs are computed by the iterative least squares method with regularization.

The image coordinates of 3D Cube points are computed with new RPCs updated iteratively.

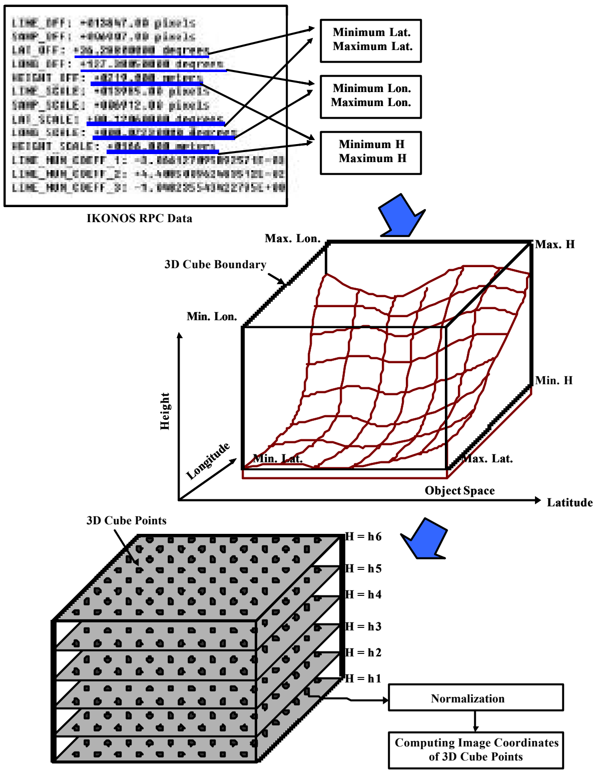

Fig. 2. The schematic process of 3D Cube determination

3. Experiment results

For the experiment, IKONOS stereo pairs acquired on 19 November, 2001 are tested. They are covering Daejon area in Korea. Each image was corrected radiometrically only. Figure 3 shows the IKONOS stereo image pair for experiment.

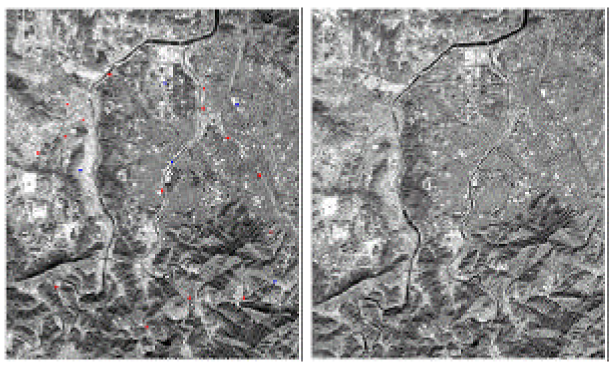

Fig. 3. IKONOS stereo images

The 20 GCPs obtained by DGPS surveying are used in this test. The 15 GCPs out of them are used to update the RPCs and the rest are check points. The distribution of GCPs and check points are shown in Figure 4.

The proposed method was tested in several cases: different number of GCPs and 3D Cube layers. A layer of 3D Cube has 121 points and the number of layers increases from 1 to 7. In each case 5, 10, and 15 GCPs are used.

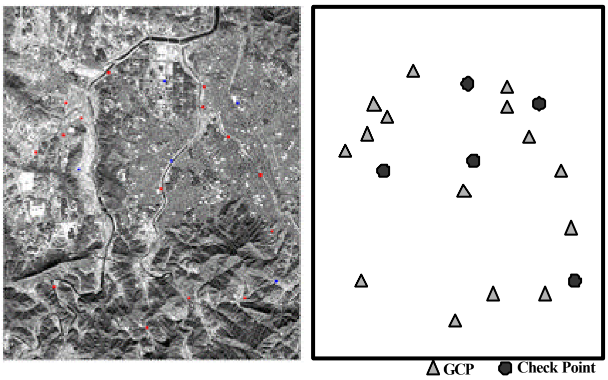

Fig. 4. The distribution of GCPs and check points

Once the RPCs are updated by the proposed method, the ground coordinates of check points are determined by the updated RPCs and compared with those measured by DGPS surveying for positional accuracy. In Table 1, the RMS and maximum errors of 5 check points are presented.

Table 1. RMS and Max. errors at 5 check points (Unit: meter)

No. of 3D Cube Points (No. of Layers)	No. of GCPs	UTM Easting		UTM Northing		WGS84 Height	
		RMSE	Max. Error	RMSE	Max. Error	RMSE	Max. Error
Initial RPCs		0.9787	1.6764	9.3866	10.6520	6.1447	7.6017
121 (1)	5	No solution					
	10	1.1668	2.3043	1.1656	2.3320	0.7384	1.3351
	15	0.5705	0.9810	0.7999	1.5620	0.8905	1.6298
242 (2)	5	2.1194	4.4043	1.0912	2.1170	0.7532	1.1501
	10	0.8522	1.3973	0.7982	1.5620	0.7791	1.4235
	15	0.7443	1.3410	0.7269	1.2670	0.5661	0.9682
363 (3)	5	1.2686	2.3873	0.6893	1.4830	0.8180	1.7111
	10	0.8784	1.5673	0.3724	0.6820	0.9501	1.9353
	15	0.7871	1.2973	0.2562	0.4620	0.6659	1.3733
484 (4)	5	1.2960	2.3873	1.1084	2.5930	0.9649	1.6612
	10	0.8979	1.6573	0.2286	0.4520	1.0570	2.0260
	15	0.7754	1.2973	0.1553	0.3520	0.7170	1.3512
605 (5)	5	1.2399	2.2073	1.3201	3.1430	1.0180	1.5754
	10	0.8979	1.6573	0.1739	0.3420	1.0942	2.0816
	15	0.7802	1.2973	0.1921	0.3420	0.7603	1.3749
726 (6)	5	1.2026	2.1173	1.5058	3.5930	1.0990	1.8466
	10	0.8708	1.5673	0.2072	0.3420	1.0382	1.9603
	15	0.7795	1.3510	0.2411	0.5130	0.7674	1.3302
847 (7)	5	1.1643	2.0273	1.5939	3.8130	1.1181	1.9298
	10	0.8945	1.5673	0.2687	0.5030	1.0484	2.0069
	15	0.7763	1.3510	0.3244	0.7330	0.7601	1.3630

The 3D positional accuracy of check points determined by the RPCs initially provided is 9.4m horizontally and 6.1m vertically. After updating RPCs with 15 GCPs, the horizontal and vertical accuracy are less than 1m. It is shown that the accuracy of updated RPC is dependent on the number of GCPs. However, if the number of GCPs and 3D cube points is not enough, the proposed method does not converge.

4. Conclusions

In this paper, we proposed a method of upgrading IKONOS RFM RPCs with 3D cube and small number of GCPs. With the proposed method, IKONOS RPCs could be updated.

The accuracy of 3D positioning determined by the updated RPCs of IKONOS stereo imagery was improved in great amount. As anticipated, the number of GCPs contributes to the improvements in accuracy. However, the number of 3D Cube points didn' t much influence the overall accuracy rather the number of elevation layers of 3D Cube influenced the convergence for least squares solution.

Conclusively, the proposed method for upgrading RPCs showed the potential for practical use in geospatial community.

Acknowledgement

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