Precision Evaluation of RPCs in HRSI Orientation of Geoeye_1

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Abstract

Nowadays physical and abstract mathematical models are used with pushbroom satellite imagery, the imagery vendors do not provide ephemeris data (or ancillary data) for the end users, so one has to rely on mathematical sensor models for extracting 3D geospatial information. Rational functions are often applied in photogrammetric and remote sensing processing to represent the transformation between the image space and the object space whenever the rigorous model is made unavailable to the users intentionally or unintentionally. The RPC sensor model is considered to be a simple and effective way to approximate a rigorous camera model. However it has been seen that using RPC without the aid of ground control points contributes to geo positioning errors. This can be corresponding to terrain inherent interior and exterior orientation errors in the rigorous sensor model. These errors in geo positioning can be compensated by additional parameters in the image space that affect a translation of image coordinates. Therefore one needs to refine the supplied-RPC to achieve higher accuracy.

This study reviews the developments in ground point determination from HRSI via the model of rational polynomial coefficients (RPCs). For geometrical accuracy improvement, the RPC sensor models by applying control points will be corrected.

The potential for RPC block adjustment to yield sub-pixel geo positioning accuracy from HRSI is illustrated using results from experimental testing with two Geoeye_1 stereo images. Finally error propagation issues in RPC block adjustment of HRSI in various methods (supplied-RPC, supplied-RPC with compensated bias, generated RPCs with users) are considered.

Keywords: HRSI Orientation, RPCs, Geoeye_1

1. Introduction

With the very high resolution space sensors a competition between aerial and space images exists. For medium and small scale mapping the decision of the use of aerial or space images is just a question of availability and financial relation. Space images do have the advantage of covering a large area with just one scene, requiring only a limited number of ground control points. With IKONOS, QuickBird and OrbView-3 the absolute geo-reference is in the range of 10m or better, so even for some cases mapping is possible without control points. For the

announced GeoEye-1 the absolute georeferencing without control points is proposed with a standard deviation in the range of 1m.
Nowadays high resolution space borne optical imagery is available from a variety of platforms and specifications. The older generation includes SPOT, IRS-1C, IKONOS, ORBIMAGE OrbView_2 and QuickBird, the newer sensors are SPOT 5, ASTER, EROS, ALOS PRISM, GeoEye_1, OrbView_3, QuickBird, WorldView, CARTOSAT and FORMOSAT2 etc. All these sensors deliver pushbroom type of images with nominal ground resolution from half a meter to about 10 meters in the highest resolution band (normally the panchromatic channel). Some of them offer along-track stereo capability, while others provide images with cross-track overlap from two adjacent orbits. Because of their high resolution, stable geometry and stereo capability, mapping the Earth from these images is becoming more and more production workflow rather than a research activity. Sensor models are required to establish the functional relationship between the image space and the object space. They are of particular importance to stereo measurements and image ortho-rectification. Sensor models are typically classified into two categories: physical and generalized models. The choice of a sensor model depends primarily on the performance and accuracy required and the camera and control information available (McGlone, 1996).

The RFM is already available within some digital photogrammetric software packages such as ZI Imaging Image Station (Madani, 1999), LH Systems SOCET Set (Dowman and Dolloff, 2000), PCI OrthoEngine (Toutin and Cheng, 2000), and ERDAS IMAGINE OrthoMAX (Yang, 2000).

As now we know that nowadays RPCs are provided instead of physical parameter with HRSI, if one would want to generate DSM from the recently lunched high resolution imagery he would have to use the RPCs. However with the supplied RPC's one can generate DEM with limited Precision because of the bias in polynomial coefficients. Therefore one needs to refine the supplied RPC to achieve higher accuracy levels (Cho et al., 2003), It's demonstrated that sensor orientation of sub-pixel level can be achieved with minimal ground control (Fraser et al., 2006). Thus, modifying/correction RPCs will open the gates for generating accurate photogrammetric products.

With the modified RPCs, it is possible for the end users to directly obtain information from the imagery with higher precision.

This study discusses the georefrencing of HRSI with Rational Function Model (RFM): RFMs with supplied-RPCs and bias/drift corrected supplied-RPCs. The potential for RPC block adjustment to yield sub-meter geo positioning accuracy from HRSI is illustrated using results from experimental testing with Geoeye_1 stereo images.

2. **Data and Material**

In this search, a stereo pair of HRS images(Geoeye_1) of TEHRANSAR is used. TEHRANSAR is a part of TEHRANSAR, the capital of IRAN, located at 51 15'E 35 42'N. TEHRANSAR densely populated and crowded city having typical characteristics like heterogeneous built up areas. Moreover, for stereo Geoeye_1 satellite images restitution and for evaluating the various mathematical models described above, collection of ground control and check points is needed the ground control points (GCPs) that used in search, obtain from map of 1/2000.

2.1 Geoey_1

The GeoEye-1 satellite is scheduled for launch in 2007. GeoEye-1 will be equipped with the most advanced technology ever used in a commercial remote sensing system. The satellite will be able to collect images at 0.41-meter panchromatic (black & white) and 1.65-meter multispectral resolution*. Just as important, GeoEye-1 will be able to precisely locate an object to within 3 meters of its true location on the surface of the Earth. This degree of inherent geolocation accuracy has never been achieved in any commercial imaging system. The satellite will be able to collect up to 700,000 square kilometers of panchromatic (and up to 350,000 square kilometers of pan-sharpened multispectral) imagery per day. This capability is ideal for large scale mapping projects. GeoEye-1 will be able to Revisit any point on Earth once every three days or sooner. Customers will have a choice of ordering BASIC, GEO, ORTHO and STEREO imagery as well as imagery-derived products, including DEMs (digital elevation models) and DSMs (digital surface models), large-area mosaics, and feature maps. A polar orbiting satellite, GeoEye-1 will make 12 to 13 orbits per day flying at an altitude of 684 kilometers or 425 miles with an orbital velocity of about 7.5 km/sec or 45,000 mi/hr. Its sun-synchronous orbit allows it to pass over a given area at about 10:30 a.m. local time every day. The entire satellite will be able to turn and swivel very quickly in orbit to point the camera at areas of the Earth directly below it, as well as from side-to-side and front-to-back. This agility will enable it to collect much more imagery during a single pass. (www.geoeye.com)

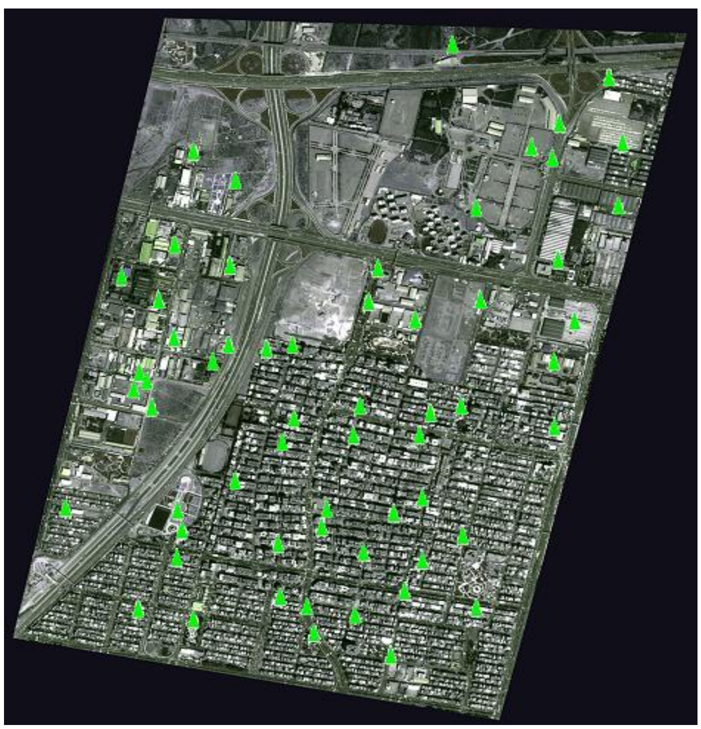

Figure 1: Geoeye_1 image of search area and ground control points

3. Research Methodology

3.1 Images Orientation

The HRS (High-Resolution Stereoscopic) instrument of Geoey_1 uses linear arrays that scan a single image line at an instant of time in the so-called pushbroom mode. Consequently each line of the HRS image is acquired at a different exposure station with different orientation elements. For the orientation of this kind of imagery two approaches, based on rigorous models and rational function models, are used. The rigorous model tries to describe the physical properties of the sensor and its image acquisition mode. It is based on collinearity equations, which are extended in order to describe the specific geometry of pushbroom sensors. The adjustment parameters must include the exterior orientation and selfcalibration parameters to describe the physical imaging process. Alternatively, rational function models use a general transformation to describe the relationship between image and ground coordinates.

Since the launch of the IKONOS II satellite, the rational function model (RFM) has gained considerable interests in photogrammetric community. SpaceImaging Company provides the RFM to users instead of the physical sensor model, subsequently, Digital Globe Corporation provides the RFM together with the strict geometric model in order to satisfy different users. The RFM has been universally accepted, and validated, as an alternative sensor orientation model for high resolution satellite imagery (HRSI). The RFM is an approximation of the rigorous sensor model, via a number of control points. Then it could be utilized in the photogrammetric process instead of the complex rigorous sensor model. It would be a part of the standard image transfer format, and it is becoming a standard way for economical and fast mapping from remotely sensed imagery.

The key of the RFM is to gain accurate rational polynomial coefficients (RPCs). Compared with the rigorous model based on the collinearity model or the affine model, the RFM with 80 coefficients would be over parameterized (Fraser et al., 2005).

3.2Characteristics of RFM

The RFM has better interpolation properties. It is typical smoother and can spread the approximation error more evenly between exact fit points. The RFM has the added advantage of permitting efficient approximation of functions that have infinite discontinuities near, but outside, the interval of fitting; while polynomial approximation is generally unacceptable in this situation (Burden and Faires 1997). The RFM is independent of sensors and platforms. It also has coordinate system flexibility. It can accommodate object coordinates in any system such as geocentric, geographic, or any map projection coordinate system (Paderes et al., 1989). The RFM resembles projective equations very well (Madani, 1999). With adequate control information, the RFM can achieve a very high fitting accuracy with sufficient speed to support real time implementations. This is the primary reason why the RFM has been used as a replacement sensor model. Since there are no functional relations between the parameters of the rigorous model and those of the RFM, the physical parameters cannot be recovered from the RFM and the sensor information can be kept confidential. In order to protect the undisclosed sensor information, some commercial satellite data vendors, such as Space Imaging Inc., only provide users with the RFM parameters but do not provide any information regarding the physical sensor model. As a result, users are still able to achieve a reasonable accuracy without knowing the rigorous sensor models for photogrammetric processing. Mathematically the disadvantage of using polynomials for approximation is their tendency for oscillation. This often causes error bounds in polynomial approximation to significantly exceed he average approximation error.

There are some disadvantages to RFMs (Madani, 1999):

- inability to model local distortions (such as high-frequency variations with VIR sensors or with SAR sensors);
- limitation in the image size;
- difficulty in the interpretation of the parameters due to the lack of physical meaning;
- potential failure to zero denominator;
- potential correlation between the terms of polynomial functions

3.3 Rational functions model

The RFM relates object point coordinates to image pixel coordinates in the form of rational functions that are ratios of polynomials. For the ground-to-image transformation, the defined ratios have the forward form (OGC, 1999):

$$l_n = \frac{P_1(X_n, Y_n, Z_n)}{P_2(X_n, Y_n, Z_n)} \qquad s_n = \frac{P_3(X_n, Y_n, Z_n)}{P_4(X_n, Y_n, Z_n)}$$

$$P = \sum_{i=0}^{m1}\sum_{j=0}^{m2}\sum_{k=0}^{m3} = a_{ijk}X^iY^jZ^k a_0 + a_1X + a_2Y + a_3Z + a_4XY + a_5XZ + a_6YZ + a_7X^2 + a_8Y^2 + a_9Z^2 + a_{10}XYZ + a_{11}X^3 + a_{12}XY^2 + a_{13}XZ^2 + a_{14}X^2Y + a_{15}Y^3 + a_{16}YZ^2 + a_{17}X^2Z + a_{18}Y^2Z + a_{19}Z^3$$

$$P_2 = b_0 + b_1X + b_2Y + \cdots + b_{18}y^2Z + b_{19}Z^3$$

$$P_3 = c_0 + c_1X + c_2Y + \cdots + c_{18}y^2Z + c_{19}Z^3$$

$$P_4 = d_0 + d_1X + d_2Y + \cdots + d_{18}y^2Z + d_{19}Z^3$$

Here, a_i, b_i, c_i *and* d_i and are the 80 RPCs; b_i and $d_i$are commonly set to 1.(l_n, s_n) are the normalized line and sample index of the pixels in image space, while (X,Y,Z) are normalized object point coordinates. That is:

$$l_n = \frac{l - \text{LineOffset}}{\text{lineScale}} \qquad s_n = \frac{s - \text{SampleOffset}}{\text{SampleScale}}$$

$$X_n = \frac{\varphi - \text{LatitudeOffset}}{LatitudeScale} \qquad Y_n = \frac{\lambda - LongitudeOffset}{LongitudeScale} \qquad Z_n = \frac{h - HeightOffset}{HeightScale}$$

Here,(l,s) are the image line and sample coordinates;(φ,λ,h) represent latitude, longitude, height; the offsets and scales normalize the coordinates to [-1,1], minimizes the introduction of errors during computation.

The RFM has nine configurations with some variations, such as subset of polynomial coefficients, equal or unequal denominators. Also, it has forward and backward forms (Tao and Hu, 2001a). Generally speaking, the RFM refers to a specific case that is in forward form, has third-order polynomials with unequal denominators, and is usually solved by the terrain-independent scenario.

That may cause the design matrix to become almost rank deficient because of the complex correlation among RPCs. It may result in numerical instability in the least squares adjustment, or even producing wrong solutions. The regularization technique was often suggested to tackle the possible ill-conditioned problem during the adjustment (Tao and Hu, 2001a). It has been proved to effectively improve the condition of the normal equations. But the determination of the regulation parameter has still been considered to be a challenge.

The Rational Polynomial Coefficients (RPCs) are estimated utilizing the physical IKONOS camera model, known only to Space Imaging, without using any ground control points (GCPs). The physical orientation parameters are derived from the satellite ephemeris and attitude. The satellite ephemeris is determined using on-board GPS receivers and sophisticated ground processing of GPS data. The satellite attitude is determined by optimally combining star tracker data with measurements taken by the on-board gyros (Hu et al., 2004). Therefore, it is expected that the modeling accuracy will be improved when using GCPs in the RFM model was performed in order to estimate 6 parameters for each image (affine transformation) to remove remaining systematic errors. As mathematical model of the adjustment, we used the method proposed by (Grodecki et al., 2003). The method is an affine transformation:

$$x + a_0 + a_1 x + a_2 y = \frac{P_1(X_n, Y_n, Z_n)}{P_2(X_n, Y_n, Z_n)}$$
$$y + b_0 + b_1 x + b_2 y = \frac{P_3(X_n, Y_n, Z_n)}{P_4(X_n, Y_n, Z_n)}$$

where *a0*, *a1*, *a2* and *b0*, *b1*, *b2* are the adjustment parameters for an image, (*x*, *y*) and (X_n, Y_n, Z_n) are image and object coordinates of a GCP or a tie point. Using this adjustment model, we expect that *a0* and *b0* will absorb any shifts and misalignments in the position and attitude, and the residual interior orientation errors in image line and sample directions. The parameters *a1*, *a2*, *b1*, *b2* are used to absorb the effects of on-board drift errors.

4. Results and Analysis

The RFM model equations, as shown in subsection 3.3, in state of terrain-dependent need a large number of ground control points (minimum 40) to calculate the 80 RPCs. In this search, used 60 of GCPs.

Several experiments were performed to apply the above mentioned mathematical model (the RFM), described in section 2, for the Geoeye_1 images and results presented in various scenarios(RFM of terrain-dependent, RFM of terrain-independent with bias, RFM of terrain-independent with bias /drift in 3 state with different GCPs, RFM of terrain-independent without bias/drift)

Table 1: Supplied-RPCs with bias/drift

Order of Rational Function	RMSE(m) of Control Points				RMSE(m) of Check Points 60			
	Δx	Δy	Δp	Δz	Δx	Δy	Δp	Δz
1 Order RFM					6.435	7.564	9.931	93.863
2 Order RFM					8.543	8.974	12.390	45.437

3 Order RFM					7.453	8.432	11.254	36.013

Table 2: Supplied-RPCs with remove of bias

Order of Rational Function	RMSE(m) of Control Points-1				RMSE(m) of Check Points - 59			
	Δx	Δy	Δp	Δz	Δx	Δy	Δp	Δz
1 Order RFM					2.796	3.342	4.475	15.543
2 Order RFM					3.345	3.432	4.792	11.324
3 Order RFM					2.456	2.753	3.689	9.435

Table 3: Supplied-RPCs with remove of bias and drift (1)

Order of Rational Function	RMSE(m) of Control Points - 4				RMSE(m) of Check Points -56			
	Δx	Δy	Δp	Δz	Δx	Δy	Δp	Δz
1 Order RFM	0.564	0.456	0.725	2.343	1.233	1.678	2.082	11.456
2 Order RFM	0.323	0.231	0.397	4.453	1.045	0.854	4.534	9.945
3 Order RFM	0.083	0.173	0.192	2.234	1,867	1.367	2.619	4.453

Table 4: Supplied-RPCs with remove of bias and drift (2)

Order of Rational Function	RMSE(m) of Control Points - 20				RMSE(m) of Check Points - 40			
	Δx	Δy	Δp	Δz	Δx	Δy	Δp	Δz
1 Order RFM	0.542	0.756	0.930	3.345	1.021	0.857	1.338	8.275
2 Order RFM	0.654	0.434	0.785	4.543	0.856	1.934	2.115	5.234
3 Order RFM	0.021	0.032	0.038	3.231	1.434	1.167	1.849	2.345

Table 5: Supplied-RPCs with remove of bias and drift (3)

Order of Rational Function	RMSE(m) of Control Points - 40				RMSE(m) of Check Points -20			
	Δx	Δy	Δp	Δz	Δx	Δy	Δp	Δz
1 Order RFM	0.876	0.653	1.092	3.343	0.986	1.005	1.407	6.657
2 Order RFM	0.836	0.342	0.903	1.982	2.253	1.867	3.171	2.543
3 Order RFM	0.067	0.032	0.074	1.321	0.456	0.565	0.726	1.834

5. Conclusions

The RFM model provides more accurate results when using just one GCP which compensates for the bias/shift in the supplied RPCs.

- Sub-meter accuracy in (X and Y) and 1.834m in (Z) can be achieved for the Stereo Geoeye_1 imagery triangulation process using the refined RFM.
- The Geoeye_1 RPC camera model provides a simple yet accurate way to communicate Geoeye_1 image geometry to end users.
- More accurate results for Stereo Geoeye_1 sensor modeling can be achieved with higher precision image point measurements and better identification of GCPs.
- FRM is sensitive to distribution and number of GCPs. if distribution and number of GCPs are not suitable then there shouldn't be an expectation of high precision.
- Response to this question that which state of RFM gives the best answer is difficult. Therefore, different methods of solutions are needed for determining the best answer. Because these functions have various answers on the ground with different covers.
- RFM take the account of ground elevation in corrections and is suitable for smooth relief but not for the grounds that have high different elevations.
- The orthoimages can be generated in the 1/2500 scale using Geoeye_1 images.

Reference:

1- Burden, R. L., and J. D. Faires, 1997. *Numerical analysis* (6th edition), Brooks/Cole Publishing Company.

2- Cho, W., Bang, I.K., Jeong, S. and Kim, K-O., 2003. *Automatic DEM Generation Using IKONOS Stereo Images*. IGRASS 7(21): 4289-4291

3- Dowman, I., and J. T. Dolloff, 2000. *An evaluation of rational functions for photogrammetric restitution*. Int'l Achieve of Photogrammetry and Remote Sensing, Amsterdam, Vol. 33, Part B3: 254-266.

4- Fraser,C,S., Dial, G. and Grodecki, J., 2006. *Sensor Orientation Via RPCs*. ISPRS Journal Photogrammetry and Remote Sensing, 60:182-194.

5- Fraser,C,S., and Hanley, H.B., 2005. *Bias-copensaion RPCs for sensor Orientation of High resolution Satellite Imagery*. Photogrametric Engineering and Remote Sensing, 71(8): 909-915

6- Hu, Y., Tao, V., and Croitoru, A., 2004. *Understanding the Rational Function Model:Methods and Applications*, the International Archives of Photogrammetry and Remote Sensing, Istanbul, Turkey.

7- McGlone, C., 1996. *Sensor Modeling in Image Registration*, Digital Photogrammetry An Addendum to the Manual of Photogrammetry, Chapter 5, American Society for Photogrammetry and Remote Sensing.

8- Madani, M., 1999, *Real-Time Sensor-Independent Positioning by Rational Functions*, Proceedings of ISPRS Workshop on Direct Versus Indirect Methods of Sensor Orientation, Barcelona, Spain, November 25-26, (Barcelona, Spain: ISPRS) pp. 64-75.

9- OpenGIS Consortium (OGC), 1999. The openGIS abstract specification-Topic 7: *Earth imagery*.

10- Paderes, Jr, F.C., Mikhail, E. M., and J. A. Fagerman, 1989. *Batch and on-line evaluation of stereo SPOT imagery, Proceedings of the ASPRS-ACSM Convention*, Baltimore, US, 31-40.

11- Specification of Geoeye_1 sensor Presented in site of www.geoeye.com .

12- Toutin, T., and P. Cheng, 2000. Demystification of IKONOS, EOM, 9(7): 17-21.

13- Tao, C.V., Hu, Y., 2001a. A comprehensive study on the rational function model for photogrammetric processing, *Photogrammetry Engineering and Remote Sensing*, 67(12), pp. 1347-1357

14- Yang, X., 2000. *Accuracy of rational function approximation in photogrammetry*. Proceedings of ASPRS Annual Convention (CD-ROM), Washington D.C., May 22-26, 2000.