Rational Function Model Generation for CCD Linear Images and its Application in JX4 DPW

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Abstract: Rational function model (RFM) is a universal sensor model for remote sensing image restitution. It is able to substitute for models of all known sensors.

In this paper, RFM generation by CCD linear image models is described in detail. A principle of RFM-based 3D reconstruction and its implementation in JX4 DPW is also described. Experiments using IKONOS and SPOT5 images are carried out on JX4 DPW. Results show that RFM generated is feasible for photogrammetric restitution of CCD linear images.

Key words: senor models, rational function model, CCD linear image, JX4 DPW, IKONOS, SPOT5

1. Introduction

During past a few years, along with the use of IKONOS images, the Rational Function Model (RFM) has been gradually recognized and utilized by photogrammetric community. The use and acceptance of the RFM in military area have led to proposal to the OGC for image restitution standard [5].

Many scholars have studied issues of photogrammetric restitution using the RFM. The studies indicate that the RFM can be treated as a sensor model, and it can also provide very high fitting accuracy, relative to rigorous sensor models.

Because of the RFM' s universal and high accuracy, and it can be implemented in any image exploitation system, and how to use the RFM and how to solve the RFM coefficients are paid attention by many researches [2,3,6]. In this paper, a solution to the RFM generation is implemented.

In this study, IKONOS image and SPOT5 image were used to test the fitting accuracy of the RFM with software JX4 DPW.

2. Rational Function Model

The RFM provides an abstraction of many types of camera models. It maps points in space to points in an image in terms of rational polynomial functions of the world-coordinates of the object point. [2]

Thus, the mapping defined by the ratios of polynomial is of the form

$$r_n = \frac{p1(X_n, Y_n, Z_n)}{p2(X_n, Y_n, Z_n)}$$

$$c_n = \frac{p3(X_n, Y_n, Z_n)}{p4(X_n, Y_n, Z_n)} \qquad (1)$$

where, X_n , Y_n and Z_n is the homogeneous coordinate of a 3D point, r_n and c_n is the corresponding image point, and $p1$, $p2$, $p3$ and $p4$ are homogeneous polynomials of degree m. For the 3rd-order case, they are 20-term polynomials:

$$p1 = \sum_{i=0}^{m1} \sum_{j=0}^{m2} \sum_{k=0}^{m3} a_{ijk} X_n^i Y_n^j Z_n^k$$

$$p2=\sum_{i=0}^{m1}\sum_{j=0}^{m2}\sum_{k=0}^{m3} b_{ijk} X_n^i Y_n^j Z_n^k$$

$$p3=\sum_{i=0}^{m1}\sum_{j=0}^{m2}\sum_{k=0}^{m3} c_{ijk} X_n^i Y_n^j Z_n^k$$

$$p4=\sum_{i=0}^{m1}\sum_{j=0}^{m2}\sum_{k=0}^{m3} d_{ijk} X_n^i Y_n^j Z_n^k$$

and hence may be parameterized by 20 coefficients. This amounts to a total of 80 parameters. [2,5,6]

3. Solutions to RFM

The iterative least square solution can be used to estimate the RFM coefficients. Data normalization and regularization are applied to improve the accuracy and minimize noise [2].

In the Eq.(1), there are a total of 59 unknown parameters when $p2=p4$ and $b_0=d_0=1.0$. Since each correspondence gives a pair of equations, therefore, at least 30 correspondences are needed to solve for the polynomial coefficients.

In theory, when more than 30 the ground control points (GCPs) on the terrain surface are collected, RFCs can be solved. But in this case, the solution is highly dependent on the actual terrain relief, the number and the distribution of GCPs. In fact, the RFM generated by this approach may not be used to as a replacement sensor model if high accuracy is required.

Therefore, in order to restitute every image points from the corresponding 3D object points with high accuracy, we must use the all correspondence when solving RFCs. We know, with the known physical sensor model, image grids can be generated by its corresponding 3-D object grid. Then RFCs are estimated with the object grid points and the corresponding image grid points. The RFM generated in this way, for include every possible 3D object and image points when calculating RFCs, can be used to as a replacement sensor model, the achievable accuracy is equal to the physical sensor model used, i.e., in order to obtain high accuracy using the RFM, we must assure the high accuracy of the physical sensor model.

In this paper, we use Viewing Geometry Model (VGM) [1] and 2D affine transformation model [4] to express the image geometry of CCD linear images, and then generate RFM using the 3D grid ground points and their corresponding image points produced by the two models.

4. RFM-based 3D Reconstruction

Similar to the collinearity equations based 3D reconstruction of aerial photo, RFM-based 3D reconstruction can be performed using the corresponding points in the stereo pair with the known RFM for each image. The iterative least square solution can be used to estimate the 3D object position from its corresponding image points.

5. Experimental Results and Evaluation

In order to test the stability and feasibility of the proposed methods, viewing geometry model and 2D affine transformation model were used to solve RFCs on JX4 Digital Photogrammetric Workstation. In this study, IKONOS image, SPOT5 image were used for the test.

1) IKONOS Images

The IKONOS image was collected at a hilly area in the Zhejiang province, China. Panchromatic 11-bit images were geometrically corrected to the *Geo* level with pixel ground resolution of 1 meter. And the image was supplied together with a set of RFCs and normalization parameters.

We collected 8 ground points using GPS; they were evenly distributed in both horizontal and vertical directions in the test region. Then, we solved the two method' s RFMs and compared the fitting accuracy using two groups of 1331 image grid points and its corresponding 3D object grid points, which were generated using the above two models, respectively.

The RMSE and MAX error of RFMs from the above models of the corresponding points and the check points are listed in Table 1 and Table 2, respectively.

Table 1. Error of corresponding points (unit: pixels)

	RFM		2D Affine Model	
	Row	Column	Row	Column
RMSE	1.04e-5	1.05e-5	1.69e-8	1.61e-8
MAX	4.13e-5	3.45e-5	1.19e-7	7.28e-8

Table 2. Error of check points (unit: pixels)

	RFM		2D Affine Model	
	Row	Column	Row	Column
RMSE	1.19e-5	4.76e-6	1.13e-5	3.50e-5
MAX	3.07e-5	1.02e-5	1.68e-5	4.53e-5

Table 3. Error of corresponding points (unit: pixels)

	VGM		2D Affine Model	
	Row	Column	Row	Column
RMSE	6.86e-2	2.52e-1	8.14e-4	6.77e-4
MAX	1.39e-1	6.40e-1	3.12e-3	1.50e-3

Table 4. Error of check points (unit: pixels)

	VGM		2D Affine Model	
	Row	Column	Row	Column
RMSE	5.90e-2	1.98e-1	4.61e-4	5.24e-4
MAX	8.36e-2	5.69e-1	7.79e-4	9.35e-4

2) SPOT5 Images

The testing SPOT5 image was collected at a hilly area in France. Panchromatic 8-bit images were geometrically corrected to the level 1A with pixel ground resolution of 5 meter. And the image was supplied together with a set of parameters in DIMAP format.

A set of 21 GCPs well-distributed over the region was collected. Then, we calculated 2662 image grid points and its corresponding 3D object grid points using the viewing geometry model of SPOT images and the affine transformation model, respectively. The RFM was solved using half of these points; fitting accuracy relative to original sensor models was compared using the others, which were as check points.

The RMSE and MAX error of RFMs from the above models of the corresponding points and the check points are listed in Table 3 and Table 4, respectively.

3) Discussion

The fitting accuracy of the regenerated RFM from the original RFM depends on the fitting accuracy of the original RFM in the IKONOS images case.

The lower fitting accuracy of the RFM relative to the viewing geometric model of SPOT images may be brought by the dithering satellite attitude and satellite ephemeris of this model.

6. Conclusion

Experiments with on IKONOS and SPOT images are carried out on JX4 Digital Photogrammetric Workstation. It is shown that the RFM generated by these models using a few GCPs is feasible for the above CCD linear images, and it can achieve high accuracy for photogrammetric restitution.

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