Comparison Between 2-D and 3-D Transformations for Geometric Correction of IKONOS images

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ABSTRACT

Very high-resolution satellite image technology is considered as a basic information sources for mapping and different applications in geomantics. For using of parametric models in geometric correction of satellite images, we need orbital parameters and calibration data. In Ikonos imagery, however, both the camera model and precise satellite ephemeris data are withheld from the user. Therefore we should use empirical methods. In this paper, different non-rigorous mathematical models in 2-D and 3-D cases are comprised and applied for geometric corrections over an Ikonos geo-product image in Iran. Multiquadratic ,polynomials and DLT models are used for this test area.

KEYWORDS: Remote Sensing, High-Resolution, DLT, Polynomial, Multiquadratic

1. INTRODUCTION

The preprocessing of remotely sensed image consists of geometric and radiometric characteristics analysis. By realizing these features, it is possible to correct image distortion and improve the image quality and readability. Radiometric analysis refers to mainly the atmosphere effect and its corresponding terrain feature's reflection, while geometric analysis refers to the image geometry with respect to sensor system With the launch of various commercial high-resolution earth observation satellites, such as Indian Remote Sensing Satellite IRS-1C/1D, the Space Imaging IKONOS system, SPOT 5 and Digital Globe QUIKBIRD system, precise digital maps generated by satellite imagery are expected in the spatial information industry. For last decades, airborne photography is the primary technique employed in producing national map products due to its high accuracy and flexible schedule (Li, 1998). However, it cannot map areas where airplanes cannot reach and its mapping frequency is constrained by the limits of flight planning (Li, 2000). Now with the high-resolution satellites era, accuracy required by medium and small-scale maps are achievable, with the possibility to frequently map an area without the special flight planning and scheduling required using aerial photographs. Successful exploitation of the high accuracy potential of these systems depends on accurate mathematical models for the satellite sensor. In the last decade, many studies and researches are performed with rigorous and non-rigorous mathematical models to rectify IKONOS images by Baltsavias et al. (2001), Hanley and Fraser (2001), Fraser et al. (2001a, and b) and Fraser et al. (2002a, b, c) respectively. Investigations into 3D positioning using alternative models have also been reported by Jacobsen (2001, 2002a,b), Toutin et al. (2001), Hu and Tao (2001, 2002) and Tao and Hu (2002a, b). One of the main goals of these researches is to find an appropriate mathematical model with precise and accurate results. The geometric accuracy of data products is terminated by the knowledge of precise imaging geometry, as well as the capability of the imaging model to use this information. The precise imaging geometry in its turn is stablished by knowledge of orbit, precise attitude, precise camera alignments with respect to the spacecraft and precise camera geometry (Srivastava and Alurkar, 1997). Rigorous mathematical models for geometric corrections of any images can be defined as the models, which can be precisely, present the relationship between the image space and the object space. Perspective geometry and projection performs the basis of the imaging model frame cameras as well as other sensors. For any point in the space, there is a unique projective point in the image plane, however , for any point in the plane there are infinite number of corresponding points in the space (Mikhail et al. 2001). Due to this fact, an additional constrain is needed to define the point in the 3D space. Collinearity equations are the rigorous model, which describe this projection relation between 2D image space and 3D object space.Unlike ordinary photogrammetric photography, high-resolution satellites are a line sensing imaging systems where every line is imaged at different time. That may help to understand the need of a special treatment of the sensor model (Makki, 1991). In general, the rigorous time dependent mathematical models are based on the collinearity equations, which relate image coordinates of a point to its corresponding ground coordinates. Published studies reported to date on IKONOS and other satellites focus in two main aspects ,the accuracy attainable in ortho-image generation and DTM extraction concerning 3D positioning from stereo spatial intersection using rigorous and non-rigorous sensor orientation models. Due to some limitations, most of the new High Resolution Satellite Imagery (HRSI) vendors hide the satellite orbit information and calibration data from the customers community such as for IKONOS and QUICKBIRD imagery. This means that other alternative models should be used to solve practically this problem and calculate the imagery parameters. Therefore, these empirical approaches can be applied to determine the ground point coordinates in either 2D or 3D.

In this paper, the different non-rigorous mathematical models in 2D and 3D have been used for geometric corrections of Ikonos image. Different orders of polynomials, projective, affine, conformal, Multiquadratic and DLT model were used with different numbers of GCPs. Figure 1 shows the steps of geometric correction in satellite images.

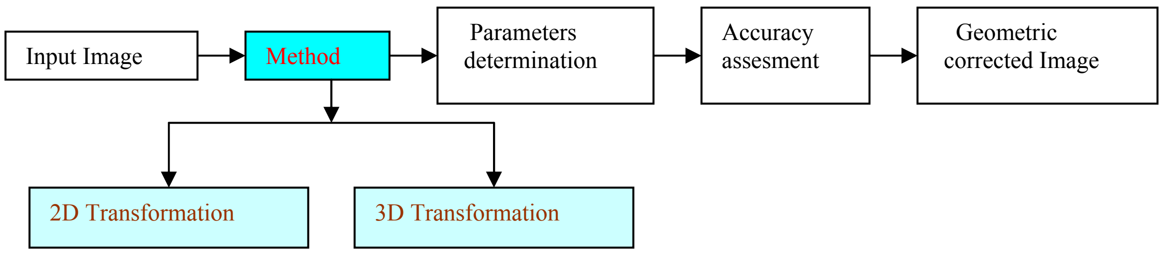


Figure 1. Steps of geometric correction

In the rest of the paper,mathematical models are discused in section 2, exprimental results and accuracy assesment are discribed in the last section.

2. Mathematical Models

During the satellite imaging process, the projection, the tilt angle, the scanner, the atmosphere condition, the earth curvature and the undulation etc., will cause the satellite image distorted. It is necessary to correction these distortions before one can really use it as a precise measurement in the large scale operations. In this paper, as previously stated, the orbital parameters were unknown. The mathematical model used to compensate the distortion correction is the so-called rubber shifting method. It neglects all the sources of distortions but deal with the present ones with the help of control points. This also makes the correction procedure easier in the circumstance of insufficient parameters. In this paper, some of 3D and 2D transformation used with different numbers of ground control points. These models are generally available within most of remote sensing image processing systems. These models can be used to provide sufficient insight about the ground elevation effects on the metric integrity of the rectified images. The following sub sections discuss the models characteristics.

2.1. Polynomial models

Polynomial models usually can be used in the transformation between image coordinates and object coordinates. The needed transformation can be expressed in different orders of the polynomials based on the distortion of the image, the number of GCPs and terrain type. A 1st-order transformation is a linear transformation, which can change location , scale, skew, and rotation. In most cases, first order polynomial used to project raw imagery to a object for data covering small areas .

Transformations of the 2nd-order or higher are nonlinear transformations that can be used to convert Lat/Long data to object or correct nonlinear distortions such as Earth curvature, camera lens distortion. The following equations are used to express the general form of the polynomial models in 2D and 3D cases :

Two-dimensional general polynomials

- Linear polynomial

$$x=a_0+a_1X+a_2Y \qquad (1)$$
$$y=b_0+b_1X+b_2Y$$

- Quadratic polynomial

$$x=a_0+a_1X+a_2Y+a_3XY+a_4X^2+a_5Y^2 \qquad (2)$$
$$y=b_0+b_1X+b_2Y+b_3XY+b_4X^2+b_5Y^2$$

- Cubic polynomial

$$x=a_0+a_1X+a_2Y+a_3XY+a_4X^2+a_5Y^2+a_6X^2Y+a_7XY^2+a_8X^3+a_9Y^3 \qquad (3)$$
$$y=b_0+b_1X+b_2Y+b_3XY+b_4X^2+b_5Y^2+b_6X^2Y+b_7XY^2+b_8X^3+b_9Y^3$$

Three-dimensional general polynomials

- Linear polynomial

$$x=a_0+a_1X+a_2Y+a_3Z \qquad (4)$$
$$y=b_0+b_1X+b_2Y+b_3Z$$

- Quadratic polynomial

$$x=a_0+a_1X+a_2Y+a_3Z+a_4XY+a_5XZ+a_6YZ+a_7X^2+a_8Y^2+a_9Z^2 \qquad (5)$$
$$y=b_0+b_1X+b_2Y+b_3Z+b_4XY+b_5XZ+b_6YZ+b_7X^2+b_8Y^2+b_9Z^2$$

- Cubic polynomial

$$x = a_0 + a_1X + a_2Y + a_3Z + a_4XY + a_5XZ + a_6YZ + a_7X^2 + a_8Y^2 + a_9Z^2 + a_{10}X^2Y + a_{11}X^2Z + a_{12}Y^2X + a_{13}Y^2Z + a_{14}Z^2X + a_{15}Z^2Y + a_{16}X^3 + a_{17}Y^3 + a_{18}Z^3 + a_{19}XYZ \qquad (6)$$

$$y = b_0 + b_1X + b_2Y + b_3Z + b_4XY + b_5XZ + b_6YZ + b_7X^2 + b_8Y^2 + b_9Z^2 + b_{10}X^2Y + b_{11}X^2Z + b_{12}Y^2X + b_{13}Y^2Z + b_{14}Z^2X + b_{15}Z^2Y + b_{16}X^3 + b_{17}Y^3 + b_{18}Z^3 + b_{19}XYZ$$

2.2. Multiquadratic Model

Process in the multiquadric model consists of the following steps:

1) Calculate the distance $f_j(x,y)$ between an image point (x,y) and G.C points (X_j,Y_j).
2) Calculate the distance f_{ij} between *i*th and *j*th point in G.C.P.s (x_i,y_i). And (x_j,y_j).
3) Confirm the interpolation matrix $F=(f_{ij})_{(n,n)}$.
4) Calculate the residual vectors [dX] and [dY] from step 3. Solve the following equation to calculate the coeeficent matrix A and B (F*A=dX , F*B=dY).

$$f_{k1}a_1 + f_{k2}a_2 + f_{k3}a_3 + \ldots + f_{kn}a_n = dX_k$$
$$f_{k1}b_1 + f_{k2}b_2 + f_{k3}b_3 + \ldots + f_{kn}b_n = dY_k \qquad (7)$$

5) Calculate the correction for each image points from the following equation.

$$f_1a_1 + f_2a_2 + f_3a_3 + \ldots + f_na_n = dx_k$$
$$f_1b_1 + f_2b_2 + f_3b_3 + \ldots + f_nb_n = dy_k \qquad (8)$$

6) Calculate the true value for each points

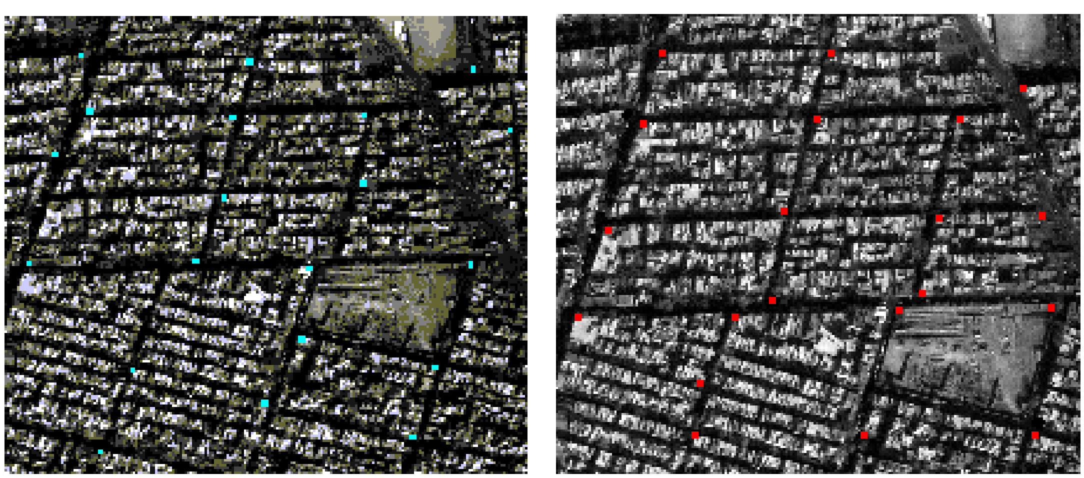
x'=x+dx
y'=y+dy (9)

2.3. DLT model

$$y = \frac{L5X + L6Y + L7Z + L8}{L9X + L10Y + L11Z + 1}$$
$$x = \frac{L1X + L2Y + L3Z + L4}{L9X + L10Y + L11Z + 1} \qquad (10)$$

3. Experimental results and Accuracy assessments

An IKONOS satellite image from a region of Tehran is used as a test field area.This image is located near the central part of Tehran. Figure 2a,2b respectivly show the image with ground control and check points distribution. Table 1 presents the main characteristics of the acquired images.



(a) (b)

Figure 2. The test area with a) GCP and b) check points distribution

Table 1.Technical specification of the Ikonos Image

Image type	Pan , Mono
Datum	WGS 84
Map Projection	UTM
Zone Number	39
Acquisition date	2001-05-25
File Format	Geo TIFF

The check points and the ground control points (GCPs) in this research were derived from a digital 1/500 topographic map that produced by National Catrographic Center (NCC) of Iran. It provides approximately 10cm planimetric accuracy and 50cm vertical accuracy. In Compare with the ground resolution of the IKONOS image, this digital map provides sufficient control data.

For Investigation of the results from the mathematical models in section 2,firstly the unknown coefficients were determined with 20 control points for each model.then with this determined coefficients,the corrected Image coordinates were calculated for 20 check points.RMS errors were calculated for each model base on the two types of coordinates for check points.Table 2 shows results for each model.

Table 1:RMSE values for IKONOS data over Tehran test field with 22 G.C.Ps

		Control		Check	
2_D Methods		point	σxy	point	σxy
Conformal		22	4.1298	16	2.9948
Affine		22	3.6136	16	3.2741
Second order polynomial		22	2.7640	16	3.4700
3^{rd} order polynomial		22	2.2648	16	3.3095
2D_Projective		22	4.6439	16	4.2284
Multiquadratic	First order	22	0	16	3.6780
	Third order	22	0	16	3.5637
Multiquadratic(2D_Projective)		22	0	16	3.5788

Table 2:RMSE values for IKONOS data over Tehran test field with 16 G.C.Ps

		Control		Check	
2_D Methods		point	σxy	point	σxy
Conformal		16	3.6811	22	3.0586
Affine		16	3.2776	22	3.4527
Second order polynomial		16	2.7056	22	3.1385
3^{rd} order polynomial		16	2.4070	22	2.8899
2D_Projective		16	4.3938	22	4.4440
Multiquadratic	First order	16	0	22	2.7173
	Third order	16	0	22	2.6078
Multiquadratic(2D_Projective)		16	0	22	3.4854

Table 3:RMSE values for IKONOS data over Tehran test field with 22 G.C.Ps

3_D Methods		Control point	Control σx	Control σy	Check point	Check σx	Check σy
Second order polynomial		22	1.8509	1.7330	16	2.0579	2.4090
3rd order polynomial		22	1.2257	0.9883	16	4.7042	4.9815
DLT		22	2.6638	3.4870	16	2.7559	3.3067
Multiquadratic	First order	22	0	0	16	1.9614	2.7491
	Third order	22	0	0	16	3.8653	2.7704
Multiquadratic(DLT)		22	0	0	16	2.3300	2.4414

Table 4:RMSE values for IKONOS data over Tehran test field with 16 G.C.Ps

3_D Methods		Control point	Control σx	Control σy	Check point	Check σx	Check σy
Second order polynomial		16	1.8175	1.6038	22	3.2264	4.0684
DLT		16	2.7586	3.5879	22	2.7995	3.5010
Multiquadratic	First order	16	0	0	22	2.3558	2.8370
Multiquadratic(DLT)		16	0	0	22	2.4799	2.6921

As we see in above tables,Multiquadratic with third order polynomial is the best model in 2_D case and Multiquadratic with DLT model is the best model in 3_D case. Also we see in comparison between 2_D and 3_D cases, the accuracy is nearly similar because the test area is flat .

4. Conclusion

The preprocessing of remotely sensed image consists of geometric and radiometric characteristics analysis. By realizing these features, it is possible to correct image distortion and improve the image quality and readability. Radiometric analysis refers to mainly the atmosphere effect and its corresponding terrain feature's reflection, while geometric analysis refers to the image geometry with respect to sensor system.

In this paper, some of 3_D and 2_D transformation models were used with different ground control points distribution. These models are generally available within most of remote sensing image processing systems. Comparison between the applied models showed that the multiquadratic with DLT model was the best model for the test area. The accuracy 2.5 m was be achived with this model.

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