

2D Geometric Correction of IKONOS Imagery Using Genetic Algorithm

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Abstract

The number of high resolution space imageries, in the civilian market is growing fast. This images have great interest in the photogrammetric and remote sensing communities.

The problem with this images for many users, at the present time is the lack of sensor calibration information and precise ephemeris data. Consequently it is not possible to apply the precise mathematical models such as orbital parameter model to determine the dynamic geometry of them at the time of imaging. Therefore for, there is a need for an alternative approach to extract 2D and 3D spatial information from this images.

This paper presents a mathematical solution to extract planimetric information as accurate as possible from IKONOS. This method uses Genetic Algorithm technique to find the best terms of global polynomial that provides the best fitness model of the imagery to the ground space.

Using the output of global polynomial in multiquadric transformation gives better results in term of accuracy.

The result of this method is compared with other 2D mathematical models such as global polynomial, 2D direct linear transformation and multi-quadric models. Also the model is applied to the IRS-1C imagery.

IKONOS, Geometric correction, Genetic Algorithm, DLT, Polynomial, multiquadric transformation

1- Introduction

The new generation of commercial high resolution space imageries such as IKONOS have provided a considerable progress in photogrammetric mapping and map revision. One of the great promises of IKONOS is its potential to generate 3D spatial information products in meter accuracy and to produce large scale topographic maps such as 1:10000 scale and even larger.

IKONOS is a pushbroom linear array imaging system, which can take the high-resolution images of the earth using satellite's flexible pointing capability. Accurate geometric correction of IKONOS imageries is an important matter in using these imageries for map production and spatial information extraction.

There have been many investigations for 3D spatial information extraction from pushbroom scanners over the past decade. Mathematical models were developed to determine the dynamic geometry of the cross-track stereo images taken by SPOT and IRS-1C/1D by Valadan and Petrie (1998), Radhadevi et al. (1998) and Valadan and Foomani (1999). There were also mathematical models developed to determine the exterior orientation parameters of the along-track stereo images taken by MOMS-02 such as Ebner et al. (1992), Fraser and Shao (1996) and Valadan (1997).

In many applications and conditions, 2D geometric correction of satellite imageries is required. Having just a mono image, requesting just a planimetric map, producing fast and accurate geometric correction of image, having no information of camera model and etc. are the reasons to use 2D geometric correction of satellite imagery.

At the time of writing this paper, space imaging has refused to release information on the camera model for IKONOS, as well as data on the precise in-flight and attitude of the imaging sensor. Also due to the high expense of stereo images most of users prefer to get the mono images and extract required information after geometric correction. 2D mathematical models seem to be the easiest and the most rapid way for geometric correction of IKONOS imageries. Finding the best method for fast, easy and accurate correction of IKONOS imageries is an important issue in this field.

There are several mathematical models for 2D geometric correction of satellite imageries such as global polynomial, piecewise polynomial, pointwise polynomial and multi-quadric transformation, 2D projective transformation. Each of these methods has their advantages and disadvantages and is suitable for geometric correction of satellite imageries depending on the topographic specification of the ground and the nature of the features existing on the image.

In this paper three new methods for 2D geometric correction of satellite imageries has been introduced and has been tested on IKONOS and IRS-1C images. These methods are construction a combination of global polynomial and

improved 2D projective, of Global polynomial and genetic algorithm (GA) as well as, Multiquadric and genetic algorithm.

2- 2D mathematical models

Some mathematical models has been overviewed as follows:

2-1- Global polynomial

This model describe the relation between image and object space independent of sensor geometry with the bellow general equation Eq(1),Eq(2):

$$x = \sum_{i=0}^n \sum_{j=0}^n a_{ij} X^i Y^j \quad \text{Equation (1)} \quad y = \sum_{i=0}^n \sum_{j=0}^n b_{ij} X^i Y^j \quad \text{Equation (2)}$$

Each term of the global polynomial models and removes a specific error from the satellite imagery. Selecting appropriate number of terms is an important issue in using global polynomial for 2D geometric correction of satellite imagery. If the image covers an area having different topographic conditions (flat area and mountains) global polynomial can not model the image by itself.

2-2- Pointwise Transformation

In the so-called pointwise procedure, a global polynomial is first used in a preliminary stage to match the image and ground coordinates of the control points. Residual vectors will then result at each of the GCPs. Then a new transformation procedure is defined for each new point in the image, using only the surrounding subset of ground control points (GCPs). Essentially this comprises an individual transformation for each point (or pixel) in the image using only the closest GCPs. In this case, for each new point, the technique assembles a set of neighbouring GCPs according to some criterion. This may be the n closest GCPs or it may be the m GCPs lying in each of the four quadrants centred on the position of the new point (Leberl 1990).

These pointwise methods make it possible to obtain a good fit at any number of points by attaching a larger weight to the contributions from nearby control points. A good overall result of the adjustment can be obtained by careful selection of the weight function and the polynomial that are used in the procedure.

2-3- Multiquadric Transformation

The Multiquadric procedure can be summarized as follows: i) calculate the distance $f_j(x',y')$ between a point (x,y) in the image and the GCP (X_j, Y_j) , ii) Calculate the distance f_{ij} between two ground control point i and j with planimetric coordinates (x_i, y_i) and (x_j, y_j) , iii) set up the interpolation matrix $F=(f_{ij})_{(n,n)}$, where (n,n) means that F is an n by n matrix, (iv) the residual vector $[dX]$ and $[dY]$ should be modeled so that they can be calculated from F, where $[dX]=F.A$ and $[dY]=F.B$ this residuals in n equation for n unknowns in each set and these can be solved to determine A. the matrix F is symmetric and has zero in its diagonal. Now the above equation can be solved to produce A and residual improvements dX_k (where $k=1,2,\dots,n$) can be modeled as follows: $f_{k1}a_1 + f_{k2}a_2 + f_{k3}a_3 + \dots + f_{kn}a_n = dX_k$. (v) the same must be done with the Y coordinates and vector B to give the $[dY]$ values. (vi) Now a geometric interpolation can be performed for every pixel (x,y) in the image using the interpolation function $f_j(x,y)$. Let f_j now stand for $F_j(x,y): f_1a_1 + f_2a_2 + f_3a_3 + \dots + f_na_n = dx$, $f_1b_1 + f_2b_2 + f_3b_3 + \dots + f_nb_n = dy$ (Sadeghian, Valadan 2001)

Now the true location of each point (x,y) can be calculated using the improvement vectors (dx,dy) as follows: $(x,y) = (x',y') + (dx,dy)$. For all other points in the images, an interpolation is carried out according to the model given above (Ehlers, 1997)

2-4- 2D projective Transformation

Eight parameters define Eq(3) the relationship between the object and image planes:

$$x = \frac{a_0 + a_1 X + a_2 Y}{1 + c_1 X + c_2 Y} \quad y = \frac{a_0 + a_1 X + a_2 Y}{1 + c_1 X + c_2 Y} \quad \text{Equation (3)}$$

There are more 2D mathematical models, which has been described in Sadeghian & Valadan (2001).

3- Developed 2D mathematical models

In order to achieve better and more accurate 2D spatial information from satellite imageries, specially on IKONOS, some mathematical models were developed. Bellow conditions were considered for developing these models:

- The model should be efficient and flexible enough in order to remove most of the errors from imagery

- The model should require minimum ground control points for geometric correction of satellite imagery
- The speed of processing should be fast
- It should be able to model the errors automatically
- The model should be suitable for different satellite imageries with different sensor specifications

The developed models are described as following:

3-1- Hybrid Model-1 (global polynomial and improved 2D projective)

The main idea of this approach is based on overcorrection to result of global polynomial using a mathematical model such as 2D-DLT and polynomial. After geometric correction of satellite imagery using global polynomial, the main residual errors are affected from relief displacement, which the global polynomial has not been able to model it. In order to model relief displacement, 2D-DLT is used.

This method consists of two main stages. At the first stage, a global polynomial is used for geometric correction of satellite imagery. After that the image coordinate of ground control points is recalculated using global polynomial. At the second stage, the calculated coordinates in step 1 and the real image coordinates are used in a 2D-DLT model as described in Eq(4).

$$x = \frac{a_0 X + a_1 Y + a_2 Z + a_3}{c_0 X + c_1 Y + c_2 Z + 1}$$

$$y = \frac{b_0 X + b_1 Y + b_2 Z + b_3}{c_0 X + c_1 Y + c_2 Z + 1}$$

Equation (4)

$$Z = d_0 + d_1 X + d_2 Y$$

$$x = \frac{a_0 X + a_1 Y + a_2}{c_0 X + c_1 Y + 1}$$

$$y = \frac{b_0 X + b_1 Y + b_2}{c_0 X + c_1 Y + 1}$$

In order to remove residual errors efficiently we should find a model that maps the calculated coordinates from global polynomials to original coordinates. Therefore we can assume that results of global polynomials are mapped to an intermediate space closed to actual space of image.

Assume that the elevation of the earth to be a function of X,Y therefore the 2D projective will be as Eq(5).

$$Z = f(X, Y)$$

$$Z = d_0 + d_1 X + d_2 Y + d_3 XY$$

$$x = \frac{a_0 X + a_1 Y + a_2 XY + a_3}{c_0 X + c_1 Y + c_2 XY + 1}$$

$$y = \frac{b_0 X + b_1 Y + b_2 XY + b_3}{c_0 X + c_1 Y + c_2 XY + 1}$$

Equation (5)

In order to calculate the coordinate of each unknown point, At the first, a global polynomial is used and then the output of global polynomial is overcorrected using 2D-DLT.

The advantages of this method are as following:

- Using this method we can overcorrection the results of global polynomial
- As the most of systematic errors such as earth rotation and earth curvature are removed by global polynomial, improved 2D-DLT for considerable for topographic modeling
- This method is faster than Multiquadric
- Improved 2D-DLT can reduce the errors affected from relief displacement
- This method is independent from geometry of image, considering that 2D-DLT is dependent on the geometry of the image, as earth rotation and earth curvature errors should be removed from image before using 2D-DLT

3-2- Hybrid Model-2 (global polynomial and genetic algorithm)

As it was described in 2-1, each term of a global polynomial models and removes a specific error from satellite imagery. In general, one may select a specific number of terms (i.e. 9 terms) and use them for geometric correction. In this condition some equations will be resulted as below:

$$x = a_0 + a_1X + a_2Y + a_3XY + a_4X^2 + a_5Y^2 + a_6X^2Y + a_7XY^2 + a_8X^2Y^2 + \dots \quad (\text{Equation 6})$$

$$y = b_0 + b_1X + b_2Y + b_3XY + b_4X^2 + b_5Y^2 + b_6X^2Y + b_7XY^2 + b_8X^2Y^2 + \dots \quad (\text{Equation 7})$$

Imagine that errors concerning to 7th and 9th terms in equation1 and errors concerning to 6th term in equation2 do not exist on a specific image. Therefore applying these terms to the model will cause error by itself. If one can find those terms that just their related errors exist on the image and use them in the model, better accuracy will be resulted.

Using genetic algorithm, it is possible to find the best terms of global polynomial for each image automatically and in a flexible manner. A program is developed which generates a set of random chromosomes. Each block of a chromosome represents one of the terms of global polynomial. The block may have a value of 1 or 0 which 0 indicates the related term should not be considered and value 1 indicates the related term should be considered in the global polynomial.

Considering errors on each of the checkpoints, two sets of chromosomes, which have the least error, are selected. Using genetic algorithm rules, the chromosomes are inoculated with each other and new sets of chromosomes are generated which result better model for 2D geometric correction of satellite imagery.

3-3- Hybrid Model-3 (global polynomial, Multiquadric and genetic algorithm)

The first step of multiquadratic model, as is described in 2-4, is using a global polynomial for geometric correction of satellite imagery. In the new method, the resulted model of hybrid of global polynomial and genetic algorithm is used in multiquadric model. Therefore, not only the best model (in global polynomial) is fitted to the image, but also the reminded error on each of the ground control points due to the weakness of the model is affected as a correction which will cause better results.

4- Practical test

In order to test the accuracy of new developed mathematical models and comparing them with classic models two test areas in the west and east part of Iran covered by IKONOS and IRS-1C images respectively has been selected. In the followings image measurements GCPs extractions and the results of the tests are discussed in details.

4-1- Test fields and image measurements

The IKONOS Geo panchromatic image employed covered an 8 x 7 km² area of central Hamedan city in the west of Iran. It was acquired in 7 October 2000 with 20.4 degree off-nadir angle and 47.4 degree sun elevation. Carterra Geo products are georectified, which means that they are rectified to an inflated ellipsoid and selected projection, in this case UTM on the WGS84 datum. No terrain-correction model is applied so these images are only rectified, as opposed to orthorectified. The stated accuracy of the Carterra Geo products is specified as 50m CE90 exclusive of terrain displacement (Groddecki 2001). In this investigation the elevation within the IKONOS test area ranged from 1700m to 1990m. The GCPs/ICPs for the tests were extracted from NCC-produced digital maps, which employed a UTM projection on the WGS84 datum. In this instance the mapping scale was 1:1000 with the compilation have been carried out using 1:4000 scale aerial photographs. The selected GCPs/ICPs in the imagery were distinct features such as buildings and pools corners, and wall and roads crossings, etc. The image coordinates of the GCPs/ICPs were monoscopically measured using the PCI EASI/PACE software system.

IRS-1C image covers an area of 23 x 23 km² of Mashad city in the east part of Iran. For more details about image points and GCPs extractions readers may refer to Valadan and Foomani 1999.

4-2- Geometric accuracy test

Tables 1 to 3, shows the result of tests on IKONOS and IRS-1C images with different mathematical models.

Table 1: RMSE values in term of pixels for IKONOS data over Hamedan test field with 63 GCPs

Method	Control				Check			
	Point	σ_x	σ_y	σ_{xy}	Point	σ_x	σ_y	σ_{xy}
Global Polynomial (8 Terms)	63	2.2	1.70	2.78	31	2.21	1.72	2.80
Multiquadric	63	0	0	0	31	1.30	0.75	1.50
Hybrid model-1	63	2.01	0.91	2.20	31	1.32	1.02	1.67
Hybrid model-2	63	1.9	1.54	2.45	31	2.1	1.61	2.64
Hybrid model-3	63	0	0	0	31	1.05	0.70	1.26

The best terms which have been chosen by genetic algorithm in hybrid model-2 and hybrid model-3 are: $a_0, a_1, a_2, a_3, a_4, a_5, a_8, a_9, a_{10}$ & $b_0, b_1, b_2, b_3, b_4, b_5, b_6, b_7, b_9, b_{10}, b_{11}$

Table 2: RMSE values in term of pixels for IKONOS data over Hamedan test field with 20 GCPs

Method	Control				Check			
	Point	σ_x	σ_y	σ_{xy}	Point	σ_x	σ_y	σ_{xy}
Global Polynomial (8 Terms)	20	1.4	0.60	1.52	74	2.23	1.75	2.83
Multiquadric	20	0	0	0	74	1.04	0.81	1.32
Hybrid model-1	20	1.04	0.81	1.31	74	1.36	0.96	1.66
Hybrid model-2	20	0.99	1.11	1.48	74	2.04	1.65	2.62
Hybrid model-3	20	0	0	0	74	1.01	0.76	1.26

The best terms which have been chosen by genetic algorithm in hybrid model-2 and hybrid model-3 are: $a_0, a_1, a_2, a_3, a_4, a_5, a_8, a_{10}, a_{11}$ & $b_0, b_1, b_2, b_3, b_4, b_5, b_6, b_7, b_9, b_{12}$

Table 3: RMSE values in term of pixels for IRS-1C data over Mashad test field

Method	Control				Check			
	Point	σ_x	σ_y	σ_{xy}	Point	σ_x	σ_y	σ_{xy}
Global Polynomial (5 Terms)	40	1.8	1.06	2.09	22	2.21	1.78	2.84
Multiquadric	40	0	0	0	22	1.2	1.14	1.65
Hybrid model-1	40	1.07	1.20	1.61	22	1.50	1.03	1.81
Hybrid model-2	40	1.16	0.79	1.40	22	2.03	1.36	2.44
Hybrid model-3	40	0	0	0	22	1.07	1.04	1.49

The best terms which have been chosen by genetic algorithm in hybrid model-2 and hybrid model-3 are: $a_0, a_1, a_2, a_3, a_4, a_5, a_7, a_8, a_9, a_{10}, a_{12}$ & $b_0, b_1, b_2, b_3, b_4, b_5, b_8, b_9$

As can be seen from tables 1, 2 and 3, the genetic algorithm increases the accuracy of global polynomial method but still multiquadric transformation shows better accuracy. A combination of global polynomial, genetic algorithm and multiquadric transformation (hybrid model-3) gives the best result. Table 2 shows that decreasing the number of GCPs do not change the accuracy of hybrid model-3. The vector plot of RMS values shows no systematic errors in the tests after implementing the models.

5- Conclusion

With respect to the results of practical test, it is concluded that hybrid model-3 gives the best results comparing to the other methods specially for high resolution satellite imageries such as IRS-1C and IKONOS.

Advantage of hybrid model-3 to other methods is its more accurate and flexible computation and its requiring to less number of ground control points than the other methods.

An interesting future research work may be selecting effective ground control points in pointwise polynomial functions utilizing neural network and genetic algorithm, which is an important matter in such method.

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