GEOMETRICAL CORRECTION OF SATELLITE IMAGES BY GENERIC MODELS

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ABSTRACT:

Dynamism of satellite images of linear array leads to complexity of execution of one accurate algorithm for real time positioning which needs information of satellite orbits.
In other hand vendors of high resolution satellite images have no aptitude to issue information of their sensors.
Then to relate the object space and image space we should use the approximate models to satisfy the accuracy without need to orbital information of satellite. Generic models take part in computations for this reason. One of these models is Rational Function (RF) model and the other is Direct Linear Transformation (DLT) model.
In this paper we address the implementation of these models by writing some programs in Visual C language and apply several test on images of SPOT & IKONOS & IRS satellites. The results show eligibility of geometric correction of these models for selected images. Although these models has less accuracy comparing with models of orbital parameters but noting that the orbital parameters model are not utilizable in IKONOS images. The value of Generic models is distinguished. Also simplicity and speed of these models in specific application are very important.

1. INTRODUCTION

The importance of producing topographic map of different scale such as 1/25000, 1/10000, 1/5000 and so on is not hidden from any body for sustainable development and military goals. These maps are as a basis for geographical information systems and as a proper tools for cultural, economical and social programming as well(Petrie,G.,Al-Rousan,N., Valadan Zoej,M. J. , 1999, Petrie,G.,Al-Rousan,N.,El-Niweiri,A. H. A.,Li,Z., and Valadan Zoej, M. J.,1997, Valadan Zoej,M.J.,1997). According to these points the request for accurate middle scale maps is augmenting day by day. Nowadays shortage of geo information is feeling in most of the points. So just 33.5 percent of lands of earth have maps of 1/25000 and 65.5 percent have 1/50000 maps and 55.7 percent have 1/100000 and 95 percent have 1/250000 maps(Valadan Zoej,M.J.,1997). Also updating these maps is an important problem for example, the time needed for updating maps of 1/25000 last some 20 years usually. Though the usual way of producing such a maps is using of aerial photographs but difficulties of aerial photography and time and cost of this way lead the specialists to study and choose the other ways.
Today, utilization of satellite images as a complementary and substitute for small scale aerial photograph to produce new maps and correct old maps more speedy than before is seen to eliminate shortage of geo information and need to update these information. Fast access to information and needed geometry accuracy of photogrammetry for maps of different scales leads to a demand for proper mathematical model from accuracy and speed point of view. Thus this paper presents a suitable solution to solve the problem.

2. EXISTING MATHEMATICAL MODELS FOR GEOMETRIC CORRECTION

Generally, used mathematical model for geometrical correction of satellite images are divided in two type of physical or rigorous models and generic models.
Selection of these models is based on utility and accuracy wanted and camera used and number and distribution of control points. Physical models show the procedure of imagery physically and the parameters used in this type show the position and tilt of sensor in object space. Physical models such as co linearity equation are very suitable for adjustment of analytical aerial triangulation and have high accuracy in range of less than one pixel.
In generic models, the type of sensor has no importance and parameters used in connecting object space and image space are not related to sensor physics.
Rational Function Models, polynomials, affine model and so on are of this type.
Due to photo grammetric operations such as 3D image reconstruction, rectification and DEM generation that is to be in real time , usage of generic models are very suitable and it is done in photogrammetric instruments without any attention to sensor type and for new sensors it is sufficient to update only the coefficients of models. To substitute sensor model by generic one should be done by best fitting to physical sensor models.
Advantages and disadvantages of these model types are as following:
Advantages of physical models are:

- high accuracy because of inclusion of sensor physics
- need to least number of ground control points
- independency of its parameters
- gaining higher accuracy by exceeding self calibration parameters

Disadvantages of physical models are:

- time consuming because of iteration

- need to initial values because of linearization of non linear equations
- being sensor dependent that changes in different sensors

Advantages of generic models are:

- no need to iteration
- no need to initial values
- sensor independent
- arbitrary object coordinates
- high speed of computations
- higher accuracy in case of self calibration

and disadvantages of generic models are:

- high dependency of coefficients
- lower accuracy comparing physical one
- uncertainity in number of terms selection occurs
- high dependency to number and distribution of GCPs

by attention to above mentioned points in this paper the geometric accuracy of some generic models evaluated.

2.1 Modified Direct Linear Transformation Model

Direct Linear Transformation (DLT) model initially used by Abdel-Aziz and Karara in 1971 for non metric cameras in close range photogrammetry and Novak in 1997 for geometric correction of satellite images used and also Fraser extended usage of modified DLT model. In this approach actually there is a transformation from an arbitrary image coordinate system to a ground coordinate system. The origin of the image coordinate system is at left upper corner of the image. The X axis is in the direction of increasing row numbers and Y axis is perpendicular to it in the direction of increasing pixels. The used ground coordinate system is the same as reference ground coordinate system CT and WGS84 ellipsoid(El-Manadili Y., K. Novak,1996,). See figure 1.

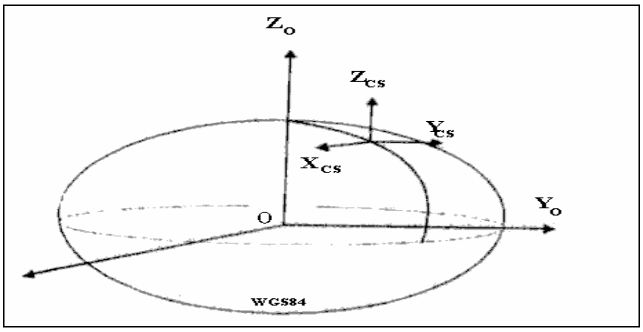

Figure1. Geocentric and Shifted Geocentric ground coordinate system.

DLT model to relate these tow system is as:(1)

$$x = \frac{L_1 X_{GS} + L_2 Y_{GS} + L_3 Z_{GS} + L_4}{L_9 X_{GS} + L_{10} Y_{GS} + L_{11} Z_{GS} + 1} + L_{12} xy$$

$$y = \frac{L_5 X_{GS} + L_6 Y_{GS} + L_7 Z_{GS} + L_8}{L_9 X_{GS} + L_{10} Y_{GS} + L_{11} Z_{GS} + 1} \qquad (1)$$

Where x, y are coordinates of a point in image space and X, Y, Z are coordinates of same point in ground space and $l_1, l_2, \ldots l_{12}$ are transformation parameters .
Thus we can write equations of resection and intersection.

2.2 Rational Function Model

Rational Function Model (RFM) relates between 2 dimensional image space and 3 dimensional ground space and acts independent from image geometry. Rational Functions are defined ratios of polynomials have the forwarded form:

$$x = \frac{P_1(X,Y,Z)}{P_3(X,Y,Z)} \qquad y = \frac{P_2(X,Y,Z)}{P_4(X,Y,Z)} \quad (2)$$

It is worth mentioning that here we have:

$$P_3(X,Y,Z) = P_4(X,Y,Z) \quad (3)$$

and polynomials are as following: (4)

$$P_1(X,Y,Z) = a_0 + a_1X + a_2Y + a_3Z + a_4XY + a_5XZ + a_6YZ + d7XYZ + \ldots + a_{19}Z^3$$

$$P_2(X,Y,Z) = b_0 + b_1X + b_2Y + b_3Z + b_4XY + b_5XZ + b_6YZ + b7XYZ + \ldots + b_{19}Z^3$$

$$P_3(X,Y,Z) = c_0 + c_1X + c_2Y + c_3Z + c_4XY + c_5XZ + c_6YZ + c7XYZ + \ldots + c_{19}Z^3$$

$$P_4(X,Y,Z) = d_0 + d_1X + d_2Y + d_3Z + d_4XY + d_5XZ + d_6YZ + d7XYZ + \ldots + d_{19}Z^3$$

Where x, y are normalized row and column index of pixels in the image respectively and X, Y, Z are normalized coordinate value of ground coordinate points (object space). And $a_0, a_1, \ldots, d_{19}$ are coefficients of polynomials in RFM.

2.3 Affine model

By exceeding the substitution generic models instead of physical models, some experts recommended different models. As explained previously RFM is one of them. Usually coefficients of RPC of satellite images of HR is in disposal of users. Simple six parameter affine model is specific case of RFM that is used in 2D positioning of Ikonos Geo images. Eight parameter affine model is used for 3D positioning and relating object space (X,Y,Z) and image space (x, y) with following functions:

(5)
$$x = A_1 X + A_2 Y + A_3 Z + A_4$$
$$y = A_5 X + A_6 Y + A_7 Z + A_8$$

where A_i are coefficients of affine including 3 tilt parameter and 2 transformation parameter and 3 scale parameter and 1 parameter of skew totally 9 parameter and (x, y) are image space coordinates and (X,Y,Z) are object space coordinates.
In programming affine equation in orientation and aerial triangulation of HR images, all coefficients and coordinates of ground control points synchronously is produced by bundle adjustment. Combining above function with additional parameter, we can model other effective non linear parameters.

3. TESTED AREAS AND SATELLITE IMAGES

first study area is chosen about Isfehan named Varzane which the highest and lowest points from ellipsoid are 2469 m and 900 m respectively and average of height is 1500 m .
Mashad in north east of Iran is the second study area. The highest and lowest points from ellipsoid are 1170 m and 919 m respectively and average of height is 330 m.
and third study area is Hamedan in west of Iran with The highest and lowest points from ellipsoid are 1900 m and 1700 m respectively.
Existing images of Varzane is a SPOT panchromatic stereo pair of 10m pixel size and proper radiometric quality and type 1A a base to height ratio equal to 0.98 taken on august 1993. The off nadir viewing angles are 22.7°and 29.7° for left and right images respectively.
studied images of mashhad is a IRS-1C panchromatic stereo pair of 5.86m pixel size and proper radiometric quality and type 1A a base to height ratio equal to 0.97 taken on 27 august 1998. The off nadir viewing angles are 24.7° and 20.82° for left and right images respectively.
Existing images of Hamedan is an Ikonos panchromatic of 1m pixel size a base to height ratio equal to 0.8 and inclination angle of 20.4°.

3.1 Control point selection

In varzane – Isfehan and Mashhad areas control points are extracted from 1: 25000 topographic maps provided by National Cartographic Center (NCC) of Iran from aerial photos 0f 1370 Hejri shamsi (1991). Control point selection is done how as same sparseness in image space especially in corners of image. Control points are selected from crossings of roads, streets and railway stations and so on. In Hamedan images ground control points were extracted from 1:10000 maps produced by NCC from 1:40000 photos.

4. 3D GEOMETRICAL CORRECTION TEST USING DLT MATHEMATICAL MODEL AND EVALUATION OF RESULTS

4.1 Results of SPOT images of Varzane(Isfehan)

There were 31 ground point accessible that we used in three case of with 12 check point, with 18 check point, 24 check point. The results is shown in table 4-1-1

Mean residuals of check points(mm)		Mean residuals of control points(mm)		Check points no	Control points no	Total points
Mean residual of y	Mean residual of x	Mean residual of y	Mean residual of x			
80.09	135.96	3.08	1.71	24	7	31
61.35	24.37	27.36	7.11	18	13	31
55.05	18.67	33.26	8.71	12	19	31

Tab 4-1-1 remaining mean of x, y of control and check points of varzane Isfehan in image coordinate system

4.2 Results of IRS-1C Mashhad image

There were 64 ground point accessible that we used in three case of with 17 check point, with 37 check point, 57 check point. The results is shown in table 4-2-1

Mean residuals of check points(mm)		Mean residuals of control points(mm)		checkpoints no.	Control points no.	Total points
Mean residual of y	Mean residual of x	Mean residual of y	Mean residual of x			
61.93	52.90	4.76	3.00	57	7	64
17.66	13.50	9.56	5.38	37	27	64
14.84	8.59	12.15	5.96	17	47	64

Tab 4-2-1 remaining mean of x, y of control and check points of Mashhad in image coordinate system

4.3. Results of IKONOS image of Hamedan

There were 72 ground point accessible that we used in three case of with 17 check point, with 37 check point, 57 check point. The results is shown in table 4-3-1

Mean residuals of check points(mm)		Mean residuals of contro points(mm)		Check points no	Control points no	Total points
Mean residual of Y	Mean residual of X	Mean residual of Y	Mean residual of X			
5.02	3.20	2.43	1.83	57	15	72
5.21	4.02	2.31	1.88	37	35	72
6.02	5.02	2.91	2.12	17	55	72

Tab 4-3-1 remaining mean of x, y, of control and check points of Australia in image coordinate system

5. 3D GEOMETRIC CORRECTION TEST BY RFM AND EVALUATION OF RESULTS

5.1 Results of IRSC-1C images of Mashhad

As above there were 64 ground point accessible that we used in three case of with 13 check point, with 23 check point, 33 check point. The results is shown in table 5-1-1 for first and second and third order equations.

Order	Total points	Control points no	Check points no	Mean residuals of contro points(mm)		Mean residuals of check points(mm)	
				Mean residual of X	Mean residual of Y	Mean residual of X	Mean residual of Y
first	64	31	33	12.58	10.57	21.39	16.44
	64	41	23	14.39	13.16	17.24	11.30
	64	51	13	14.60	12.66	17.80	14.32

second	64	31	33	3.76	3.09	13.38	9.33
	64	41	23	5.17	5.40	7.94	6.06
	64	51	13	5.36	4.82	9.26	5.18
third	64	31	33	2.75	2.4	10.5	7.48
	64	41	23	4.20	4.45	6.94	5.05
	64	51	13	4.10	4.20	6.05	5.10

Tab 5-1-1 remaining mean of x, y, of control and check points of Mashhad in image coordinate system

5.2 Results of Ikonos image of Hamedan

As above there were 64 ground point accessible that we used in three case of with 17 check point, with 37 check point, 57 check point. The results is shown in table 5-2-1

Order	Total points	Control points no	Check points no	Mean residuals of control points(mm)		Mean residuals of check points(mm)	
				Mean residual of X	Mean residual of Y	Mean residual of X	Mean residual of Y
first	72	15	57	2.58	2.57	4.39	3.44
	72	35	37	4.39	3.16	5.24	4.30
	72	55	17	4.60	2.66	5.80	4.32
second	72	15	57	2.76	2.09	4.38	3.33
	72	35	37	4.17	4.40	5.94	5.06
	72	55	17	4.36	3.82	6.02	5.18
third	72	15	57	2.02	2.01	5.5	5.48
	72	35	37	1.80	1.45	3.94	3.05
	72	55	17	1.10	1.20	2.05	3.10

Tab 5-2-1 remaining mean of x, y, of control and check points of Hamedan in image coordinate system.

6. 3D GEOMETRIC CORRECTION TEST BY AFFINE MODEL AND EVALUATION OF RESULTS

6.1 Results of SPOT images of Varzane(Isfehan)

There were 31 ground point accessible that we used in three case of with 12 check point, with 18 check point, 24 check point. The results is shown in table 6-1-1

Mean residuals of check points(mm)		Mean residuals of control points(mm)		Check points no	Control points no	Total points
Mean residual of y	Mean residual of x	Mean residual of y	Mean residual of x			
70.09	115.96	2.84	1.61	24	7	31
51.35	20.37	24.44	6.81	18	13	31
50.05	18.67	30.32	7.53	12	19	31

Tab 6-1-1 remaining mean of x, y, of control and check points of varzane Isfehan in image coordinate system

6.2 Results of IRS-1C Mashhad image

There were 64 ground point accessible that we used in three case of with 17 check point, with 37 check point, 57 check point. The results is shown in table 6-2-1

Mean residuals of check points(mm)		Mean residuals of control points(mm)		checkpoints no.	Control points no.	Total points
Mean residual of y	Mean residual of x	Mean residual of y	Mean residual of x			
56.93	48.90	3.86	2.80	57	7	64
12.66	10.50	8.46	4.48	37	27	64
11.84	6.59	10.05	4.76	17	47	64

Tab 6-2-1 remaining mean of x, y of control and check points of Mashhad in image coordinate system

6.3 Results of IKONOS image of Hamedan

There were 72 ground point accessible that we used in three case of with 17 check point, with 37 check point, 57 check point. The results is shown in table 6-3-1

Mean residuals of check points(mm)		Mean residuals of control points(mm)		Check points no	Control points no	Total points
Mean residual of Y	Mean residual of X	Mean residual of Y	Mean residual of X			
3.02	2.20	2.03	1.03	57	15	72
3.21	3.02	2.01	1.08	37	35	72
3.02	3.01	2.01	2.02	17	55	72

Tab 6-3-1 remaining mean of x, y, of control and check points of Australia in image coordinate system

7- Conclusion

In existence of sufficient, accurate and well distributed ground control points RFM and DLT and affine model provide proper accuracy even better than one pixel and thus could be a proper replacement to utilize in providing image maps 3D plotting.
Above mentioned approach are sensitive to the number and distribution of ground control points and in scarcity and/or bad distribution should not expect high accuracy of results. Results of applying this approach on different data set in number and distribution show the ability of that in managing multifarious data even in critical condition (at least 7 control points).
Due to extraction of control points from 1:25000 maps for IRS images, these images have better accuracy comparing other images.
RFM has better interpolation characteristics and better fitting as well. Also it seems more smooth and has better accuracy in extrapolation. RFM and DLT affine like other generic models are sensor independent and flexible in coordinate system

selection. Because of non existence of any relation between physical model parameters and equations coefficients, though physical data has been ignored in these equations.
By launching higher resolution imagery satellites and challenging in these domains we expect depreciation of images and bring forward more facilities for access to images and their metadata. Then we should study these evolutions continually and keep our ingenuity to respond to growing need to this strategic product.

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