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PRECISION RECTIFICATION OF KFA-1000 AND IKONOS IMAGES USING MULTIQUADRIC AND DLT MODEL OVER TEST AREAS IN IRAN

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ABSTRACT

The number of high resolution satellite sensors for mapping applications is growing fast. At the present time, the necessary camera model and precise ephemeris data for IKONOS has not been published. There is consequently a need for a range of alternative, practical approaches for extracting accurate 2D and 3D terrain information from IKONOS. In this paper a block of eight KFA-1000 space photos in two strips with 60% longitudinal overlap and 15% lateral sidelap and IKONOS image with multiquadrics, DLT, 2D projective and polynomials were used in the test. The test areas cover parts West and South of Iran. 3D digital maps and model after absolute orientation were used for determining ground control points (GCPs), and independent check points (ICPs). The flexibility and good accuracy of the alternative models with KFA-1000 and IKONOS Geo images are demonstrated. Considering the quality of GCPs, the best result was related to DLT method with 1.13 m RMSE for IKONOS image.

1. INTRODUCTION

The new generation of commercial high resolution satellite imageries (HRSI) such as IKONOS are available today and have provided a considerable progress in mapping and map revision. The geometry of IKONOS is based on the pushbroom principle, which differs significantly from photogrammetric frame cameras such as KFA-1000 space photos. In contrast to frame cameras, the spatial position and orientation of the imaging sensor is continually changing along the orbit and the imaging geometry become dynamic and time-dependent. The position, velocity vectors and angular rates of the satellite platform have not been provided with IKONOS images. Therefore alternative ways of camera modeling should be used. Recently, several 2D approaches have been reported to tackle this issue (Fraser, 2000 ; Hattori, 2000). They do not require parameters of the interior orientation and ephemeris information. The solution is based only on GCPs. This is an advantage for processing the new HRSI. In this paper the possibility of using multiquadric, DLT, 2D projective and polynomials for geometric correction of KFA-1000 and IKONOS Geo images were explored and investigated.

2. THE GEOMETRY OF SPACE PHOTOS

A frame is formed as a single exposure with no significant movement of the sensor whilst the image is formed as in the case of a frame camera. In selecting a camera for use in space a trade off is necessary between high resolution and height accuracy. High resolution requires a very long focal length but this implies a small angle of view if the camera is to be kept to a manageable size. A small angle of view leads to a low base to height ratio and poor height accuracy. The highest spatial resolution space photos available for commercial before IKONOS was Russian photos. The images of the panoramic KVR-1000 camera are available as digital data with 2m pixel size and the simultaneously used TK-350 with 10 m pixel size on the ground as SPIN-2 data in the internet. The TK-350 can be used for the determination of a digital height model which is required for the mono-plotting or orthophoto generation with the KVR-1000 images because there is no stereo overlap for these. The resolution of the photos taken by the frame camera KFA-3000 can be compared with the KVR-1000. Also this system has no stereoscopic overlap. Cameras systems used in space are illustrated in table1.

Table 1. Photographic systems used in space

Cameras	MC	LFC	KFA-1000	Kate 200	MK 4	TK-350	KVR-1000	KFA-3000
Altitude (km)	250	250	250	250	180-450	220	200	280
Format (mm)	230	230*460	300	180	180	300*450	180	300
Focal length (mm)	305	305	1000	200	300	350	1000	3000
Scale	1:800000	1:800000	1:250000	1:1250000	1:600000	1:660000	1:220000	1:95000
Resolution (m)	18m	18m	5-10	15-30	5-8	10-15	2	2-3
B:H	0.31	0.64	0.12	0.4	0.7	0.54	0	0

3. KFA-1000 PHOTOS AND IKONOS IMAGES

The KFA-1000 camera system is originally planned for interpretation purposes. Much interest has arisen for its possible use in medium-scale topographic mapping because of a good resolving power of the system. Line objects like paths narrower than three meters can be seen on these images when there is sufficient contrast on the ground (Sirkia and Laiho, 1989). The KFA-1000 photo has 5 fiducial marks, 4 in the center of each side and 1 in the photo center, So, the transformation to the calibrated fiducial mark coordinates is not a problem. The fiducials are superimposed onto the film and if there is not sufficient contrast, observation of them can be difficult. The KFA-1000 imaging system has the advantage of being an optical frame sensor and is not made of a linear array sensor like IKONOS. However, they have problems like photographic processing and storage. The vertical accuracy on the other side is limited by mapping with space photos. The height accuracy is mainly determined by the height to base ratio (B/H). The KFA-1000 has not been designed for optimal height accuracy. B/H for IKONOS is 0.6 to 2. Details of IKONOS cameras and its images are given by Gerlach (2000).

4. SOME CASE STUDIES USING KFA-1000

Work on the KFA-1000 photos has produced the following results shown in Table 2.

Table 2. A summary of the accuracies attained by various workers using KFA-1000

Projects	Planimetric accuracy		Heighting accuracy	Number of photo
	X(m)	Y(m)	Z(m)	
Maalen & Johansen (1991)	9		---	1
Jacobsen (1992)	18.6	20.4	46.3	2
Jacobsen & Muller (1988)	8.1	5.4	36.3	3
Konecny et al. (1988)	10.7	10.5	29.9	4
Sirkia & Laiho (1989)	9.5	5.6	50	5

5. TEST DATA

5.1 Test area and data acquisition of KFA-1000 photos

A block of eight KFA-1000 photos in two strips with 60% longitudinal overlap and 15% lateral sidelap was used in the test. The adjacent photo strips had been exposed simultaneously with the KFA-1000 double camera system where the rotational angle between the camera units is 16 degrees. The flying height was 276 km and the image size on the ground was 80*80 km^2. The focal length of the camera was 1009 mm, and the original image scale was about 1:272000. The photos had been taken in 1990 of the South of Iran and the test area is flat. There were not remarkable differences in contrast and sharpness between photos. The radial distortions of the camera lenses were given in 8 different directions with the last digit of 10 microns. The values were given only to the radius length of 140 and 184 mm from the origin of coordinates and the distortion was strongly asymmetric. At the same distance along different radius, the difference in distortion values could be up to 50 microns.

5.1.1 Ground control points

The main problem of handling space photos and images is the availability of GCPs. In this test GCPs have been measured on the model at a scale of 1:40000 aerial photos in DSR14 analytical plotter after completion of inner, relative and absolute orientation. The accuracy of the GCPs was estimated to be better than 1 m.

5.1.2 Solutions of the large format photos

There was no available photogrammetric instrument in Iran of sufficient accuracy that could be used because of the large format of the photos (30*30cm). Ways of overcoming the problems can be as follows: 1) Making a photographic reproduction of the image in suitable pieces, measuring with traditional instruments and pining the pieces together before calculation. 2) Shipping the image to a foreign institution which has image carriers of sufficient size. 3) Reproducing the image photographically from the original 30*30cm^2 size to 23*23 cm^2 to be measurable in a mono comparator. 4) Using overlapping copies $(23*30)_{cm}$ in Planicomp P1, analytical plotter. 5) Scanning the space photos and use the digital photogrammetric and image processing systems. At first method 3 was used. For determination of geometric distortion of camera a grid was used and then the grid and its photo were measured. After computation, it was realized that geometric distortion due to photography is high (150 micron) and the root mean square errors of residuals was 530 micron because of large lens distortion of camera, therefore, method 1 was employed.

5.1.3 Preparation and measurements

Point selection, numbering and pugging were prepared. Artificial points (tie points) drilled into emulsion with PUG V Wild. After calibration, photo coordinates of the 18 pieces of 8 KFA-1000 photos were measured with a monocomparator.

5.1.4 Pinning the pieces together

After making a photographic reproduction of the image in suitable pieces and measuring with traditional instruments, the pieces are then joined together before calculation. The pieces of one KFA-1000 photo pinned with conformal using at least four common points. The result of pinning the 17957 KFA-1000 photo being displayed in Table 3.

Table 3. Results of pinning

Points	Vx(micron)	Vy(micron)
1	1	-1
2	1	7
3	1	-3
4	-2	-2
5	-1	0

5.1.5 Systematic errors of KFA-1000 photos

The additional parameters of radial distortion of the power of five was computed. Film shrinkage is corrected with affine and projective transformation. Affine inner orientation was made with 4 or 5 fiducial marks, the accuracy of the 17957 KFA-1000 photo displayed in Table 4. To take into consideration the linear distortion in any direction, a two dimensional projective transformation with 5 fiducial marks was employed and the accuracy was better than 8 microns. The refraction correction is below 2 micron.

Table 4. Results from the inner orientation

Fiducials	Vx (micron)	Vy(micron)
1	2	2
2	2	3
3	3	-3
4	3	-3
5	-12	1

5.2 TEST AREA AND DATA MATERIALS OF IKONOS GEO IMAGE

The IKONOS Geo panchromatic image that was used in this research covers the Hamedan city in the West of Iran. It was acquired at 7 October 2000. Datum was WGS84 and map projection was U.T.M.. Height range of the study area was 1700 m to 1900 m. The GCPs/ICPs for these tests were extracted from 1:1000 scale digital 3D maps produced by N.C.C. of Iran using 1:4000 scale aerial photographs. The position of the GCPs/ICPs on image were monoscopically measured using the PCI EASI/PACE package, knowing the positions of these points on the ground. Carterra Geo products are georectified that means they are rectified to an inflated ellipsoid and map projected. No terrain model is used so these images are not orthorectified. Accuracy of the Carterra Geo products is specified as 50m CE90 exclusive of terrain displacement (Dial, 2000).

6. GEOMETRIC CORRECTION OF SATELLITE DATA

Different techniques have been developed to represent the platform/sensor/camera imaging characteristics and the geometric relationship between two data source. The methods of geometric rectification include polynomials (conformal, affine,...), multiquadric, rational functions (2D projective, DLT,...), orbital parameter model, multiple projection center model and additional parameter model. All published models are generally classified into either interpolative or parametric groups. The collinearity condition is the basis for parametric models. It is argued that the orbital parameter method is superior than the other methods of geometric correction, since it models the orbit/attitude and combines the GCPs in a simultaneous adjustment. At the present time, most high resolution satellite vendors do not intend to publish their sensor models and precise ephemeris data. This means that a large number of parameters are unknown. There is consequently a need for alternatives approaches geometric correction from HRSI (Fraser, 2000 ; Hanley, 2001).

6.1 Polynomial approach

The polynomial transformation that is commonly used takes the form:

$$\begin{aligned} X &= a_0 \quad (a\,constant\ term) & Y &= b_0 \quad (a\,constant\ term) \\ &+ a_1x + a_2y \quad (linear\ terms) & &+ b_1x + b_2y \quad (linear\ terms) \\ &+ a_3xy + a_4x^2 + a_5y^2 \quad (quadratic\ terms) & &+ b_3xy + b_4x^2 + b_5y^2 \quad (quadratic\ terms) \\ &+ a_6x^2y + a_7xy^2 + a_8x^3 + a_9y^3 \quad (cubic\ terms) + \ldots & &+ b_6x^2y + b_7xy^2 + b_8x^3 + b_9y^3 \quad (cubic\ terms) + \ldots \end{aligned}$$

Where: X and Y are the ground coordinates; x and y are the image coordinates; and $a_i\ and\ b_i (i = i, \ldots n)$ are the transformation parameters.

6.2 Multiquadric approach

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 results in n equations for n unknowns in each set and these can be solved to determine A. The matrix F is symmetric and has zero values along its diagonal. Now the above equations can be solved to produce A and the residual improvements $dX_k\ (where\ k = 1, \ldots n)$ can be modeled as follows: $f_{k1}a_1 + f_{k2}a_2 + f_{k3}a_3 + \ldots + f_{kn}a_n = dX_k$. (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

$$f_j(x', y') : f_1a_1 + f_2a_2 + f_3a_3 + \ldots + f_na_n = dx \quad , f_1b_1 + f_2b_2 + f_3b_3 + \ldots + f_nb_n = dy$$

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 image, an interpolation is carried out according to the model given above (Ehlers, 1997).

6.3 Rational functions

The concept of rational functions was developed by Gyer. If f is a polynomial,

$f(X,Y,Z)= a+b.x+c.y+d.z+e.x.y+f.x.z+g.y.z+h.x+i.y+j.z+k.x.y.z+l.x.y+....$

The image coordinate, x and y, are expressed as quotients of these polynomials, as $x=f1(X,Y,Z)/f2(X,Y,Z)$, $y=f3(X,Y,Z)/f4(X,Y,Z)$. The rational function maps three-dimensional ground coordinates to image space on any differentially perspective imagery, to include panoramic, SPOT, Landsat, strip and frame imageries like KFA-1000.

6.3.1 Direct linear transformation (DLT)

DLT is written as :

$$X=\frac{a_1x+b_1y+c_1z+d_1}{a_3x+b_3y+c_3z+1},Y=\frac{a_2x+b_2y+c_2z+d_2}{a_3x+b_3y+c_3z+1}$$

where x,y and z are the ground coordinates, and eleven linear orientation parameters defining relationship between image space and three-dimensional object space.

6.3.2 Two dimensional projective transformation

Two dimensional projective transformation is a simplified version of DLT in which the third coordinate is considered as constant, and in practice, may not appear at all. Eight linear orientation parameters describes the relationship between the object and image planes ,and can be expressed as follows:

$$X=\frac{a_1x+b_1y+c_1}{a_3x+b_3y+1},Y=\frac{a_2x+b_2y+c_2}{a_3x+b_3y+1}$$

X and Y are image coordinates, and x and y are the ground (object) coordinates.

7. GEOMETRIC ACCURACY TESTS

Table 5 and 6 show the summary of the results of polynomials, multiquadrics 2D projective and DLT methods. Using a 16 terms polynomial transformation, various tests were carried out on the IKONOS Geo and KFA-1000 data.

Table 5. ΔE , ΔN RMSE values achieved in WGS84 coordinates of the KFA-1000 data

Method	Control Points (n=21)			Check Points (n= 7)		
Polynomial	ΔE (m)	ΔN (m)	ΔPl (m)	ΔE (m)	ΔN (m)	ΔPl (m)
3 term (affine)	92.18	97.86	134.44	89.23	107.85	139.98
4 term (xy)	67.66	16.54	69.65	76.18	20.28	78.83
5 term (x^2)	8.65	11.96	14.76	7.82	19.44	20.95
6 term (y^2)	7.95	9.57	12.44	7.63	17.90	19.46
7 term ($x^2 y$)	6.61	9.28	11.39	9.74	17.26	19.82
8 term (xy^2)	4.76	5.67	7.41	9.24	13.11	16.04
9 term ($x^2 y^2$)	4.74	5.39	7.18	8.63	12.84	15.47
10 term (x^3)	4.74	5.37	7.16	8.63	12.98	15.59
11 term (y^3)	4.65	5.35	7.09	8.39	12.95	15.43
12 term (xy^3)	4.61	4.77	6.64	8.70	12.33	15.09
13 term ($x^3 y$)	3.63	2.60	4.47	9.65	12.42	15.73
14 term ($x^2 y^3$)	3.39	2.59	4.27	9.61	12.46	15.74
15 term ($x^3 y^2$)	3.35	2.42	4.13	9.71	11.78	15.27
16 term (x^5)	2.71	1.64	3.17	70.38	61.80	93.66
Multiquadric (3 term)	0.00	0.00	0.00	89.22	107.85	139.97
Multiquadric (6 term)	0.00	0.00	0.00	12.21	11.22	16.58
Multiquadric (10 term)	0.00	0.00	0.00	11.70	12.38	17.03
2 D Projective	0.06	0.08	0.09	1.67	1.16	2.04
D.L.T.	0.05	0.05	0.07	1.76	1.20	2.13

Table 6. ΔE , ΔN RMSE values achieved in WGS84 coordinates of the IKONOS data

Method	Control Points (n=49)			Check Points (n=30)		
Polynomial	ΔE (m)	ΔN (m)	ΔPl (m)	ΔE (m)	ΔN (m)	ΔPl (m)
3 term (affine)	3.73	1.44	4.00	2.45	1.29	2.77
4 term (xy)	3.73	1.41	3.99	2.43	1.28	2.75
5 term (x^2)	3.67	1.33	3.90	2.36	1.26	2.68
6 term (y^2)	1.70	0.62	1.81	1.25	0.71	1.44
7 term ($x^2 y$)	1.33	0.62	1.47	1.22	0.69	1.40
8 term (xy^2)	1.31	0.56	1.42	1.24	0.75	1.45
9 term ($x^2 y^2$)	1.29	0.46	1.37	1.22	0.62	1.37
10 term (x^3)	1.21	0.46	1.30	1.23	0.62	1.38
11 term (y^3)	1.17	0.45	1.25	1.19	0.62	1.34
12 term (xy^3)	1.02	0.44	1.11	1.37	0.63	1.51
13 term ($x^3 y$)	0.95	0.43	1.04	1.39	0.60	1.51
14 term ($x^2 y^3$)	0.86	0.43	0.96	1.37	0.59	1.49
15 term ($x^3 y^2$)	0.84	0.43	0.94	1.35	0.58	1.47
16 term (x^5)	0.81	0.43	0.91	1.32	0.58	1.44
Multiquadric (3 term)	0.00	0.00	0.00	2.41	1.25	2.71
Multiquadric (6 term)	0.00	0.00	0.00	0.58	1.23	1.36
Multiquadric (10 term)	0.00	0.00	0.00	1.21	0.57	1.34
2 D Projective	1.31	3.69	3.91	2.69	0.99	2.86
D.L.T.	0.58	1.46	1.57	0.83	0.76	1.13

7.1 Space Intersection

Two intersecting rays to an object point is considers by DLT equations. Thus a single object point appearing on two photos, have XYZ-coordinates contained in four equations. Accuracy of space intersection for control and check points is shown in Table 7.

Table 7. RMSE values of intersection of control and check points 17957 and 17958 KFA-1000 photos

RMSE	Vx(m)	Vy(m)	Vz(m)
Control points	1.33	2.68	3.18
Check points	6.07	5.86	4.88

8. CONCLUSIONS

Applications to real remotely sensed data acquired from IKONOS and KFA-1000 satellites, indicate that DLT, and multiquadric function, produce good results. The results of DLT is better than 2D projective transformation. These models can be easily used to process images from other high resolution imaging systems. Since the DLT method considers elevation also, the results are better than 2D projective, polynomials and multiquadric methods. With considering information content, KFA-1000 photos can be used for production of imagemap, planimetric map, thematic map and updating of topographic map up to scale of 1:50000. With considering information content, IKONOS images can be used for production of imagemap, planimetric map, thematic map and updating of topographic map up to scale of 1:6000 and smaller.

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