PRECISION RECTIFICATION OF KFA-1000 AND SPOT IMAGES USING THE MULTIQUADRIC AND DLT MODEL OVER A TEST AREA IN IRAN

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ABSTRACT

A block of eight KFA-1000 space photos in two strips with 60% longitudinal overlap and 15% lateral sidelap and SPOT image was planned to be used in the test. KFA-1000 photos covering parts of southern Iran is examined. Using check points for polynomials (Quadratic) RMSE x,y was 20.00 m and 2D projective transformation RMSE x,y was 9.78 m and for DLT RMSE x,y was 8.43 m and for multiquadric transformation RMSE x,y was 8.40 m. Special attention has been given to the quality of ground control points which has usually been a critical point in previous studies concerning the geometric properties of space photos and images. For SPOT images using check points for polynomials and multiquadratic transformation. Multiquadratic method provided better results than polynomials methods(less than 20m).

1 INTRODUCTION

The new generation of commercial one-meter resolution satellite imagery opened a new era for producing large scale digital maps. Due to technical limitation there is still a linear relation between spatial resolution and swath width. Using high resolution systems the number of scenes would have to be increased quadratically for a certain application which causes additional time and costs for buying, storing and processing the data. But the sensor in the medium range like SPOT or KFA-1000 have large swath width. Space images are available today and have provided a considerable progress in mapping and map revision at scales 1:10000 and smaller. Relatively high positional accuracy for such maps can be reached without much, problems. The products of space camera systems, such as the MKF6, KATE-150, KATE-200, MK4, TK-350, KFA-1000, KFA-3000 and KWR-1000 (KVR-1000) are available worldwide.

2 THE GEOMETRY OF SPACE PHOTOS

A frame is formd 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 this case there is no need to introduce a time parameter into the mathematical model. 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. These differences are illustrated in Table 1. The KFA-1000 is a Russian camera which gives large scale photos but has a long principal distance. The camera also requires the film to be returned to earth which means short missions of complex operations to reject and recover the film.

	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
principal point (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

Table 1. Photographic systems used in space

The highest spatial resolution space photos available for commercial use are still the Russian photos. The distribution problem has been solved by cooperation with Western companies. The images of the panoramic KVR-1000 camera are available as digitized 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, this is not possible for a covered area of just 22 km * 22 km, otherwise the imaging interval should be 1.2sec. The KFA-3000 is stearable but because of the poor height to base relation the vertical accuracy is limited to approximately +/-15 m, so for orthophoto generation or mono-plotting a vertical accuracy of two times the required horizontal accuracy must be guaranteed.

3 KFA-1000 PHOTOS AND SPOT IMAGES

The KFA-1000 camera system is originally planned for interpretation purposes. Much interest has been arisen for its possible use in medium-scale topographic mapping because of a very good resolving power of the system (about five meters on the ground). 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 SPOT. They do not have problems like shifts or variations between successive sensor orientations. However, they have problems like photographic processing and storage. The vertical accuracy on the other side is limited by mapping with space images. For map revision the vertical component is unimportant 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 SPOT is optimal but the difference in time between the recording of the same area by SPOT can cause some problems. For example, the reflectance of the ground can change. For KFA-1000 photos such a problem with the stereo effect do not exist. A comparison of the space photos was resulted to the best interpretation of objects with photos like KFA-1000, followed by SPOT, LFC, MC and KATE 200 (Jacobsen and Muller,1988).

4 SOME CASE STUDIES USING KFA-1000

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

	Planimetric Accuracy		Heighting Accuracy	Number of Photo
	X(m)	Y(m)	Z(m)	
Maalen & Johansen	9		---	1
Jacobsen	18.6	20.4	46.3	2
Jacobsen & Muller	8.1	5.4	36.3	3
konecny et al.	10.7	10.5	29.9	4
Sirkia & Laiho	9.5	5.6	50	5

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

5 TEST AREA AND DATA ACQUISITION

A block of eight KFA-1000 photos in two strips with 60% longitudinal overlap and 15% lateral sidelap was planned to be 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 unit is 16 degrees. The flying height had been 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 no knowledge of which copies they were, but all of them had been stored in the same place and in the same way. 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. All these made the interpolation very different and inaccurate.

6 GROUND CONTROL POINTS(GCPs)

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 two color films of the KFA-1000 supported the object identification.The accuracy of the GCPs was estimated to be better than 1 m.

. 7 SOLUTIONS FO 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. The disadvantage of this solution is the greater possibility of identification errors by operators who may be unfamiliar with check points used. 3)The image photographically reproduced 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. 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, is was realized that geometric distortion due to photography is high (for example150 micron) and the root mean square errors of residuals was 530 micron because of large lens distortion of camera, therefore, method 1 was employed.

8 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. For SPOT we uses of measured coordinates monoscopically on image respect to the top corner of the scene using the PCI EASI/PACE package running on PC.

9 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 transformation using at least four common points. The resuls of pinning the 17957 KFA-1000 photo being displayed in Table 3.

Points	VX(micron)	VY(micron)
1	1	-1
2	1	7
3	1	-3
4	-2	-2
5	-1	0

Table 3. Results of pinning

10 SYSTEMATIC ERRORS OF KFA-1000 PHOTOS

The additional parameters of radial distortion of the power of five are computed. Film shrinkage is corrected with an affine and projective transformation. The refraction correction is below 2 micron (jacobsen,1992). For usual aerial photos the geometric differences are compensated by the earth curvature correction, but this is not sufficient for space photographs .If the coordinates transformed to a tangential coordinate system of the earth ellipsoid, earth curvature correction is not required in this case.

10.1 Uniform and Non-Uniform Distortion

Shrinkage of uniform nature would produce a constant scale error in any direction.To model such a direction, a simple similarity transformation will suffice: *X=a.x+b.y+c ,Y=a.y-b.x+d*.Conformal inner orientation was made with 3 fiducial marks. The accuracy was better than 4 microns. The change of shape arises because allowance is made for different scale factors in the x and y and also be used to compensate for the non-orthogonality of the image coordinates measuring devices. This can be modeled mathematically using the familiar affine transformation. *X=a.x+b.y+e ,Y=c.x+d.y+f.* Affine inner orientation was made with 4 or 5 fiducial marks, the accuracy of the 17957 KFA-1000 photo displayed in Table 4.

Fiducials	VX (micron)	VY(micron)
1	2	2
2	2	3
3	3	-3
4	3	-3
5	-12	1

Table 4. Results from the inner orientation

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.

11 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. It is essential for the precision image geometric correction process in regular pre-processing operations to obtain the best accuracy with the use of minimum number of GCPs. 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. An interpolative model is a model which is interpolative in nature, and 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. We can have an orbit attitude modeling approach with which we can rectify different image configurations like strip, twin strip, block etc., with a single GCP. The obtained results indicate that a single surveyed GCP is enough to obtain the accuracy equal to the resolution of the sensor. Attainable geometric accuracy will increase as point identification and detecability is increased. The rule of thumb for choosing a pixel size for a given map scale, is that 0.05 up to 0.1mm of scale number should be equal to the proposed pixel size. The image contents can be related to the resolution. Of course the radiometric quality and the spectral information is also important, but this corresponds to the band width of 0.05 to 0.1mm pixel size. Also the stereoscopic impression is supporting the object identification and the required map contents is as different as the object structure itself. Only sensor systems with pixel sizes better than 6 m are suitable for production of topographic maps at a scale of 1:50000. Updating many be possible with 6 m pixel size for a larger scale such as 1:25000. The lower resolution images may be useful, however intensive field checks are required. The overall procedure of using lower resolution images is not recommended. Pixel sizes of 1m or better fulfill the capability of mapping at scales 1:10000 or updating scales 1:5000. But high resolution data increase the need for higher accuracy of data modelling.

11.1 Polynomial Approach

The polynomial transformation that is commonly used takes the form:

$$
\begin{aligned}
X = {} & a_0 \quad (a\ constant\ term) \\
& + a_1 x + a_2 y \quad (linear\ terms) \\
& + a_3 xy + a_4 x^2 + a_5 y^2 \quad (quadratic\ terms) \\
& + a_6 x^2 y + a_7 xy^2 + a_8 x^3 + a_9 y^3 \quad (cubic\ terms) + \ldots
\end{aligned}
$$

$$
\begin{aligned}
Y = b_0 &\quad (a\ constant\ term) \\
&+ b_1 x + b_2 y \quad (linear\ terms) \\
&+ b_3 xy + b_4 x^2 + b_5 y^2 \quad (quadratic\ terms) \\
&+ b_6 x^2 y + b_7 xy^2 + b_8 x^3 + b_9 y^3 \quad (cubic\ terms) + \ldots
\end{aligned}
$$

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. It is most helpful when deciding which of these terms should actually be used in the transformation of image coordinates to terrain coordinates to understad the effects of each term on the transformation and the pattern of distortion or displacement that is modelled or corrected by each term.

11.2 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 modelled so that they can be calculated from F, where [dX]=F.A and [dY]=F.B. For the [dX] values the relationship is:

$$
\begin{bmatrix} dX_1 \\ dX_2 \\ . \\ . \\ . \\ dX_n \end{bmatrix} = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ . & & & \\ . & & & \\ . & & & \\ f_{n1} & f_{n2} & \cdots & f_{nn} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ . \\ . \\ . \\ a_n \end{bmatrix}
$$

This results in n equations for n unknowns in each set and these can be solved to gain values for 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 modelled 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. Again the residual improvements $dY_k\ (where\ k = 1, \ldots n)$ can be modelled as follows: $f_{k1} b_1 + f_{k2} b_2 + f_{k3} b_3 + \ldots + f_{kn} b_n = dY_k$, 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

$f_j(x', y') : f_1 a_1 + f_2 a_2 + f_3 a_3 + \ldots + f_n a_n = dx$, $f_1 b_1 + f_2 b_2 + f_3 b_3 + \ldots + f_n b_n = dy$

Now the true location of each point can be calculated using the improvement vectors(dx,dy)asfollows: $(X, Y) = (x', y') + (dx, dy)$ .If point *(X,Y)* is a GCP with coordinates (X_k, Y_k) , a perfect fit results. For all other points in the image, an interpolation is carried out according to the multiquadric interpolation model given above. The interpolation coefficents f_j provide a distance weighting function. The great advantages of the multiquadric algorithm are that :i) it describes a continuouse interpolation function; ii) all GCPs contribute to the geometric transformation; and iii) the image geometry can be wrapped in any given constraint.

11.3 Rational Functions

The concept of rational functions was developed by Gyer. If the 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.

11.3.1 Two Dimensional Projective Transformation

Two dimensional projective transformation is a simplified version of the well known DLT in which the third coordiante (dimension) is considered as constant, and in practice, may not appear at all. It describes the relationship between the object and image planes ,and can be expressed as follows:

$$X = \frac{a_1 x + b_1 y + c_1}{a_3 x + b_3 y + 1}, Y = \frac{a_2 x + b_2 y + c_2}{a_3 x + b_3 y + 1}$$

where *a1,a2,a3,b1,b2,b3,c1and c2* are the projective parameters, x and y are image coordinates, and X and Y are the ground (object) coordinates. With projective transformation the ground coordinates of tie points and relative, fitting and absolute accuracy (check points) are computed. The absolute accuracy is better than 10 m. Summery of results from the fitting accuracy of 8 KFA-1000 photos was displayed in Table 5.

Number of photo	SX(m)	SY(m)
17956	2.55	2.02
17957	16.55	13.68
17958	19.12	24.68
17959	14.67	12.86
18134	5.67	4.50
18135	14.22	16.13
18136	21.61	13.34
18137	18.21	22.67

Table 5. Summery of results the fitting accuracy

Block adjustment with conformal transformation and relative, fitting and absolute accuracy was computed. In Table 6 the results of two transformations are shown.

Transformation :	Conformal	2D Projective		
Accuracy	Sx,y(m)	Sx (m)	Sy(m)	Sx,y(m)
Fitting	55.97	14.07	14.11	19.93
Relative	35.64	21.69	27.27	34.84
Absolute	78	5.46	8.12	9.78

Table 6. Summery of results the conformal and projective transformation

11.3.2 Three-Dimensional Projective Transformation (DLT)

Direct linear transformation model originally developed by Karara and Abdel Aziz (1979) and much used with non-metric cameras in close-range photogrammetry .The projective relations between arbitrary point coordinates (x,y) in the 2D plane space (the photo plane) are written as :

$$X = \frac{a_1 x + b_1 y + c_1 z + d_1}{a_3 x + b_3 y + c_3 z + 1}, Y = \frac{a_2 x + b_2 y + c_2 z + d_2}{a_3 x + b_3 y + c_3 z + 1}$$

where X,Y and Z are the ground coordinates, and *a1, a2, a3, b1,b2, b3, c1, c2, c3, d1and d2* are the eleven linear orientation parameters defining the relationship between two dimensional image space and three-dimensional object space.These parameters can be computed through the use of a suitable bundle adjustment program and an appropriate number of GCPs. The results of DLT is better than 2D projective transformation.

11.3.2.1 Space Intersection

Two intersecting rays to an object point may be represented mathematically by DLT equations.Thus a single object point appearing on two phtographs, will have XYZ-coordinates contained in four equations. Accuracy of space intersection for control points and check points is shown in Table 7 and 8.

VX(m)	VY(m)	VZ(m)
2.71	4.06	-4.98
-0.34	-2.09	1.25
-1.70	-1.80	3.12
-1.12	-0.29	0.84
-0.65	-1.54	1.74
0.49	1.12	-1.33
0.18	0.44	-0.48
-0.59	5.05	-5.75

Table 7. Residuals of intersection of control points 17957 and 17958 KFA-1000 photos

	VX(m)	VY(m)	VZ(m)
	19.12	-5.52	-12.10
	6.86	16.86	-5. 93
	-0.00	3.06	4.04
STD	6.07	5.86	4.88
MEANS	2.26	1.76	-1.78

Table 8. Residuals of intersection of check points 17957 and 17958 KFA-1000 photos

12 SUMMERY OF OTHER EXPERIMENTS

Table 9 and 10 shows the summary of the results of polynomials and multiquadric methods.

Methods	No Control Ps	No Control Ps	RMSof control Ps $\delta_X, \delta_Y, \delta_{XY}$	RMSof check Ps $\delta_X, \delta_Y, \delta_{XY}$
Linear	30	8	84.02 16.09 85.54	72.94 18.85 75.33
Quadratic	30	8	41.75 6.18 42.20	57.50 09.71 58.31
Cubic	30	8	27.50 5.37 28.01	38.37 07.61 39.11
Quartic	30	8	13.96 4.92 14.80	27.77 07.02 28.64
Quintic	30	8	10.77 4.43 11.64	26.06 05.90 26.71
Multiquadric	30	8	0.32 0.07 0.32	15.49 08.25 17.55

Table 9. Residuals of check and control points of SPOT image(unit is m)

Methods	No Control Ps	No Control Ps	RMSof control Ps $\delta_X, \delta_Y, \delta_{XY}$	RMSof check Ps $\delta_X, \delta_Y, \delta_{XY}$
Linear	23	5	90.70 9.60 120.7	70.00 142.7 158.9
Quadratic	23	5	07.70 09.40 12.10	05.20 19.30 20.00
Cubic	23	5	05.30 05.40 07.60	13.70 15.40 21.00
Quartic	23	5	04.40 03.50 05.60	16.60 11.30 20.10
Quintic	23	5	03.60 01.50 03.90	390.0 209.0 442.5
Multiquadric	23	5	00.70 00.40 00.80	07.40 04.00 08.40

Table 10. Residuals of check and control points of KFA-1000 photo(unit is m)

13 Conclusions and Recommendations

This project described the interpolative mathematical models for geometric corrections of sapce photos and images. It is important to note that polynomials are mathematically unconstrained between control points such that higher order polynomials will begin to introduce undesireable oscillations. The application of the multiquadric method in the image registeration and rectification is suitable, than using global polynomials or local piecewice methods. For KFA-1000 photos with 2D and 3D projective and multiquadric for independent check points is better than 10m. Projective transformation with a priori affine or projective inner orientation gave better results than without it. KFA-1000 photos give better results than SPOT image. KFA-1000 photos can be used for production of photomap, planimetric map, thematic map and updating of topographic map up to scale 1:50000. As the base/height ratio of KFA-1000 is rather poor, high accuracy of DEM is not possible to achieve. Nevertheless, DEM elaborated analytically or digitally with accuracy approx. 30 m could be generated.

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