

TESTING GEOMETRIC ACCURACY OF SPOT IMAGERIES

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ABSTRACT

Two SPOT Satellites are orbiting the space, at the present time, and collecting information about the Earth's surface. The first satellite was launched in February 1986 and the second followed in January 1990. SPOT images have superior ground resolution in comparison with other commercial satellite imageries.

This paper summarizes results of an investigation carried out to assess the planimetric geometric accuracy of SPOT imageries and to test different mathematical models, which usually used in conventional photogrammetry, for SPOT images rectification and transformation.

Two SPOT scenes, in photographic formats, are used for this investigation. Image co-ordinates are measured on a WILD-BC-2 analytical plotter. Ground control points are derived from 1:50000 scale topographic maps. Two dimensional similarity and affine transformations in addition to second-order polynomials with variable degrees are used to transform SPOT image co-ordinates into ground co-ordinates. Residuals and their root mean-squares, with different number and configuration of ground control points, are computed and analysed. Root mean-square positioning error of 27.0 m. was obtained.

1- INTRODUCTION

The SPOT sensors provide images of the earth surface in panchromatic (P) mode, with Instantaneous Field of View (IFOV) of 10 m., and in the multispectral (XS) mode, with 20 m. IFOV. The SPOT satellite has an altitude of about 832 km. and covers the earth's surface in 26-days. With the availability of two satellites, the repetitive coverage for any point on the earth's surface may be reduced to 13-days.

SPOT is the first space imaging system with stereoscopic capability in addition to its continuous global coverage. A mirror situated in front of the image collecting system (the HRV), allows for recording of images of the same portion of ground surface from two, or more, different imaging (observation) points at different times and with different look angles.

Due to a, relatively, high ground resolution, stereoscopic capability, and availability, SPOT images are very attractive for mapping and maps revision applications. Research works carried out indicated that SPOT images can be used for topographic mapping and maps revision for 1:50000 and smaller scales. Mapping with larger scales requires high geometric accuracy. Accordingly, more research works are needed to investigate the possibility of enhancing SPOT images geometric capability in order to meet higher geometric accuracy requirements.

In this paper, five different types of mathematical models are used for rectification and for transformation of SPOT image co-ordinates into ground co-ordinates. Each mathematical model was applied with different numbers and different configurations of ground control points. Residuals and their root mean-squares values are computed and analysed to assess SPOT images planimetric accuracy.

2- DATA AND OBSERVATION

2.1- SPOT Imageries:

Two SPOT imageries (Scene NO. 116/291) cover the area of South West of Sinai are used in this investigation. Geographic co-ordinates of the centers of the two imageries are (29 28' N, 33 13'E) for the left and (29 28' N, 33 21' E) for the right image. The two imageries were collected by the High Visible Resolution (HRV-2) sensor on July 1987. They are imaged in the panchromatic (P) mode with 10 m. IFOV and with an approximate scale of 1:400,000. The two SPOT imageries were processed as "Level 1A", where primary geometric correction was applied. They are recorded on "Medium" (241 mm x 241 mm) photographic films with 50 mm fiducial marks provided on the image corners.

The geographic area covered by the two images are a remote desert with limited cultural features, except some paved roads and desert tracks. This represents a great difficulty in identifying a reasonable number of ground control points which can be measured on both SPOT images and topographic maps with certainty. Intersections of roads, tracks, valleys and drainage channels in addition to monuments of old triangulation points on mountains peaks are the most convenient positions of control points in

this desert environment. About 100-positions were identified in each SPOT image as suitable ground control points.

Image co-ordinates of identified control points were measured on a WILD BC-2 analytical plotter by employing the "Comparator Mode". Each point was measured 3-times with a standard deviation of 5 μ m. Misidentification is the most serious problem and the main source of errors in measured image co-ordinates.

2.2 Ground and Maps Information:

Ground control points were derived from the Egyptian Military Survey 1:50000 scale topographic maps. Planimetric co-ordinates (Eastings and Northings) of about 150-ground control points were measured and digitized on the plotting table of the WILD BC-2 analytical plotter which has been used for measuring image co-ordinates. Map co-ordinates of each point were measured 3-times with a standard deviation of 0.35 mm on map scale (17.5 m. on ground). This, however, is a low precision compared with, relatively, high measurement precision obtained in other investigation (2). Low precision of map co-ordinates in this investigation is resulted, mainly, from increasing the number of control points and due to misidentification errors in a large number of points. The nature of the desert area covered by the two SPOT imageries and the type of ground control points which can be identified in this environment are contributed, largely, to this low measurement precision of map co-ordinates.

3- IMAGE RECTIFICATION AND TRANSFORMATION

From past experiences with the geometrical properties of orbiting space imageries (5), one can expect that the main geometric error in SPOT imageries comes, mainly, from differences in image scales in the along and the cross-track directions in addition to non perpendicularity between image-axes in these two directions. These are first-order errors and can be rectified by simple mathematical models such as two-dimensional Affine Transformation. Another minor, second-order, geometrical errors resulted from small altitude and attitude variations during collection of a complete (60 km. x 60 km.) image may, also, exist.

As far as the second-order geometrical errors are concerned, second-order polynomials, with a variable number of parameters, can be used for image rectification. Other more sophisticated mathematical models, such as conventional and modified Colinearity Equations can be, also, used if more rigorous rectification is required.

In this investigation, two-dimensional similarity (Helmert's) transformation is used to transform image co-ordinates into ground co-ordinates. Two-dimensional, six-parameters, affine transformation, also, is used to rectify first-order geometrical errors. Second-order polynomials, with four, five, and six-parameters in each direction, are used for image rectification and transformation. They can take care of second-order (minor), in addition to major, geometric errors. When applying each one of these mathematical models, variable numbers of ground control points, starting with the minimum

control requirements, are tested and obtained results are analysed.

The forms of used mathematical models can be summarized as follows:-

- (a) For the 4-parameters, two-dimensional, similarity transformation, relationships between measured image co-ordinates (x,y), for an image point (i), and ground co-ordinates (E,N) for the same point may be expressed as:

$$\begin{vmatrix} E \\ N \end{vmatrix}_i = \begin{vmatrix} a & -b \\ b & a \end{vmatrix} \cdot \begin{vmatrix} x \\ y \end{vmatrix}_i + \begin{vmatrix} E_o \\ N_o \end{vmatrix},$$

- (b) For the 6-parameters two-dimensional affine transformation, the relationships are in the form:

$$\begin{vmatrix} E \\ N \end{vmatrix}_i = \begin{vmatrix} a & -b \\ c & d \end{vmatrix} \cdot \begin{vmatrix} x \\ y \end{vmatrix}_i + \begin{vmatrix} E_o \\ N_o \end{vmatrix}, \text{ and}$$

- (c) The second-order polynomials are arranged in the form:

$$E = a + a_1 x + a_2 y + a_3 x^2 + a_4 xy + a_5 y^2,$$

$$N = b + b_1 x + b_2 y + b_3 x^2 + b_4 xy + b_5 y^2,$$

where x,y and E,N are as described before, and a,b,c,d,Eo,No,..... are the transformation constants.

4- RESULTS

Image co-ordinates measured on each SPOT image are fitted into ground co-ordinates obtained from topographic maps by employing the above mentioned mathematical models. Variable numbers of control points are used and the least-squares method is employed for the determination of the transformation parameters in each case. Residuals and their root mean-squares are computed for check points.

In order to isolate points which have large identification errors, the 4-parameters similarity transformation was applied, first, on all measured ground control points and residuals are computed. About 30 % of the points are having large residuals (more than 100 m.) and they were eliminated from the process. The remaining, relatively good, ground points, 68-points for each image, are processed as described before. Analysis of residuals obtained, after applying different mathematical models, indicted that some of those, relatively good, points have large gross identification errors. So, another round of adjustment is performed after eliminating points with residuals larger than 50 m. The value of 50 m is based on the assumption of expected errors of 5 m in measurement of image co-ordinates (half of the IFOV), and 17.5 m in measurement of map

co-ordinates. This will lead to a maximum, expected, observational vector error of about 25 m.

Tables (1) and (2) give an example of obtained residuals in those points when applying different mathematical models. A summary of the whole procedure, where root mean-squares of residuals obtained after applying different mathematical models with different number of ground control points, is given in Tables (3) and (4).

Table (1) Residuals and Their Root Mean-Squares (in m.) After Applying Different Transformation Models For the Best 25 Reference Points and all Points Used as Control Points in SPOT Imagery Number (1).

Point Number	TRANSFORMATION MODELS								
	2-Dimensional Similarity		2-Dimensional Affine			6-Parameters Second-order Polynomials			
	*Ve	Vn	Vr	Ve	Vn	Vr	Ve	Vn	Vr
1	-36.10	-2.00	36.15	-32.38	15.71	35.99	-25.40	8.02	26.64
5	7.96	-29.96	31.00	10.07	-14.03	17.27	17.62	-14.72	22.96
7	21.34	2.72	21.51	26.76	18.05	32.28	20.24	10.06	22.60
8	-20.22	-9.20	22.21	-14.67	4.72	15.41	-24.75	-1.30	24.78
9	49.11	11.32	50.40	55.54	20.12	59.07	36.53	19.11	41.22
16	19.75	-34.12	39.42	18.14	-23.02	29.31	23.07	-11.41	25.74
17	-35.73	-29.98	46.64	-39.36	-15.53	42.32	-13.94	-2.58	14.18
28	6.95	15.90	17.36	0.43	16.44	16.45	-11.54	30.04	32.18
31	-18.94	-26.17	32.31	-6.54	-26.00	26.81	-16.85	-29.20	33.71
32	-13.55	6.25	14.93	-1.89	5.89	6.18	-11.56	4.22	12.30
33	21.77	0.02	21.77	28.34	-2.13	28.42	16.85	2.90	17.10
35	-37.96	23.55	44.67	-33.35	16.02	37.00	-35.38	20.13	40.71
36	7.22	-5.65	9.16	12.21	-14.88	19.24	16.28	-12.21	20.35
37	-30.11	4.24	30.41	-24.62	-5.13	25.15	-18.68	-2.63	18.87
38	15.59	28.48	32.47	21.05	17.31	27.25	33.45	18.10	38.04
39	-38.42	31.36	49.59	-33.42	18.87	38.37	-17.40	18.08	25.09
40	-0.94	-2.33	2.51	4.89	-14.96	15.74	24.55	-15.74	29.16
41	-40.74	13.41	42.89	-35.41	-1.50	35.44	-7.49	-5.42	9.24
60	7.09	51.42	51.91	0.12	39.91	39.91	-19.39	33.01	38.28
89	49.11	11.32	50.40	-6.40	15.65	16.91	-19.56	16.28	25.45
95	14.89	-37.09	39.97	4.18	-36.22	36.46	-1.24	-22.01	22.04
98	56.67	-23.38	61.30	48.64	-33.19	58.88	26.63	-37.26	45.80
99	37.63	-12.56	39.67	27.67	-21.78	35.21	3.49	-26.39	26.62
104	10.93	15.71	19.14	-19.09	13.84	23.58	7.97	2.62	8.39
107	-14.90	-11.69	18.94	6.03	6.03	12.70	-4.19	-1.69	4.52
r.m.s.	27.21	22.13	35.07	25.52	19.28	31.98	20.38	17.99	27.18

* Ve = Residuals in Eastings,
 Vn = Residuals in Northings,
 Vr = Square Root of (Ve**2+Vn**2), and
 r.m.s = Root Mean-Squares Of Residuals.

Table (2) Residuals and Their Root Mean-Squares (in m.) After Applying Different Transformation Models For the Best 36 Reference Points and all Points Used as Control Points in SPOT Imagery Number (2).

Point Number	TRANSFORMATION MODELS								
	2-Dimensional Similarity			2-Dimensional Affine			6-Parameters Second-order Polynomials		
	*Ve	Vn	Vr	Ve	Vn	Vr	Ve	Vn	Vr
20	-42.76	2.78	42.85	8.51	-14.24	16.59	-8.14	-22.63	24.05
24	16.33	18.78	24.89	47.15	6.93	47.66	34.95	-0.91	31.97
26	-3.40	35.13	35.29	29.37	36.36	46.74	13.90	29.03	32.19
28	6.83	-6.33	9.32	49.93	-4.49	50.13	30.74	-11.09	32.69
29	-45.33	8.21	46.07	-2.29	-24.93	25.03	3.29	-26.72	26.92
31	-46.41	26.64	53.51	-7.34	-3.84	8.29	-4.23	-6.38	7.66
32	-75.35	57.79	94.96	-38.83	28.86	48.38	-36.96	25.95	45.16
33	-35.11	38.25	51.92	-6.26	19.00	20.01	-12.68	13.08	18.21
35	12.67	32.51	34.89	17.13	19.54	25.99	11.83	14.48	18.70
36	3.40	15.16	15.53	-0.29	2.41	2.43	-4.65	-1.62	4.92
37	-17.36	17.02	24.31	-21.72	3.52	22.00	-25.57	-0.10	25.57
38	17.76	46.82	50.07	5.02	34.31	34.67	1.26	31.56	31.59
40	27.09	23.40	35.81	7.62	11.04	13.42	3.99	9.38	10.19
42	32.56	-3.75	32.78	-0.30	-14.90	14.90	-4.95	-14.74	15.55
45	41.31	-17.80	44.98	7.36	-40.35	41.05	11.27	-31.57	33.52
46	3.91	20.51	20.88	-35.04	-2.97	35.17	-30.87	8.19	31.94
48	-29.42	55.16	62.52	-21.44	19.93	29.27	-2.70	28.09	28.22
51	23.19	23.95	33.34	3.18	-7.89	8.51	19.02	5.56	19.81
52	28.04	-0.12	28.04	5.61	-34.95	35.40	26.06	-17.49	31.39
56	-1.18	11.27	11.33	7.31	9.10	7.94	-0.83	-3.73	3.83
57	-0.72	-12.35	12.37	6.96	-17.54	18.87	-1.81	-24.83	24.89
59	6.25	24.14	24.94	-2.32	39.16	33.24	-6.66	26.09	26.93
60	-16.59	28.14	32.67	-29.56	37.16	47.48	-33.59	30.08	45.09
76	153.92	-27.15	156.29	36.80	11.41	38.52	42.70	6.88	43.25
81	-60.52	-34.42	69.62	-12.56	-4.77	13.43	-11.06	8.31	13.83
82	-36.45	-31.51	48.18	6.20	-2.94	6.87	8.36	7.57	11.28
83	-49.35	-32.93	59.33	-10.35	-2.41	10.63	-3.85	9.06	9.84
86	-35.63	-21.82	41.78	4.61	5.73	7.35	6.29	14.65	15.95
87	-46.63	-58.93	75.15	-23.30	-32.93	40.34	-18.01	-29.21	34.31
88	-27.58	-31.61	41.95	-1.35	-8.45	8.56	-0.46	-6.27	6.28
90	11.42	-62.71	63.74	-6.69	-32.42	33.10	11.39	-33.04	34.94
92	-23.85	-43.90	49.96	-34.88	-11.77	36.81	-14.28	-10.13	17.51
93	2.74	-5.83	6.44	-32.03	26.77	41.75	-10.55	25.16	27.28
97	42.74	-20.70	47.49	45.82	-11.50	47.24	40.17	-18.31	44.14
98	-2.83	-34.61	43.73	-7.88	-24.69	25.92	-12.08	-31.60	33.83
109	167.03	-38.90	171.50	5.65	-1.05	5.74	-21.27	-2.57	21.42
r.m.s.	48.83	31.42	58.07	22.10	20.72	30.30	19.15	19.38	27.25

* Ve = Residuals in Eastings,
 Vn = Residuals in Northings,
 Vr = Square Root of (Ve**2+Vn**2), and
 r.m.s. = Root Mean-Squares Of Residuals.

Table (4). Root Mean-Squares of Residuals (in m) in Reference points Computed After Applying Different Transformation Models and Using Variable Numbers of Ground Control Points in SPOT Imagery No. (2).

* IN IK	Transformation Models										
	2-Dimensional Similarity		2-Dimensional Affine		Second-Order Polynomials						
	*RE	RN	RE	RN	4-Terms	5-Terms	6-Terms	RE	RN	RE	RN
2	89.9	51.5	--	--	--	--	--	--	--	--	--
3	77.5	42.7	96.9	57.0	--	--	--	--	--	--	--
4	68.6	45.7	45.6	46.3	--	--	--	--	--	--	--
6	64.9	44.6	45.5	41.9	86.5	71.8	64.5	79.4	78.4	88.9	88.9
68 10	64.9	45.8	47.2	41.0	63.7	40.3	76.0	45.2	76.7	77.1	77.1
15	65.3	42.9	48.3	33.1	55.6	38.3	44.1	44.1	48.7	42.1	42.1
20	76.5	43.0	50.4	32.2	62.4	33.1	46.8	34.5	43.8	44.3	44.3
30	62.4	48.3	47.8	30.8	62.4	30.4	46.3	29.1	43.9	29.0	29.0
68	62.1	40.7	42.2	29.6	42.2	29.1	33.8	28.3	33.4	28.3	28.3
2	48.8	95.6	--	--	--	--	--	--	--	--	--
3	61.4	89.2	33.5	28.6	--	--	--	--	--	--	--
4	46.9	69.8	29.9	27.0	93.4	71.4	--	--	--	--	--
6	48.3	67.6	26.1	32.9	56.8	33.8	62.8	65.6	91.3	89.3	89.3
36 10	54.5	59.6	28.7	25.5	53.9	32.3	56.8	49.6	58.9	86.2	86.2
15	52.7	60.7	27.8	24.8	49.3	21.9	59.8	30.6	40.8	77.7	77.7
20	50.0	57.9	27.3	26.2	52.8	26.4	67.8	20.9	68.7	67.7	67.7
30	45.5	38.8	22.3	21.9	22.6	20.8	20.1	19.8	19.3	21.2	21.2
36	48.8	31.4	22.1	20.7	21.9	20.5	19.8	19.6	19.1	19.4	19.4

* RE = Root Mean-Square Error in Easting Direction,
 RN = Root Mean-square Error in Northing Direction.
 IN = Number of Reference Points, and
 IK = Number of Control Points

Table (3). Root Mean-Squares of Residuals (in m) in Reference points Computed After Applying Different Transformation Models and Using Variable Numbers of Ground Control Points in SPOT Imagery No. (1).

* IN IK	TRANSFORMATION MODELS										
	2-Dimensional Similarity		2-Dimensional Affine		Second-Order Polynomials						
	*RE	RN	RE	RN	4-Terms	5-Terms	6-Terms	RE	RN	RE	RN
2	58.5	49.3	--	--	--	--	--	--	--	--	--
3	57.3	49.8	49.7	33.3	--	--	--	--	--	--	--
4	65.8	54.3	49.2	38.7	--	--	--	--	--	--	--
6	69.4	55.2	57.6	35.0	76.0	38.6	86.6	38.6	78.0	98.3	98.3
68 10	77.4	41.6	51.6	32.0	45.9	41.9	76.0	40.0	72.3	88.2	88.2
15	85.7	33.0	48.9	29.9	--	--	--	--	71.1	86.4	86.4
20	65.3	44.5	45.0	27.5	--	--	--	--	70.8	81.6	81.6
30	50.6	49.4	44.4	27.1	--	--	61.5	61.3	68.7	61.6	61.6
68	53.1	38.8	42.8	26.0	--	--	40.1	25.6	37.5	25.0	25.0
2	27.3	29.9	--	--	--	--	--	--	--	--	--
3	28.8	31.1	34.5	20.0	--	--	--	--	--	--	--
4	27.4	32.1	53.7	38.3	91.0	28.0	--	--	--	--	--
6	27.4	27.1	49.0	36.5	37.0	25.9	32.7	29.4	98.6	75.1	75.1
10	27.3	28.7	33.2	23.8	24.7	24.4	26.7	24.8	26.1	47.1	47.1
15	28.4	22.4	27.8	19.7	--	--	22.8	20.7	26.1	47.1	47.1
20	28.1	22.0	26.2	19.8	--	--	21.7	19.3	21.4	19.5	19.5
25	27.2	22.1	25.5	19.3	21.4	18.5	20.5	18.0	20.4	18.0	18.0

* RE = Root Mean-Square Error in Easting Direction,
 RN = Root Mean-square Error in Northing Direction.
 IN = Number of Reference Points, and
 IK = Number of Control Points.

5- DISCUSSION AND CONCLUSIONS

Obtained results indicated that, for 68-ground points in each SPOT image, the best r.m.s. values of vector errors are 45.2 m and 50.2 m in image one and image two respectively.

For reduced set of points (25-points for image one and 36-points of image two), the best r.m.s. values of vector errors are 27.2 m in the two images. This error is, approximately, equals to the maximum expected observation error. This indicates, that SPOT images can be rectified where all sensor's geometric errors can be removed by using conventional photogrammetric mathematical models.

Results, also, indicated that affine transformation, with 4 to 6 well-identified ground control points, is quite sufficient for SPOT image rectification. Analysis of residuals revealed that, when applying polynomials with more than three parameters, a large number of ground control points are needed and the control points must be well distributed near the image corners. Points with gross identification errors will affect all points close to their positions and may cause false results.

It can be concluded that SPOT imageries possess high geometric accuracy and suitable, geometrically, for topographic mapping and for maps revision at scales of 1:50000 and smaller. Attainable geometric accuracy will increase as point identification and detectability is increased. In order to increase points identification and detectability, image enhancement is recommended to be performed before any further photogrammetric processing is applied.

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