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PLANIMETRIC ACCURACY OF RECTIFIED SPOT IMAGERY

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ABSTRACT

Topographic mapping from space imagery has become possible on an operational basis using the SPOT system. The quantitative use of SPOT images requires that the inherent geometric distortions be corrected to a desired map projection. The most commonly used modeling technique is to apply low-order polynomials using least squares method and ground control points to empirically correct these distortions. The purpose of this paper is to determine the planimetric accuracy of SPOT images obtained using the polynomial rectification model, and to study the effect of the number, distribution, and accuracy of ground control points on the spatial accuracy of SPOT imagery.

A SPOT panchromatic image covering the area of Mahallet Roh town, El-Gharbiia, Egypt was used, and five low-order polynomials were applied. Up to twenty- five GCPs with different distributions were employed. The results show the relations between each factor of the ground control system (number – distribution – accuracy) and the planimetric accuracy of SPOT images.

KEY WORDS

SPOT images – Rectification - Polynomial transformation - Spatial accuracy.

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1. INTRODUCTION

The raw SPOT images usually suffer from a number of geometric distortions that they can not be used as maps. These distortions are due to several factors such as satellite orbit and attitude variations, Earth rotation and curvature, and sensor viewing geometry [1]. Therefore, SPOT scenes must be corrected in order to reach accuracies that are suitable for producing or updating topographic maps. The polynomial rectification is one of the most widely used techniques for correcting the satellite imagery. This procedure relies on ground control points to empirically determine a mathematical transformation model between the ground coordinate system and the image coordinate system [2]. So, the process of collecting spatial data for polynomial rectification of SPOT images is very important since the number, distribution, and accuracy of the used ground control points (GCPs) will certainly affect the positional accuracy of the rectified images.

Many studies have been carried out on the geometric correction of SPOT images, for example [3-4-5-6]. Most of these studies were based on modeling the physical reality of SPOT imaging system using the collinearity or the direct linear transformation models. These modeling techniques require a priori information about the orbit parameters and the ephemeris data during the scene acquisition time. Sometimes this priori information is not available and consequently these techniques can not be applied. Instead, since it is completely independent of the geometry of the imaging system, the polynomial rectification technique is most frequently used.

In this paper, a study involving the implementation of SPOT imagery in Mahallet Roh town located to the vicinity of Tanta, El-Gharbiia, Egypt has been carried out. The aim of this study is to evaluate the potential of using the polynomial rectification technique for the geometric correction of SPOT data. The objective is extended to investigate the influence of the number, distribution, and accuracy of the used GCPs on the obtained planimetric accuracy of SPOT imagery.

The advantages of using the polynomial rectification technique are its simple implementation and the ability to correct all distortions due to sensor geometry, Earth curvature and rotation, relief displacement, etc. simultaneously. Moreover, the relief displacement due to the topography of the Earth is relatively small compared to the flying height of the satellite, and does not influence the results significantly [7]. However, its disadvantages are the necessity of a large number of GCPs, and the lack of a physical interpretation of the model. In this study, different modules of the PCI remote sensing software from Geomatica, Ottawa, Canada was used to tie down the raw SPOT image to the ground coordinate system. The Root Mean Square (RMS) errors at the control and check points were calculated and used as an estimation for the obtained planimetric accuracy.

2. STUDY AREA AND DATA SOURCES

The study area was chosen in El-Gharbiia, Egypt covering Mahallet Roh town and the agricultural areas surrounding it. It is approximately 28.5 km^2. Extensive linear features such as irrigation canals and roads are involved in the study area, which makes it easy to locate GCPs at their intersections. The area is relatively flat and the elevation variations do not exceed thirty meters.

A subscene covering the study area was cut out from a panchromatic SPOT image acquired on August, 11,1995. The processing level of the SPOT image is 1A. The subscene size is 500 pixel by 570 pixel and the ground resolution is 10 m.

The ground coordinates of 25 control points and 16 check points were collected from two sources; a map sheet of scale 1:25000 (planimetric accuracy = 7.5 m), and 20 map sheets of scale 1:2500 (planimetric accuracy = 0.75 m). These maps were produced by the Egyptian General Survey Authority (EGSA). The coordinates of control points were determined based on the reference ellipsoid WGS 84, and the UTM map projection system. So, there were two sets of GCPs with different accuracies. Fig. 1 displays the study area overlaid by all the 41 ground points. Fig. 2 describes the image coordinate system relative to the flight direction.

3. TRANSFORMATION POLYNOMIAL

In polynomial rectification approach, the image distortion is modeled empirically as a mapping transformation from the desired map projection coordinates to the image coordinates. The transformation function takes the form [7]:

$$x = X^T A\, Y$$
$$y = X^T B\, Y$$

Where,

x, y	are the coordinates of the raw image.
X, Y	are the coordinates from the map.
A, B	are the coefficient matrices of the polynomial.

$$X^T = (1, X, X^2, X^3, \ldots\ldots)$$
$$Y^T = (1, Y, Y^2, Y^3, \ldots\ldots)$$

$$A = \begin{pmatrix} a_{00} & a_{01} & a_{02} & \ldots\ldots \\ a_{10} & a_{11} & a_{12} & \ldots\ldots \\ a_{20} & a_{21} & a_{22} & \ldots\ldots \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \end{pmatrix} \qquad B = \begin{pmatrix} b_{00} & b_{01} & b_{02} & \ldots\ldots \\ b_{10} & b_{11} & b_{12} & \ldots\ldots \\ b_{20} & b_{21} & b_{22} & \ldots\ldots \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \end{pmatrix}$$

Obviously, the degree of the used polynomial is dependent on the available number of GCPs. Up to the fifth degree polynomial were applied in this study. Table 1 presents the minimum required number for each polynomial. When more GCPs than the minimum number were used, the least squares regression was applied to determine the unknown parameters of the coefficient matrices. The factors examined in this research are:

1- **Number of GCPs**

For each polynomial, the minimum number was used, then this number was increased one GCPs at each experiment up to 25 points.

2- **Distribution of GCPs**

For each number of GCPs, different distributions expected to provide good accuracy were examined. Fig. 3 illustrates samples of these distributions where the used number of GCPs equals 6, 8, 9, 12, 13, 16, 17and 20.

3- Accuracy of GCPs

Map sheets of scale 1:2500, and a map sheet of scale 1:25000 were used individually to determine the coordinates of the 41 ground points. This means that two sets of GCPs with different accuracies are available.

4. RESULTS AND ANALYSIS

Many experiments were carried out using different configurations of the examined factors. For each experiment, the RMS errors at the check points in X, Y, and T directions were calculated according to the following equations:

$$\text{RMS for X} = \left[\frac{1}{n} \sum_{i=1}^{n} (\Delta X_i)^2 \right]^{0.5}$$

$$\text{RMS for Y} = \left[\frac{1}{n} \sum_{i=1}^{n} (\Delta Y_i)^2 \right]^{0.5}$$

$$\text{RMS for T} = \left[\frac{1}{n} \sum_{i=1}^{n} (\Delta X_i^2 + \Delta Y_i^2) \right]^{0.5}$$

Where

ΔX_i, ΔY_i = residuals of point (i) in X, and Y directions.

n = number of check points.

Three scenarios were conducted to investigate the influence of each factor separately on the positional accuracy of SPOT images. The examined factor was considered to be the only variable while the other factors were kept unchanged.

In the first scenario, each polynomial model was processed with different number of GCPs ranging from the minimum required number to a maximum of 25. From the two distributions namely; (a) and (b) of each number, that one which produced higher accuracy was considered. This means that each number of GCPs was examined under the best distribution of it. Map sheets of scale 1:2500 was used to collect the coordinates of ground points in this scenario. For space limitation a representative sample of the obtained RMS errors at the check points is provided in Table 2. Fig. 5 displays the obtained RMS errors due to using different numbers of GCPs. The results indicated that:

- The planimetric accuracy has generally improved with increasing the used number of GCPS. The accuracy improved considerably in the first part of the curve but marginally with increased number of GCPs in the second part of the curve.
- The RMS errors have considerably decreased due to using two or three GCPs more than the minimum required number. Table 1 provides the proposed minimum number of GCPs to be used for each polynomial model and the obtained RMS error using this number.

- Although the proposed minimum numbers for the first and second degree polynomials are sufficient to provide adequate accuracy, it is preferred, to use 13 GCPs because the results tend to stabilize beyond this number.

The second scenario is devoted to evaluate the performance of different degrees of the polynomial model. Referring to Fig. 5, it is evident that:

- The first degree polynomial has provided the lowest accuracy compared to the other polynomial models
- Second and third degree polynomials have provided very convergent results. Using these polynomials is quite enough to rectify SPOT images rather than using higher order polynomials, which are mathematically complex and require more GCPs.

Comparing the results obtained using different distributions of GCPs revealed that, GCPs must be equally scattered over the whole scene. This distribution gives the chance for all the inherent distortions, due to different sources and in various directions, to be empirically considered in the polynomial transformation model. Referring to Fig. 3, and Table 2, it can be easily noticed that:

- Using few GCPs with good distribution has provided more accurate results than using more GCPs with bad distribution (compare case (9a) with cases (12b), (13b), and (16a)).
- Distribution case (16a) has provided less accurate results compared to distribution case (16b). The reason is the bad locations of the GCPs in case (16a) where all the GCPs are located along the borders of the scene without any point in the central region (compare case (16a) and (16b) for 2nd, 3rd, and 4th degree polynomials).
- Adding a control point located close to the center of the scene (ID=95 in Fig. 1) to any distribution resulted in improving the accuracy (compare cases (8), and (9), cases (12), and (13), and cases (16), and (17) for both distributions a, and b).
- Distribution of GCPs along the upper and lower edges (parallel to X-axis) is better than that along the right and left edges (parallel to Y-axis). The positional RMS errors of case (6a) = 10.24 ms and of case (6b) = 12.22 ms. This can be interpreted by the fact that SPOT satellite has a near-polar orbit so that the Y-axis is parallel to the flight direction as shown in Fig. 2. It is well known that errors due to pitch and spacecraft velocity variations are in Y- direction as shown in Fig. 4, and therefore the existence of GCPs along the upper and lower edges has accounted for these distortions in the transformation model.
- The influence of the distribution of GCPs on the planimetric accuracy decreases with increasing the number of GCPs. For example, the average absolute difference of the RMS errors for different polynomial degrees between cases (12a) and (12b) = 1.42 ms, between cases (20a) and (20b) = 0.41 ms, and between cases (23a) and (23b) = 0.11 ms.

The purpose of the third scenario is to investigate the effect of the quality of the GCPs used to control the transformation model. Fig. 6 displays the RMS errors at the check points due to using GCPs from map sheets of scale 1:2500, and a map sheet of scale 1:25000 using the third degree polynomial. The planimetric accuracy has significantly improved by about 30% due to using more accurate GCPs from maps of scale 1:2500.

5. CONCLUSION

This study involved the implementation of SPOT imagery in Mahallet Roh town, El-Gharbiia, Egypt. The experiments were conducted to determine the planimetric accuracy of SPOT images obtained using the polynomial transformation model, and to investigate the influence of the number, distribution, and accuracy of the GCPs on the spatial accuracy of the rectified image. The results show the potential of the polynomial transformation for rectifying SPOT imagery. The obtained accuracy is less than one pixel which is suitable for producing and updating topographic maps of scale 1:50000. Second and third degree polynomials are adequate to be employed since no significant improvement has been detected due to using higher order polynomials. Although the accuracy increases with increasing the used number of GCPs, it is recommended to use 13 GCPs with distribution case (13a) because the RMS error values tend to stabilize beyond this number and the accuracy improvement due to using more GCPs is slight. The planimetric accuracy has improved by about 30% due to using more accurate GCPs from map sheets of scale 1:2500 rather than using less accurate GCPs from a map sheet of scale 1:25000.

The distribution of GCPs is the most significant factor influencing the planimetric accuracy of SPOT images. A good design of the distribution of GCPs can compensate for the accuracy deterioration due to lack of sufficient number of GCPs. The best distribution nominated from this study using as few as possible GCPs is case (13a) as shown in Fig.3 where the GCPs are approximately located at the corners, mid-side the borders, and over the central region of the scene.

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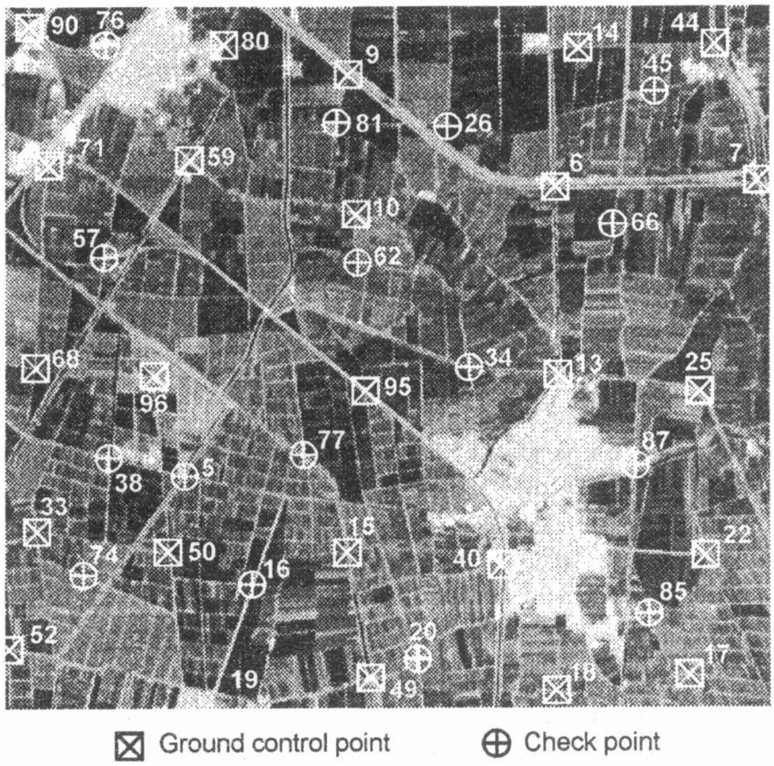

Fig. 1. Locations of GCPs and checkpoints on the study area

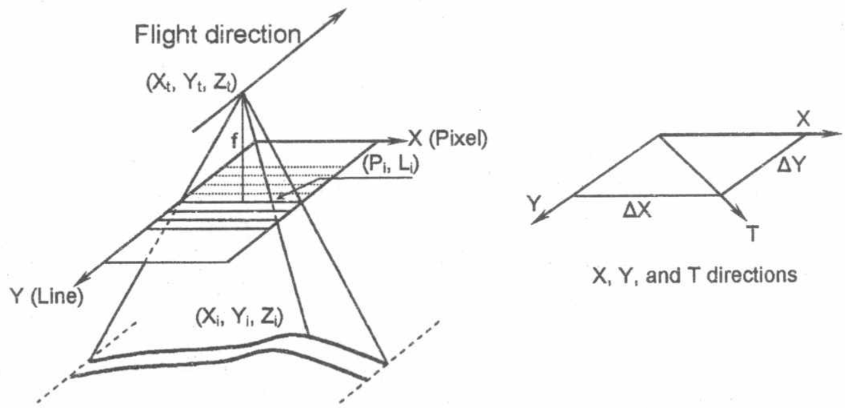

Fig. 2. The Image coordinate system relative to the flight direction

Table 1. Minimum and proposed number of GCPs for each polynomial

Polynomial degree	Minimum. No. of GCPs	Proposed No. of GCPs	RMS errors (ms)
First	3	6	10.24
Second	6	9	9.29
Third	10	13	9.01
Fourth	15	18	8.02
Fifth	21	23	7.80

Table 2. A sample of the results: RMS error at check points (ms) in T direction using different numbers and distributions of GCPs

Distribution	First	Second	Third	Fourth	Fifth
6a	10.24				
6b	12.22				
8a	9.94	12.29			
8b	10.64	12.54			
9a	9.79	9.29			
9b	10.34	10.25			
12a	9.45	9.26	9.07		
12b	10.92	10.56	10.55		
13a	9.08	8.96	9.01		
13b	10.69	10.30	10.30		
16a	9.00	10.87	10.74	10.37	
16b	9.58	9.29	9.20	8.93	
17a	8.92	8.98	8.96	9.18	
17b	9.51	9.18	9.16	8.86	
20a	8.80	8.30	8.31	8.07	
20b	9.01	8.51	8.51	8.78	
22a	8.43	7.90	8.04	7.93	7.95
22b	8.64	7.95	7.95	7.87	7.91
23a	8.39	7.77	7.76	7.85	7.80
23b	8.59	7.85	7.87	7.78	7.87

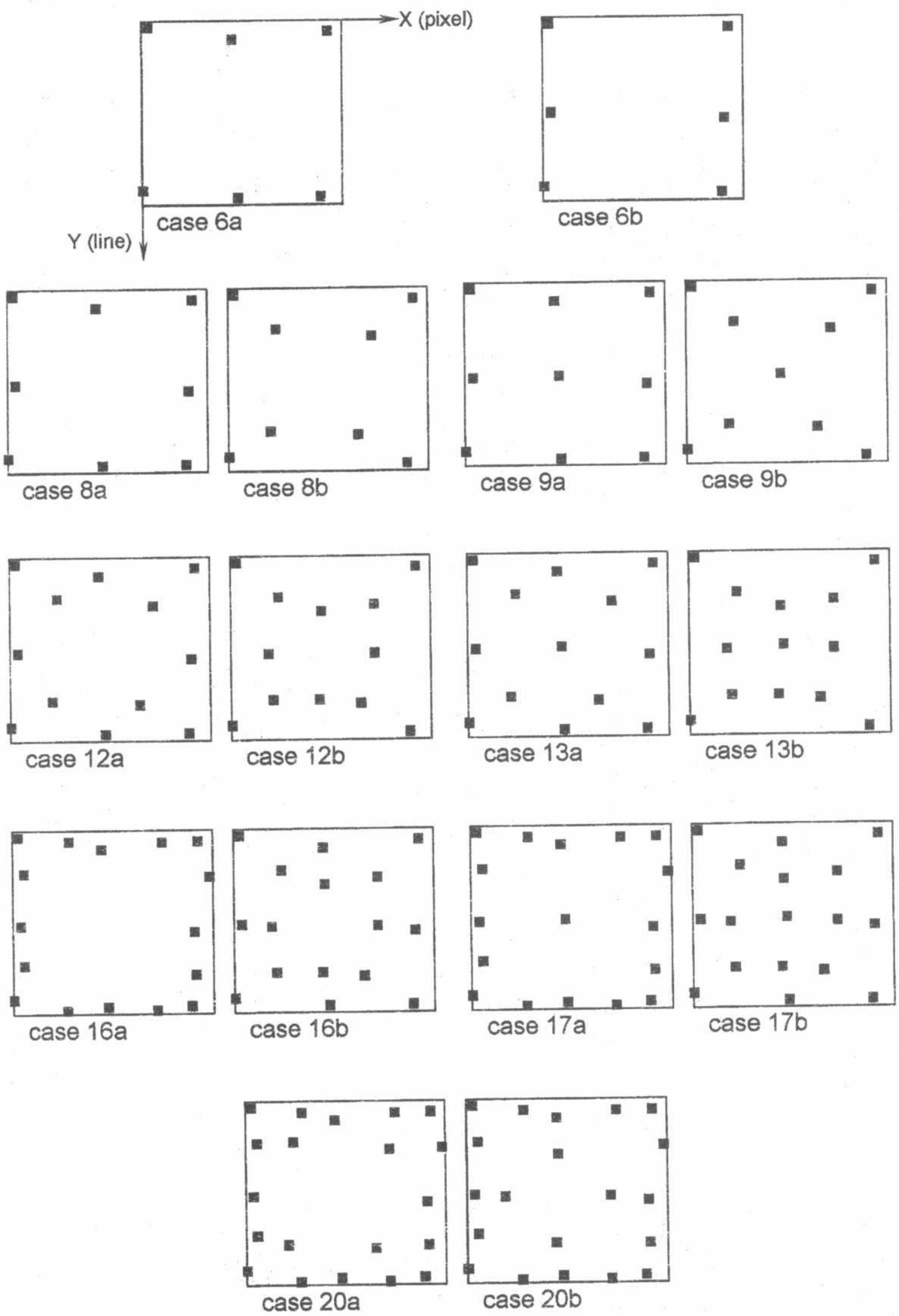

Fig. 3. Different distributions of ground control points

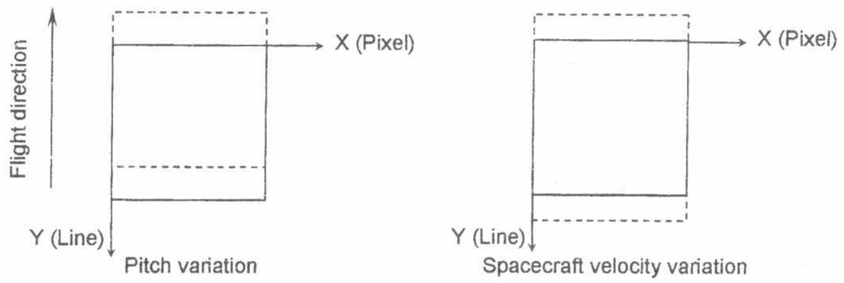

Fig. 4. Distortions relative to the flight direction

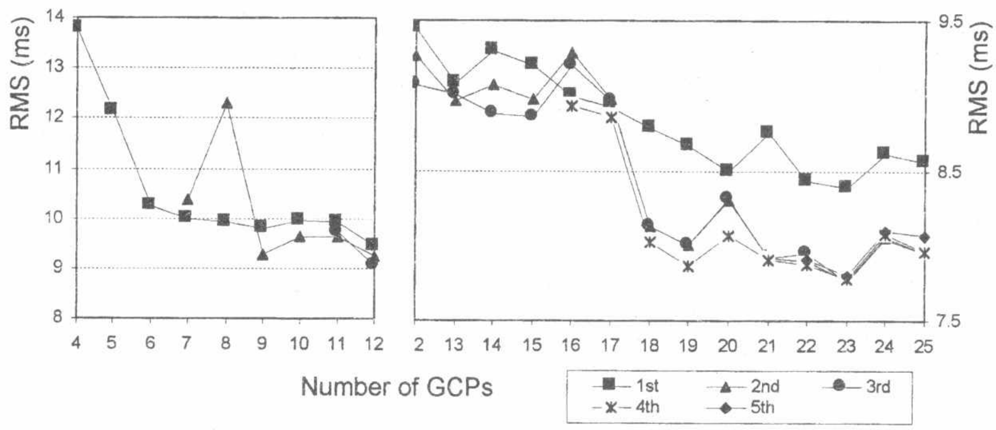

Fig. 5. RMS error at the check points for different numbers of GCPs

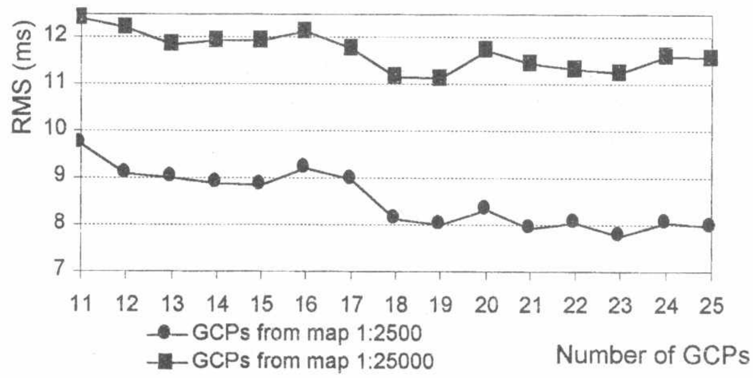

Fig. 6. RMS errors at the check points using different accuracies of GCPs