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GEOMETRIC ACCURACY OF LANDSAT-4 MSS IMAGE DATA[1]

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GEOMETRIC ACCURACY OF LANDSAT-4 MSS IMAGE DATA

INTRODUCTION

The Landsat-4 mission is presenting investigators with an opportunity to assess the mapping potential of satellite image data of improved geometric quality in digital formats. This paper focuses on the geometric characteristics of Landsat-4 multispectral scanner (MSS) data available in CCT-p formats (57 m pixels) from the EROS Data Center (EDC).

When compared to characteristics of the previous Landsat missions, the improved pointing accuracy and attitude stability of the Landsat-4 platform offer significant advantages for mapping purposes. For example, Landsat-1, -2, and -3 data were acquired from a platform with 0.7 degree pointing accuracy and an attitude stability of 10^{-2} deg/sec. The geometric distortion within these early MSS scenes was estimated to be $\pm$200 to $\pm$300 m root-mean-square vector error ($RMSE_{xy}$) and was probably caused by variations in the attitude of the satellite (Schoonmaker, 1974; Wong, 1975; Bahr, 1976). Wong (1975) and Bernstein (1976) demonstrated that distortions could be reduced to about $\pm$100 m with a first degree polynomial, and to a limiting rectification accuracy of about $\pm$50 m with 20 term polynomials, when a dense network of ground control points (GCPs) was available. Relief was not a significant factor in these studies.

The MSS sensor on Landsat-4 is identical to that utilized on Landsats-1, -2 and -3, but with an instantaneous field-of-view (IFOV) of 83 m as compared to the 79 m of the earlier missions. The multimission modular spacecraft (MMS) of the Landsat-4 system, on the other hand, is designed to meet specifications for a pointing accuracy of 0.01 degree (1σ) and an attitude stability of 10^{-6} deg/sec (1σ), which represent approximately 2 and 4 orders of magnitude improvement over the previous Landsat systems. Thus, from an altitude of 705 km, pointing should be to within about $\pm$120 m of the nadir

and attitude should not vary by more than 0.1 sec (or about 0.4 m ground distance) during the approximate 25 second time interval required to record a 185 x 185 km scene. Therefore, it should prove possible to fit Landsat-4 data to a reference map by applying relatively simple rectification procedures based on a few well-distributed control points. In fact, these pointing accuracy and attitude control specifications led to the development of geodetic error tolerances for the CCT-p data of ±0.5 IFOV 90 percent of the time (Carr, 1982).

It is the objective of this paper to evaluate the errors in EDC CCT-p products for MSS data acquired over test areas in North Georgia. In addition, assessments will be made of the possibilities for rectifying the image data by applying polynomials to full- and subscene areas, and of the effects of sensor resolution, digitizing techniques (for GCPs) and terrain relief on geodetic accuracy.

STUDY AREA AND DATA SETS

The study area is centered on North Georgia and is covered by two Landsat-4 scenes corresponding to path 18, row 36 (P18R36) and path 19, row 36 (P19R36) in the Landsat-4 Worldwide Reference System (Figure 1). This region is characterized by a blend of urban and rural land use features with terrain relief varying from about 1000 m in the rugged southern Appalachians of Georgia, Tennessee and North Carolina, to less than 30 m in the southernmost portions of the study area near Athens, Georgia. Thus, these scenes are ideally suited for assessments of the impact of relief on rectification accuracy.

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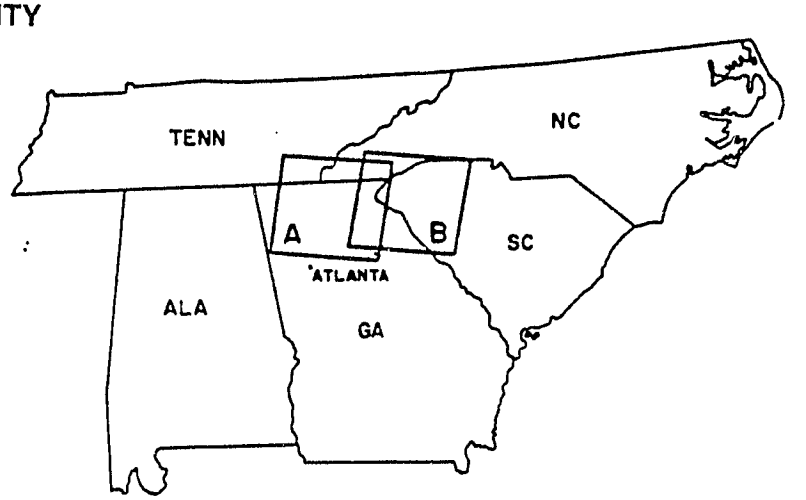

Fig. 1 Landsat-4 scenes from path 19, row 36 (A) and path 18, row 36 (B).

The specific Landsat-4 coverage which has been used to-date includes one MSS acquisition over each of the scene centers recorded on October 29 (P19R36) and December 9 (P18R36). Subscenes are centered on Blue Ridge, Georgia (P19R36) in the rugged North Georgia mountains and include data sets of 1024 x 1024 and 256 x 256 pixels. Terrain elevations in the area covered by the subscenes range from 400 to over 1000 m.

RECTIFICATION PROCEDURES

In order to implement rectification procedures, it was first necessary to locate a dense network of GCPs which could be correctly identified and precisely located on both the Landsat-4 image data and on 1:24,000 scale USGS topographic maps of the study areas. Image locations (in pixel and scan-line coordinates) of the GCPs were determined with the aid of an ERDAS 2400 interactive image processing system. Unfortunately, however, the limited spatial resolution of the MSS data poses a problem in identifying and locating features normally used as GCPs such as the intersections of roads, rivers and pipelines. For example, the center of a road intersection may be completely obscured by a pixel. Unless refinements are made to the location process, image coordinates can only be determined to about ± 1 data pixel, i.e. to about ± 60 m.

The image coordinates can be more precisely determined by reformatting/resampling image data to smaller pixels, which are then redisplayed on the CRT. Although rather tedious, this procedure does permit image coordinates to be determined to approximately one-half the dimension of the original data pixel, i.e. to ± 30 m in the case of the MSS.

Once provisional control points were located on the image data, their UTM map coordinates were manually digitized from 1:24,000 scale U.S. Geological Survey topographic quadrangles with an Altek Super Micro digitizing system (resolution $\pm .025$ mm). The errors in the maps and in the digitizing procedure influence the accuracy of the resulting rectifications and are estimated to have an $RMSE_{xy}$ value of approximately ± 10-15 m.

After the coordinates of the GCPs in image (pixel, scan-line) and map (Easting, Northing) space were determined, an accuracy validation procedure was undertaken to establish misidentified or suspect points. This procedure is referred to as a point-pair distance check and involves the computation and comparison of map and scaled image distances between all possible combinations of point-pairs (Figure 2). By performing distance checks, suspect points may be quickly identified. Once the suspect points have been eliminated, the point-pair distances are recomputed and the RMS difference in distance between the map and scaled image values determined. Linear regression of RMS distance differences against $RMSE_{xy}$ for the same data sets yielded correlation coefficients (r) of about +0.9. Thus, the RMS difference value is, for practical purposes, a surrogate measure of $RMSE_{xy}$ and serves as an indicator of the inherent geometric errors in the CCT-p data supplied by EDC.

An average RMS distance difference of ± 130 m was obtained for the MSS scenes of North Georgia, which is comparable to values reported by Bryant et al. (1983) for other geographic areas. Thus, it appears the geometric quality of the Landsat-4 MSS data is considerably better than those available from the Landsat-1, -2 and -3 missions.

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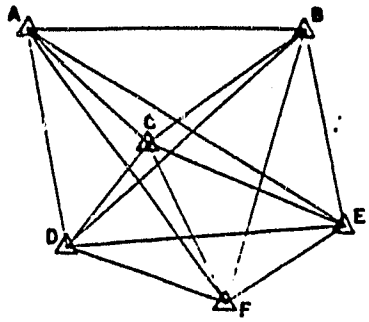

Fig. 2 Distance checks are performed between all possible point-pairs to validate the GCPs.

Probably the most direct method for the rectification of digital MSS data is by means of polynomials (Konecny, 1976; Figure 3). For example, early rectifications of Landsat MSS data by NASA involved the use of a computer program package known as the Digital Image Rectification System (DIRS) (Van Wie and Stein, 1975) which employs affine and polynomial transformation equations. DIRS is available from COSMIC, University of Georgia, and was subsequently obtained and modified to facilitate its use for the current studies. The DIRS procedures include the development of polynomial mapping functions of the general form:

$$z = c_0 + c_1x + c_2y + c_3x^2 + c_4xy + c_5y^2 + c_6x^3 + c_7x^2y + c_8xy^2 + c_9y^3 + \ldots$$

where x,y are the known image or map coordinates of GCPs.

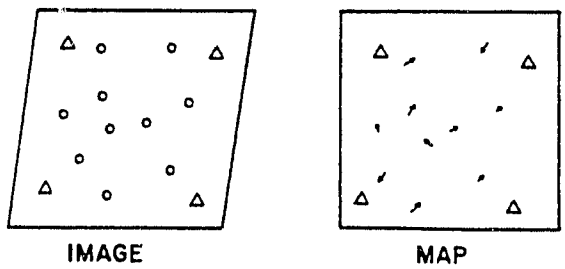

Fig. 3 Polynomials are employed to transform the image data to a map reference base. Error vectors at test points are used to calculate the $RMSE_{xy}$.

These functions may be used to solve (by the method of least-squares) for UTM Easting and Northing coordinates in terms of image pixel and scan-line coordinates. Correspondingly, the image coordinates may be determined by an inverse procedure. The minimum number of GCPs required to establish the unknown coefficients is dependent on the degree of the polynomials used in the rectification process. For example, 5th, 4th, 3rd, 2nd and 1st degree polynomials require a minimum of 21, 15, 10, 6, and 3 GCPs, respectively.

The pixel-by-pixel application of the polynomial mapping functions is computationally inefficient, thus, an interpolation grid of horizontal and vertical lines is established in the UTM coordinate system. Standard linear equations are used to compute the UTM coordinates of the grid intersections which are then transformed through the polynomial mapping functions to determine their corresponding image coordinates (pixel and scan-line). A regular lattice of output pixel locations is computed in the UTM system from the grid. The output image coordinates of these pixels are then determined by bilinear interpolation from the corners of each grid cell in the image space. Because the output pixels will not correspond to the input pixel locations, a resampling of the gray level values is necessary. DIRS permits nearest neighbor resampling for whole scenes and cubic convolution resampling for subscenes.

Rectification of Whole MSS Scenes

Over 100 GCPs were located in each of the two MSS scenes (P18R36, P19R36). From these GCPs, 42 well-distributed points were selected as control for the rectification of P19R36 and 21 points for P18R36. In order to provide an independent check of the rectification accuracies achieved, a total of 40 and 27 (withheld) test points were selected from the GCPs in P19R36 and P18R36, respectively. The distribution of control and test points for P19R36 is shown in Figure 4.

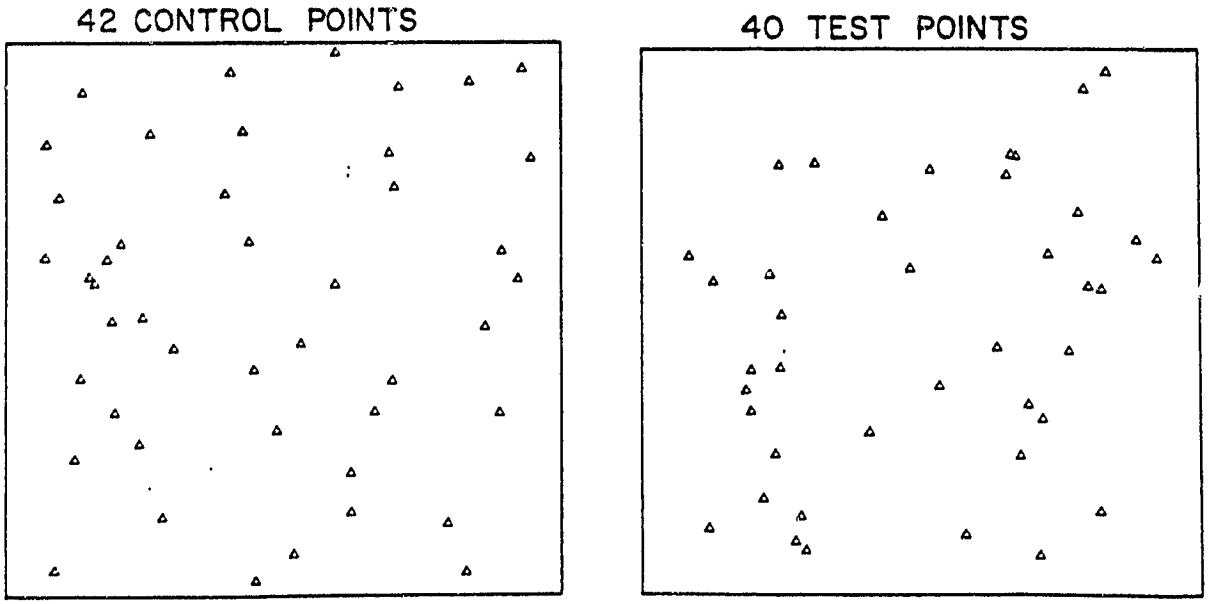

Fig. 4 Distribution of the control and test points for full scene rectification of P19R36.

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For P19R36, the number of GCPs used in the rectification process was reduced in steps for polynomials of the 5th through 1st degree as shown in Figure 5 and Table 1. The $RMSE_{xy}$ value in each case was determined from the error vectors at the 40 withheld test points. These $RMSE_{xy}$ values were then plotted as a function of the number of GCPs used in the solutions of the different polynomials (Figure 6). It is evident from Figure 6 that a polynomial of the first degree based on 10 or more control points provides an $RMSE_{xy}$ of approximately ± 80 m and that the minimum $RMSE_{xy}$ of between ± 55 and 60 m can be obtained with a 3rd degree polynomial and 30 or more control points. Although the rectification experiments undertaken with P18R36 were not as comprehensive, comparable results were obtained for solutions of the first through 4th degree based on 21 GCPs (Table 1). Overall, rectifications with 2nd and 3rd degree polynomials and 20 or more control points yielded RMSEs of about ± 1 data pixel (± 57 m), even in this rugged terrain.

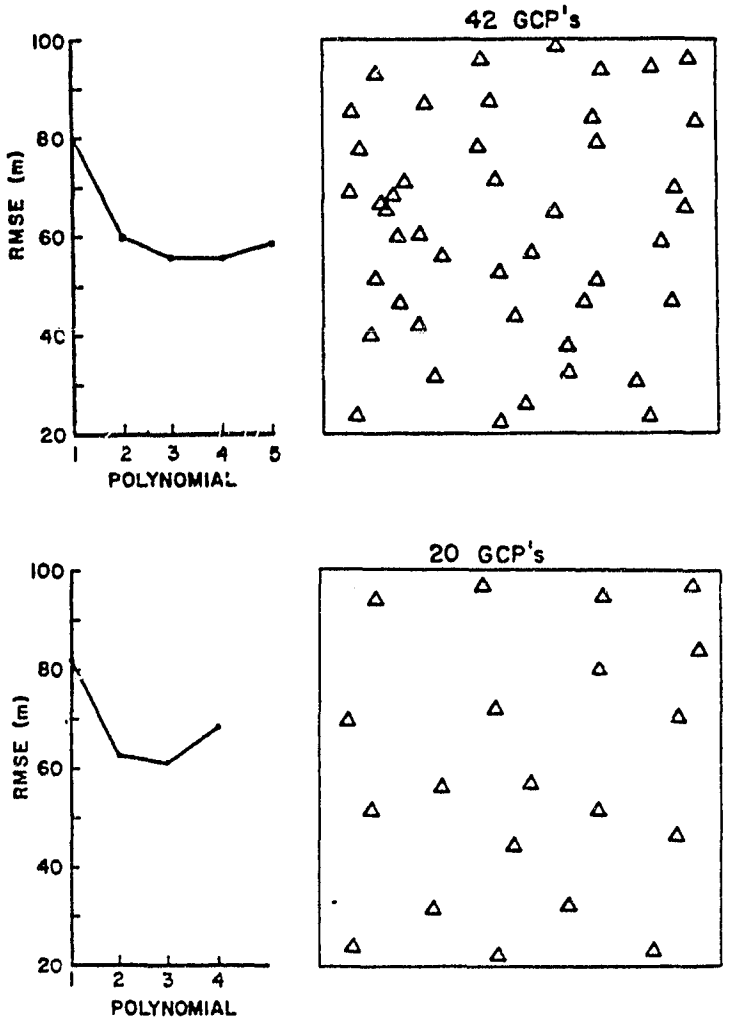

Fig. 5 $RMSE_{xy}$ at 40 test points as a function of the degree of polynomials used in the rectification process. The diagrams on the right show the distribution of the GCPs.

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Table 1

$RMSE_{xy}$ FOR WHOLE SCENE RECTIFICATION

Number of control points used in the rectification	$RMSE_{xy}$ values (from 40 test points) for polynomials of degree 1-5.				
	5th	4th	3rd	2nd	1st
42	59m	56	56	60	80
30	69	61	57	60	82
21*	66	64	62	70	80
20		69	61	63	82
15			73	73	83
10				70	83
5					91

*from P18R36 @ 27 test points

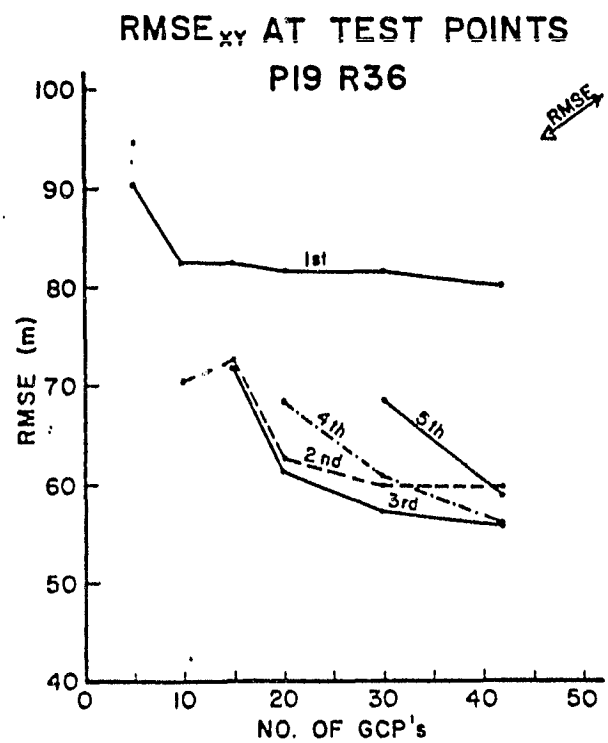

Fig. 6 $RMSE_{xy}$ as a function of the number of GCPs used to solve polynomials of the 1st through 5th degree.

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Rectification of MSS Subscenes

Subscenes of 1024 x 1024 pixels and 256 x 256 pixels were also rectified to determine the number of GCPs and the degree of polynomial required to maximize the geometric accuracy within the areas displayed by high (1024 x 1024) and low (256 x 256) resolution CRT devices. Because a 256 x 256 pixel subscene roughly corresponds to the area covered by a USGS 1:24,000 scale quadrangle, these rectification studies also permit an assessment of the accuracies to which Landsat-4 MSS data can be registered to a relatively large scale topographic map.

The 1024 x 1024 pixel test area is centered on the town of Blue Ridge, Georgia, and the 256 x 256 pixel subscene corresponds to the USGS Blue Ridge 7 1/2 minute quadrangle. Rectification was accomplished using the previously described procedures. In the case of the 1024 x 1024 pixel area, 15 GCPs were employed to develop least squares solutions for polynomials of the 1st through 3rd degree. Accuracy was evaluated at 16 withheld test points, and minimum RMSEs of ±45 m were obtained with 1st and 2nd degree equations (Table 2). When the number of GCPs was reduced to 10 points, the $RMSE_{xy}$ increased to approximately ±60 m. The smaller 256 x 256 pixel subscene was rectified with a 1st order polynomial based on 5 GCPs and 3 withheld test points. The $RMSE_{xy}$ of ± 40 m indicates that subpixel accuracy is feasible for quadrangle-sized areas with limited control.

Table 2

$RMSE_{xy}$ VALUES FOR SUBSCENE AREAS

Number of GCPs	$RMSE_{xy}$ values for polynomials of degree 1-3.		
	3rd	2nd	1st
15*	55m	46	45
10*		60	61
5**			40

*1024 x 1024 pixels areas with 16 test points
**256 x 256 pixel areas with 3 test points

ERROR ANALYSES

Although of good geometric quality, the MSS data acquired from the EDC in CCT-p formats for this study has an $RMSE_{xy}$ error of about ±130 m. This value indicates the CCT-p data do not meet the pre-launch specifications for geodetic accuracy which states that 90 percent of the pixels will be correctly located to within ±0.5 IFOV (±41.5 m) in both the x and y directions. Based on this specification, the acceptable vector error ($RMSE_{xy}$) is ±59 m.

It must be noted that the two CCT-p scenes used in this study were not corrected to ground control as part of the EDC processing, and consequently

errors of approximately ±130 m are quite reasonable. As discussed below, by using adequate control the $RMSE_{xy}$ can be reduced to less than ±59 m. However, this requires significantly more processing than was performed on these scenes at the EDC.

The minimum $RMSE_{xy}$ of about ±55 m obtained for whole scenes after rectification with polynomials of the 2nd and 3rd degree is equivalent to about ±1 data pixel. This appears to be about the best result that can be expected for these test sites, given that the spatial resolution of the MSS prevents features from being located to better than about ±0.5 pixel, that errors in digitizing the UTM coordinates from 1:24,000 scale maps amount to approximately ±0.25 pixel, and that average displacements in the image data caused by terrain relief are greater than ±0.35 pixel. The typical RMSE values of ±55-60 m are compatible with national map accuracy standards for cartographic products of 1:200,000 scale and smaller.

CONCLUSION

Analyses of the Landsat-4 MSS image data of North Georgia provided by the EDC in CCT-p formats reveal that errors of approximately ±130 m in the raw data can be reduced to about ±55 m based on rectification procedures involving the use of 20-30 well-distributed GCPs and 2nd or 3rd degree polynomial equations. Higher order polynomials do not appear to improve the rectification accuracy. A subscene area of 256 x 256 pixels was rectified with a 1st degree polynomial to yield an $RMSE_{xy}$ value of ±40 m, indicating that USGS 1:24,000 scale quadrangle-sized areas of Landsat-4 data can be fitted to a map base with relatively few control points and simple equations.

The errors in the rectification process are caused by the spatial resolution of the MSS data (±0.5 pixel), by errors in the maps and GCP digitizing process (±0.25 pixel), and by displacements caused by terrain relief (>±0.35 pixel). Overall, due to the improved pointing and attitude control of the spacecraft, the geometric quality of the Landsat-4 MSS data appears much improved over that of Landsats -1, -2 and -3.

ACKNOWLEDGMENTS

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