Geometric Correction of SPOT and Landsat Imagery: A Comparison of Map- and GPS-Derived Control Points

N.G. Kardoulas, A.C. Bird, and A.I. Lawan

Abstract

Problems arise with the geometric correction of satellite imagery in areas where suitable topographic maps are not available. GPS technology is increasingly seen as a potential solution in such areas. In this study, the geometric correction of Landsat MSS (80-metre pixel), Landsat TM (30-metre pixel), and SPOT Panchromatic (10-metre pixel) satellite images was investigated using 1:100,000-scale topographic maps and GPS data in an area of Nigeria. The geometric corrections with first-degree polynomials, using either GPS-derived points or 1:100,000-scale topographic map derived points, yielded RMS error values on the order of ±35 metres for all three types of satellite image regardless of pixel size. The importance of employing independent check points for assessing the accuracy of the correction was demonstrated.

Introduction

The quantitative use of remote sensing satellite images in many applications requires that the geometric distortion inherent in these images be corrected to a desired map projection. Geometrically corrected images are needed for the following purposes:

- To bring an image into a standard projection,
- To locate points of interest,
- To bring adjacent images into registration,
- To overlay images of the same area from different dates and sensors, and
- To overlay an image on a map or merge it into a geographic database.

The most widely used geometric correction technique relies on the use of ground control points (GCPs) located on the image and the corresponding map in order to empirically determine a mathematical coordinate transformation to correct the geometry (Richards, 1986). The quality of the correction will depend on the number and quality of the control points which is often related to the quality of the source.

Publications on geometric correction of satellite imagery using map-derived GCPs have reported sub-pixel accuracy. Here the quality of the points depends on the map scale and the type of feature that can be located both on the map and on the image. For example, Forster (1980) found standard errors of approximately 30 metres (0.4 pixel) in the geometric correction of Landsat MSS imagery using GCPs derived from 1:10,000-scale planimetric maps of the Sydney, Australia metropolitan area (100 points) and a stepwise polynomial transformation. Welch *et al.*, (1985) found root-mean-square (RMS) errors of ±0.23 to ±0.93 pixels (±7 to ±28 metres) in the geometric correction of Landsat-4 and Landsat-5 TM imagery using 1:24,000-scale map-derived GCPs (five points) from USGS topographic maps of Georgia and Iowa and first-degree polynomials. Michaelis (1988) found an accuracy of 0.6 to 0.8 pixels in the along-track and 0.6 to 0.9 pixels in the across-track direction in the geometric correction of SPOT multispectral (SPOT-XS) imagery (Level 1A, 20-metre pixel, off-nadir view). This work used 1:25,000-scale topographic map (Gauss-Kruger) derived GCPs (nine points) and first-degree polynomials, and transformed the image-derived GCPs into a nadir view. The study covered the Hannover area of Germany. Forster (1988) found RMS errors on the order of 10 metres (one pixel) in X and Y in the geometric correction of SPOT PAN imagery using 1:25,000-scale map-derived GCPs (nine points) and first- and second-degree polynomials, in the Sydney area of Australia. Thormodsgard and Feuquay (1988) found an RMS error of residuals at the GCPs (12 points) of 4 metres (0.4 pixel) in the geometric correction of SPOT PAN imagery for the production of an image map. They used 1:24,000-scale USGS topographic map-derived points and second-order polynomials, in the San Diego, California area. They also found RMS errors of 10 metres at the 1:24,000-scale USGS topographic-map-derived check points (ten points) after merging the SPOT PAN image with the corresponding SPOT-XS image. Clavet *et al.* (1993) found a mean-square-error in planimetry of 25 metres (2.5 pixels) in the production of orthoimages from SPOT PAN imagery using 1:50,000-scale map-derived points (31 points), in the Sherbrooke and Coaticook areas of Canada.

These results show that the accuracy of correction can depend on a number of variables. These can include the spatial resolution of the image, the scale of the maps, and the number of control points located. The above examples concerned developed areas with a good coverage of large-scale topographic maps. For some areas of the world, large-scale maps do not exist or do not contain features which are readily recognizable on a satellite image. Problems arise with the geometric correction of satellite imagery in these areas which are sometimes resolved by falling back on small-scale maps.

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A further solution to this problem is to use Global Positioning System (GPS) technology.

Under ideal circumstances, GPS can provide reliable and accurate geographic positioning around the globe. There are many sources of error that can degrade the accuracy of GPS-derived positions, but it is possible to minimize these errors through careful mission planning and post-processing of field data. Positions recorded by a single receiver in autonomous mode are necessarily less accurate than those recorded in differential mode in conjunction with a second receiver (Gibbons, 1992). In practical terms, GPS is most commonly used in developing countries in the form of single hand-held units operating in autonomous mode. Field workers use them as navigation aids in locating and revisiting villages, wells, boreholes, and other physical features in the absence of clear road networks. The opportunity also therefore exists to use GPS for the collection of control points for image correction.

There are few publications on the geometric correction of satellite imagery using GPS-derived GCPs. Clavet *et al.* (1993) found a mean-square-error in planimetry of 6 metres (0.6 pixel) in the production of ortho-images from SPOT PAN imagery using GPS derived points (11 points) acquired by the Magellan NAV 1000 PRO GPS receiver in differential mode. The study covered the Sherbrooke and Coaticook areas of Canada. August *et al.* (1994) found differences on the order of 30 metres between the GPS-derived positions and the true positions at two stations over the University of Rhode Island, Kingston area. This work used a three-channel Trimble Pathfinder Basic portable GPS receiver in autonomous mode and 300 averaged sequential fixes at each station. They also found that the differential correction improved the accuracy to better than 3 metres.

The study area of the project discussed in this paper is an area of northeast Nigeria. In contrast with the publications mentioned above, Nigeria is a developing country, the existing topographic maps date from the 1960s, and there are limited features that can be used as GCPs. In such areas GPS technology could be very important for the geometric correction of satellite imagery. In addition, satellite imagery is an important source of natural resource information because thematic maps are frequently not available. Therefore, it was essential that the image data were geometrically corrected in order to ensure that the derived information could be related to other geographic data.

Objectives

The objective of this project was to investigate the geometric correction of Landsat MSS, Landsat TM, and SPOT PAN satellite images corresponding to an area of northeast Nigeria, using the following two sources of GCPs:

- 1:100,000-scale topographic maps, and
- GPS points acquired in autonomous mode.

Evaluation of the results of the geometric correction of each satellite image was carried out by using a set of check points which were different from the set of GCPs used in the geometric correction. A comparison was also carried out between the different sources of ground control for each satellite image.

Study Area

The Gorgoram and Gashua districts of northeast Nigeria are the study area of the project (Figure 1). The area covers approximately 60 by 30 km, and its extents are:

Latitude : N 12° 45' – N 13° 00'

Longitude : E 10° 45' – E 11° 15'

The area is characterized by the flat nature of the landscape centered on the River Yobe floodplain with many land-water interfaces and an absence of a regular, systematic pattern of roads and transportation features. The only urban features are the town of Gashua and some scattered small villages. Hence, the selection and identification of control and check points, both on the existing topographic maps and on the satellite images, is not straightforward.

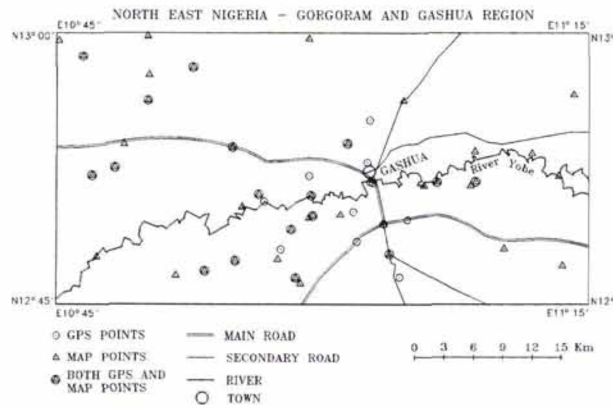

Figure 1. Distribution of the GPS and 1:100,000-scale topographic-map-derived control points within the Gashua and Gorgoram regions of northeast Nigeria.

Data Sets

GPS-Derived Points

GPS observations in the project were determined with the Magellan GPS NAV 5000 PRO receiver in 1993, as a part of a project in the northeast of Nigeria. The Magellan is a hand-held GPS C/A-code and carrier phase code receiver. It uses five channels working simultaneously to locate and collect data from the GPS satellites, and it is generally capable of 12 metres (RMS) horizontal accuracy in autonomous operation in the absence of SA, and better than 3 metres (RMS) horizontal accuracy in differential operation (Magellan User Guide, 1992).

GPS data were collected during a field survey being carried out to support land-cover mapping. The set of field sites was selected using a stratified random sample design of fixed-sized segments. The field worker had SPOT-XS imagettes and 1:25,000-scale photo mosaics, and took the opportunity to take GPS measurements of identifiable points within or close to the randomly distributed segments. GPS positions were determined at 29 points (Figure 1) in autonomous operation, and three-dimensional (3D) mode. The GPS point locations were also recorded on 1:25,000-scale semi-controlled photo mosaics. The GPS coordinates were referenced to the WGS 84 ellipsoid, and the UTM-zone 32 projection. Most of the GPS points were chosen to be land-water interfaces or turns of roads or rivers with only two of them at road intersections and one at a bridge across a river.

Three independent averaged positions, each with 100 position fixes, were determined at each GPS point, within about a 20-minute period, and four satellites were used for each averaged position. The average position dilution of precision (PDOP) value is a measurement of the possible position error that is related to the geometric quality of the satellites being used. The PDOP varied from 2.2 to 5.8 for all but one of the 29 GPS points, and these values were within the limit of 6 recommended for good accuracy in 3D operation (Magellan User Guide, 1992). The PDOP value of the remaining GPS point was above but close to the limit and was not rejected.

The average signal quality value, which is an indication of the carrier-to-noise ratio (C/N_0) of the signal of each satellite being used for an averaged position, varied from 4 to 9. These values of signal quality indicated a signal sufficiently strong that the receiver unit would not lose its lock on the satellites. The standard deviation (SD) of the horizontal position variation ranged from 3.8 to 67.2 metres for all the averaged positions.

In order to investigate whether or not the variances of the three independent averaged positions of the same GPS point were similar, we used the Chi square statistical test (Griffith and Amrhein, 1991) at the 5 percent level of significance. If the variances between the three averaged positions were similar, then all of the information in the three samples could be pooled to arrive at a better estimate of variance which was applicable to the three sample datasets.

In order to investigate then if there was any difference in the means of the three independent averaged positions of the same GPS point, the F-statistical test (Griffith and Amrhein, 1991) was used at the 5 percent level of significance.

The results of the Chi square statistical test revealed that only three out of 29 GPS points had similar variances for the three independent averaged positions. The final standard deviation (SD) and standard error of the mean (SE) of each GPS point ranged from 10.1 to 81.6 metres and from 1 to 8.1 metres, respectively. From these variations, it seems that the SA was enabled during the time of the GPS observations, introducing random errors in coordinate readings.

The results of the F-statistical test revealed that no GPS point had similar Easting (X) and Northing (Y) means for the three independent averaged positions. Both the Chi square test and the F-test confirmed that the magnitude of error in GPS measurements was not constant over time, again indicating that the SA was enabled during the time of the observations and that other potential sources of error such as atmospheric disturbance and poor satellite geometry could vary with time.

Finally, in order to reduce the magnitude of error in the coordinate readings and because there was no indication about which averaged position was more accurate, the X- and Y-coordinate means of the three independently averaged positions of each GPS point were calculated. These X- and Y-coordinate means of each GPS point were used in the geometric correction procedure. The standard deviation (SD) and standard error of the mean (SE) of the final averaged positions of each GPS point ranged from 6.5 to 72.4 metres and from 3.8 to 32.6 metres, respectively, except for one point whose SD and SE were 119.4 and 68.9 metres, respectively. A reason for the exception of this point could be its PDOP value, which ranged from 6.3 to 6.6, and this highlights the value of following the guidelines laid down concerning assessing the quality of points based on this measure. These levels of SD and SE are within the limits of error imposed by SA ($\pm$100 metres for 95 percent of GPS fixes) as was mentioned above. In comparison with the SD and SE values calculated by the Chi square test, the SD values are in the same range, but there is an increase in the SE values due to the smaller sample size (three samples).

1:100,000-Scale Topographic Maps

The Gorgoram and Gashua 1:100,000-scale map sheets were used for the derivation of GCPs and check points used in the geometric correction procedure. The maps are dated from 1961 and they are referred to the Clarke 1880 ellipsoid and UTM Zone-32 projection. A geodetic datum conversion was not carried out between the two datums used in this work. This was not necessary due to the fact that the GPS coordinates were not compared directly to the map coordinates.

Geographic coordinates (latitude and longitude) at 40 points (Figure 1) were manually derived from measurements on the two maps, which were then converted to plane coordinates [Eastings (X) and Northings (Y)] on the UTM Zone-32 projection. The accuracy of measurement of the map-derived points was 0.5 mm, or 50 metres at the 1:100,000 map scale. Most of the points were chosen to be land-water interfaces and intersections of rivers with only a few at road intersections.

Only 17 out of 29 GPS-derived points could be identified on the 1:100,000-scale topographic maps. This was due to the fact that the GPS points had been selected in the field in conjunction with imagery rather than maps. Thus, it was impossible to use the same GPS- and map-derived points in the geometric correction procedure.

Image Data

The study area lies within single frames of Landsat MSS, Landsat TM, and SPOT PAN satellite images.

The Landsat MSS image was acquired on 18 November 1978 and corresponded to path 201 and row 51 in the Landsat Worldwide Reference System for Landsats 1 to 3. The part of the image that corresponds to the study area covers approximately 500 rows by 1000 columns.

The Landsat TM image was acquired on 12 February 1991 and corresponded to path 187 and row 51 in the Landsat Worldwide Reference System for Landsats 4 and 5. The part of the image that corresponds to the study area covers approximately 1200 rows by 2000 columns.

The SPOT PAN image (1B level) was acquired on 17 January 1991 and corresponded to path 79 and row 324 in the SPOT reference system. The part of the image that corresponds to the study area covers approximately 3200 rows by 5500 columns.

Geometric Correction Procedure

The geometric correction procedure for the satellite imagery involved the following steps:

- Location of the GPS- and map-derived points on the satellite images (pixel and line coordinates).
- Least-squares solution of first-degree polynomial equations using GCPs uniformly distributed through the datasets. This determined the coefficients which must be applied to the image coordinates in order to derive UTM zone-32 coordinates. A minimum, a medium, and a maximum number of GCPs (in the range of five to 15 points) were used for each data set, in order to investigate the optimum number of GCPs required. After the least-squares solution, the polynomial equations were used to solve for X and Y coordinates of the GCPs in the UTM projection, and to determine the residuals and the RMS errors between the source X, Y coordinates and the retransformed X, Y coordinates. Correspondingly, residuals and RMS errors of the image coordinates were determined by the inverse procedure.
- Evaluation of the results of the geometric correction using a set of check points different from the GCPs used in the least-squares transformation, and using the same polynomial equations as for the GCPs set to determine residuals and RMS errors for the check points.

The location of GCPs and check points were identified visually. The near-infrared band of the Landsat MSS image was found to be preferable for point identification, because of the high contrast between vegetation, water features, and man-made features in this band. The green, red, and near-infrared bands of the Landsat TM image displayed as a false composite image were found to be preferable for point identification because they yielded maximum contrast between land, vegetation, and water features.

Geometric Correction of Satellite Images

Results from Use of GPS-Derived Control and Check Points

All satellite images were geometrically corrected to the UTM Zone 32 projection and to the WGS 84 ellipsoid.

TABLE 1. NUMBER AND TOTAL ROOT-MEAN-SQUARE ERRORS ($RMSE_{XY}$) OF THE CONTROL, CHECK, AND ALL POINTS (CONTROL PLUS CHECK POINTS), AFTER THE GEOMETRIC CORRECTION OF LANDSAT MSS, LANDSAT TM, AND SPOT PAN SATELLITE IMAGES USING EITHER GPS OR 1:100,000-SCALE TOPOGRAPHIC-MAP-DERIVED CONTROL POINTS

Satellite Image	Source of Points	Control Points			Check Points			All Points		
		No.	$RMSE_{XY}$ (m)	$RMSE_{XY}$ Pixels	No.	$RMSE_{XY}$ (m)	$RMSE_{XY}$ Pixels	No.	$RMSE_{XY}$ (m)	$RMSE_{XY}$ Pixels
Landsat MSS	GPS	5	± 11.3	± 0.14	14	± 36.7	± 0.51	19	± 32.1	± 0.44
Landsat MSS	GPS	7	± 19.1	± 0.25	12	± 32.6	± 0.46	19	± 28.4	± 0.40
Landsat MSS	GPS	9	± 22.7	± 0.31	10	± 31.8	± 0.44	19	± 27.9	± 0.39
Landsat TM	GPS	5	± 23.8	± 0.83	23	± 37.2	± 1.30	28	± 35.2	± 1.23
Landsat TM	GPS	10	± 25.4	± 0.89	18	± 35.7	± 1.25	28	± 32.4	± 1.14
Landsat TM	GPS	14	± 27.9	± 0.98	14	± 35.8	± 1.25	28	± 32.1	± 1.13
SPOT PAN	GPS	5	± 20.4	± 2.04	24	± 38.6	± 3.86	29	± 36.1	± 3.61
SPOT PAN	GPS	10	± 30.2	± 3.02	19	± 35.0	± 3.50	29	± 33.4	± 3.34
SPOT PAN	GPS	15	± 32.2	± 3.22	14	± 35.9	± 3.59	29	± 34.1	± 3.41
Landsat MSS	MAP	5	± 25.8	± 0.36	26	± 40.5	± 0.55	31	± 38.5	± 0.52
Landsat MSS	MAP	10	± 29.1	± 0.43	21	± 39.7	± 0.54	31	± 36.6	± 0.50
Landsat MSS	MAP	15	± 34.2	± 0.48	16	± 34.3	± 0.48	31	± 34.3	± 0.48
Landsat TM	MAP	5	± 23.4	± 0.82	33	± 39.7	± 1.39	38	± 37.9	± 1.33
Landsat TM	MAP	10	± 30.0	± 1.05	28	± 38.9	± 1.37	38	± 36.8	± 1.29
Landsat TM	MAP	15	± 32.8	± 1.15	23	± 36.0	± 1.27	38	± 34.8	± 1.22
SPOT PAN	MAP	5	± 33.5	± 3.35	32	± 44.4	± 4.44	37	± 43.1	± 4.31
SPOT PAN	MAP	10	± 33.7	± 3.37	27	± 44.1	± 4.41	37	± 41.5	± 4.15
SPOT PAN	MAP	15	± 36.6	± 3.66	22	± 36.9	± 3.69	37	± 36.7	± 3.67

The Landsat MSS subscene was geometrically corrected using five, seven, and nine GPS-derived GCPs, respectively. As stated earlier, this represented a minimum, medium, and maximum number of GCPs, given that the remaining points would be required for the independent checking procedure. Nineteen out of 29 GPS-derived points were used either as control or as check points. Only these points could be identified on the Landsat MSS image due to the relatively coarse spatial resolution of the sensor.

As shown in Table 1, the total RMS error values ($RMSE_{XY}$) for the points used in the least-squares transformation increased from ±11.3 metres (±0.14 pixels) for five GCPs to ±19.1 metres (±0.25 pixels) for seven GCPs, and to ±22.7 metres (±0.31 pixels) for nine GCPs. A more reliable indication of the fit between the two datasets was given by the total RMS error values for the check points (Table 1). These decreased from ±36.7 metres (±0.51 pixels) for five GCPs to ±32.6 metres (±0.46 pixels) for seven GCPs, and to ±31.8 metres (±0.44 pixels) for nine GCPs.

The Landsat TM subscene was geometrically corrected using five, ten, and 14 GPS-derived GCPs, respectively. Twenty-eight out of 29 GPS-derived points were used either as control or as check points, with only one GPS point not identified on the Landsat TM image.

As shown in Table 1, the total RMS error values for the points used in the least-squares transformation increased from ±23.8 metres (±0.83 pixels) for five GCPs to ±25.4 metres (±0.89 pixels) for ten GCPs, and to ±27.9 metres (±0.98 pixels) for 14 GCPs. The RMS error values for the check points decreased from ±37.2 metres (±1.30 pixels) for five GCPs to ±35.7 metres (±1.25 pixels) for ten GCPs, and they remained effectively the same for 14 GCPs at ±35.8 metres (±1.24 pixels).

The SPOT PAN subscene was geometrically corrected using five, ten, and 15 GPS-derived GCPs, respectively. All the GPS-derived points (29 points) were used either as control or as check points, because all of them were identified on the SPOT PAN image.

As shown in Table 1, the total RMS error values for the points used in the least-squares transformation increased from ±20.4 metres (±2.04 pixels) for five GCPs to ±30.2 metres (±3.02 pixels) for ten GCPs, and to ±32.2 metres (±3.22 pixels) for 15 GCPs. The total RMS error values for the check points decreased from ±38.6 metres (±3.86 pixels) for five GCPs to ±35.0 metres (±3.50 pixels) for ten GCPs, and increased a little to ±35.9 metres (±3.59 pixels) for 15 GCPs.

The above results reveal no significant differences in absolute locational accuracy between the corrections applied to the three types of image. The best accuracies range from ±31.8 metres for Landsat MSS, through ±35.0 metres for SPOT PAN, to ±35.7 metres for Landsat TM. It also appeared that the geometric correction accuracy was not always improved by increasing the number of GCPs. This was once again an indication that the errors in GPS measurements were not constant for each GPS point.

A further important point to note is that, when the GCPs themselves were used for assessing the accuracy of the corrections, they suggested a higher accuracy than the independent check points. They also implied that the correction could be improved by reducing the number of GCPs, while the independent points indicate that the reverse is the case. In practice, the fit of the GCPs themselves improved as their number was reduced, but this was not representative of the image as a whole.

Overall, these results indicated that the GPS-derived points in autonomous operation were well suited for the geometric correction of a Landsat MSS image, because the geometric correction accuracy obtained was on the order of 0.4 pixels, and marginally suited for the geometric correction of a Landsat TM image because the geometric correction accuracy obtained was on the order of 1.2 pixels. This was unsuitable for the geometric correction of a SPOT PAN image, because the geometric correction accuracy obtained was on the order of 3.5 pixels. However, this measure of suitability was based on the need for sub-pixel accuracy. The results of most geometric correction work are based on using the GCPs themselves for the assessment. Using such criteria, Table 1 indicates that the method would be suitable for Landsat MSS and Landsat TM data.

As shown in Table 1, the total RMS error values for all points (control plus check points) followed the same trend as the check points. The level of accuracy decreased as the number of control points increased, and leveled off for more than ten control points. Again, this was the reverse of the trend shown when assessing the fit using the control points. Thus, it was reasonable to conclude that, in practice, the geometric correction accuracy should be evaluated at independent check points instead of at the GCPs used in the least-squares transformation.

Results from Use of 1:100,000-Scale Map-Derived Control and Check Points

All satellite images were geometrically corrected to the UTM Zone-32 projection and to the Clarke 1880 ellipsoid using five, ten, and 15 1:100,000-scale topographic-map-derived GCPs, respectively.

In total, 31 points for the Landsat MSS, 38 points for the Landsat TM, and 37 points for the SPOT PAN images were identified both on the maps and on the images and used either as control or as check points.

Table 1 shows that the general trends found for the GPS-derived control points could also be seen for the map-derived points. The best accuracies ranged from ± 34.3 metres for Landsat MSS, through ± 36.0 metres for Landsat TM, to ± 36.9 metres for SPOT PAN. Once again, it could be seen that a more reliable measure of the accuracy of the correction was obtained with the use of independent check points. In this case, the accuracy of the correction improved as more GCPs were used.

The geometric correction accuracy using GPS-derived points was not greatly improved by increasing the number of GCPs to more than ten. This was due to the fact that the GPS measurements in autonomous operation included errors which were not constant either over time or for each GPS point. The errors of map coordinates, however, could be considered constant for all points, and the more GCPs used, the better the geometric correction accuracy became. Overall, all the geometric corrections demonstrated a marginal superiority for the GPS data, with a further advantage being that fewer points were needed to achieve the same accuracy as the topographic maps.

Conclusions

The geometric correction accuracy in metres was on the same order of magnitude for all satellite images being geometrically corrected. This result was found using either GPS- or map-derived control and check points. The geometric corrections with first-degree polynomials using either GPS- or 1:100,000-scale map-derived control points yielded RMS error values on the order of ± 35 metres, or ± 0.5 pixels for the Landsat MSS image, ± 1.2 pixels for the Landsat TM image, and ± 3.5 pixels for the SPOT PAN image.

The results indicated that, even in autonomous operation, GPS technology can be suitable for the geometric correction of Landsat MSS and Landsat TM imagery if the requirement is for single-pixel accuracy. Similar accuracy levels for SPOT imagery would require the use of GPS in differential mode. The level of accuracy demanded should be based on the particular application. A coarser result can be accepted for thematic work such as land-cover mapping than is the case for topographic mapping. The results could also be presented, therefore, by stating that, in the absence of suitable large-scale topographic maps, a GPS receiver in autonomous operation can collect control points which lead to a correction accuracy on the order of 35 metres for Landsat or SPOT imagery. An implication of the absence of topographic maps is that the GPS points must be chosen on the satellite images or on aerial photographs and then measured on the ground in order to obtain good ground control.

This study also demonstrated that it is desirable to evaluate the geometric correction accuracy at independent check points instead of at the GCPs used in the geometric correction procedure. This was illustrated by the fact that the GCP-based assessment implied that the correction was improved by using fewer points. While it may seem obvious that independent points should be used for the check, it is nevertheless a feature of most software packages that measures of correction accuracy are based on the GCPs alone.

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