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"Integration of Remote Sensing Data Sets by Rectification to
UTM Coordinates With the Use of Digital Terrain Models"

by

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Abstract

Digital analysis of integrated multisensor data sets acquired from aircraft and satellite platforms requires rectification of the data sets to a common geographical coordinate system. The relative importance of factors affecting registration are discussed quantitatively. The Universal Transverse Mercator projection was selected as the standard in an experiment to compare LANDSAT 4-channel multispectral scanner (MSS) data, aircraft 11-channel MSS data, and aircraft 4-channel synthetic aperture radar data for agricultural and forest test sites. For the aircraft imagery, a geometric correction scheme has been developed to model the flight path of the sensor relative to the ground. Digital terrain elevation models have been incorporated into the rectification process in order to correct for positional distortions due to topographic relief.

Introduction

Operational remote sensing systems meeting future needs must include the capacity to overlay multisensor and multitemporal imagery to subpixel accuracy and to integrate this digital imagery with geocoded data bases. This integration of various data sets implies the development of techniques to rectify imagery to a variety of map projections and to account for the effects of diverse viewing and sampling geometries under varying atmospheric and illumination conditions. These factors cause differences which are not related to the intrinsic properties of the targets under scrutiny, so they must be taken into account if interpretive analysis is to yield meaningful results. The radiometric and geometric correction of digital image data requires different approaches, depending on whether the data are acquired from aircraft or satellite, whether the sensor is a multispectral scanner (MSS) or a synthetic aperture radar (SAR), or whether the terrain is flat or has significant topographic relief (Goodenough, Guindon, and Teillet, 1979).

Since the Universal Transverse Mercator (UTM) projection is the primary geographic reference system in use in Canada, it was selected as the standard for our initial experiments at the Canada Centre for Remote Sensing (CCRS). Since topographic relief can lead to significant distortions for a given imaging geometry, the rectification to a map grid may also involve terrain elevation information.

It is well known that full scene rectification of LANDSAT MSS data can be accomplished by identifying the map and image coordinates of ground control points (GCPs) and approximating the image-to-image transformations by low-order polynomials. Accuracy is determined in large part by the precision with which the GCP map coordinates can be acquired. This relatively

straightforward approach has been successful primarily for LANDSAT MSS imagery because of its low resolution and narrow scan angle range, but future satellite sensors such as the LANDSAT-D thematic mapper and the high resolution vidicon (HRV) on SPOT will present more difficult problems because of significant distortions due to topography.

This paper discusses, in quantitative terms, the relative importance of factors affecting geometric rectification of both aircraft (SAR and MSS) and satellite imagery. A brief description of a geometric correction scheme developed for the case of aircraft MSS and SAR imagery of mountainous terrain is also presented. Approaches to radiometric correction of multisensor data sets with the use of digital elevation data will be the subject of another paper.

The data set used in this experiment includes 4-channel LANDSAT MSS data, 11-channel aircraft MSS data, and 4-channel aircraft SAR data. Two test sites have been studied: an agricultural area near Grand Falls, New Brunswick, Canada, and a forest area in the coastal mountains of British Columbia, Canada. Potato crops and rolling terrain with topographic relief on the order of 30 metres or more characterize the former site, whereas coniferous forest types and topography ranging from 275 to 1500 metres above sea level characterize the latter site. The dimensions of both test areas are 8 km by 8 km.

Factors Affecting Registration Accuracy

Several factors influence the geometric correction accuracy that one can attain when digitally overlaying multisensor data: (a) horizontal and vertical map accuracy; (b) distortions due to topography; (c) irregularities in sensor platform motions. Table 1 summarizes the magnitude of the first two factors in terms of pixels for three satellite systems (LANDSAT MSS, LANDSAT thematic mapper, and SPOT HRV) and two aircraft systems operated by CCRS (MSS and SAR).

1. Horizontal and Vertical Map Accuracy

In order to establish a transformation between an image and the corresponding UTM map, a number of common ground control points are required since sensor platform position and motion are not usually well enough known. Thus, the degree of which a given image matches the UTM coordinate system after rectification will depend on how precisely points are located on the map, as well as on the transformation function and the number and distribution of GCPs. The degree to which different images of the same terrain are in registration with respect to each other after the images have been rectified to the UTM grid is less dependent on map positional accuracy, provided the same GCPs are used in each case. Since GCP coordinates are extracted from maps, positional accuracy will be a function of map scale, class and projection. Canada has extensive UTM map coverage at 1:50,000 scale. The best of these maps (Class A) have an estimated error of ± 25 metres relative to the UTM grid. The horizontal and vertical map accuracies for the UTM maps which include the two test areas are given in Table 2. The positional accuracies listed are relative to the map grid and represent the 90 percent confidence level (1.65 standard deviations). Finally, we note from Table 1 that the spatial resolving power of forthcoming satellites will approach and surpass the best horizontal map accuracies available in Canada at 1:50,000 scale.

2. Topographic Relief

High-resolution aircraft MSS and SAR images exhibit severe positional distortions due to topographic relief. The scales of these distortions depend on sensor platform altitude and view angle. Even for the undulating terrain of the New Brunswick test site, distortions due to topography preclude a good overlaying of images rectified to a UTM grid without the aid of a digital elevation model (Goodenough, Guindon and Teillet, 1979). The discrepancies can be over 100 pixels for the mountainous terrain in our British Columbia test area (cf. Table 1).

In the case of the SAR data, topographic variations introduce layover, foreshortening, and shadowing. Layover is an extreme case of relief displacement and arises as a result of the slant range decreasing with increasing distance up steep slopes facing the radar. Since the SAR is an active sensor providing its own illumination, areas not in a direct line of sight will not be imaged and will therefore be in shadow. The MSS data is also affected by pixel offsets, shadowing and shape distortions (in the form of slope forelengthening rather than foreshortening). Shadowing in this case differs from shadowing in the radar situation because the imaging process is based on look angle rather than slant range and the direction of solar illumination does not coincide with the sensor viewing direction. Moreover, imaged terrain which is not directly illuminated by the sun will not be completely dark in an MSS image because of diffuse sky illumination due to atmospheric scattering. Thus, image distortions due to terrain can be dominant or comparable to the errors due to map inaccuracy in mountainous and undulating terrain (cf. Table 1). In order to achieve subpixel integration accuracy, topography must somehow be taken into account, even at the resolution of LANDSAT-D thematic mapper data. To accomplish this, one could try to rubber-sheet stretch many small areas of an image with lower-order polynomials or a larger area with a single higher-order function. In either case, this method requires a high density of GCPs, a requirement which cannot be met in remote areas of Canada.

Alternatively, terrain information can be incorporated into the rectification procedure by means of a digital elevation model (DEM). Such an approach also makes it possible to allow for topographic effects in radiometric corrections and digital image classification. A common source of DEMs is the digitization of map contours followed by resampling to a specified grid spacing. The resolution of a DEM produced in this way is limited by the vertical map accuracy for the map under consideration. A finer grid of elevations can be obtained from the correlation of stereo pairs of aerial photographs. However, such a technique requires more specialized equipment to produce the DEM. Automated production of digital elevation models still has its problems. Discontinuities arise between correlations obtained on tree tops and adjacent non-forested areas, as well as around bodies of water. Procedures to smooth these effects are difficult to apply in a reliable and efficient manner.

3. Irregularities in Sensor Platform Motion

The relative position of image points recorded by a scanning sensor like the MSS will be affected by variations in the aircraft flight trajectory. Changes in aircraft velocity or height above ground expand or contract image scale in the along-flight direction; altitude variations also affect the image scale in the scanning direction. Deviations in aircraft attitude lead to a variety of distortions due to roll, pitch and crab motions. Although sophisticated techniques have been devised to compensate for these effects while in flight, residual distortions may still exist. In order to minimize the effect of these residual problems, we have chosen to work on small test areas.

The SAR case is somewhat different in that compensation is required only for those motions which affect the doppler phase history of target returns. An on-board navigation system is essential to guide the aircraft along a straight line and to keep the antenna directed toward zero doppler during aperture synthesis. A motion compensation subsystem applies finer phase corrections (Rawson, Smith, and Larson, 1975). Again, the effect of residual errors is minimized by the choice of a small test area.

Flight Line Modelling

Having concluded that the effects due to topography are greater than those due to map inaccuracies on the rectification of aircraft data in mountainous terrain and even in rolling countryside, one is faced with the problem of actually incorporating a DEM into the geometric rectification scheme. To rectify a given image to UTM coordinates requires knowledge of terrain elevations, but elevations are given in terms of UTM coordinates.

One approach to solving this circular problem is to determine the location of the flight path in map space (Goodenough, Guindon and Teillet, 1979). If a series of GCPs are available with known image coordinates, map coordinates, and elevations, then the ground range to each ground control point can be determined from the geometry of the sensor. The flight path can be thought of as a trajectory in map space which is tangent to circles centered on the GCPs with radii equal to respective ground ranges to the GCPs.

For the short flight lines required to cover our test sites, a reasonable first approximation to the flight path is a straight line flown at constant altitude with no attitude variations. Such a path can be uniquely specified by the aircraft heading and one ground point over which the aircraft has flown. With the flight parameters and the relationship between image line number and distance travelled along the flight line in hand, one can uniquely relate a map coordinate set including elevation to a corresponding image set. Geometric correction can proceed if a DEM can be obtained or produced for the map area of interest. FIGURE 1 shows the overall data flow for the geometric rectification of aircraft data of topographically varied terrain. Further details on the flight line modelling technique may be found in Guindon, Harris, Teillet and Goodenough (1980).

The flight modelling approach has been used on the aircraft imagery of our two test sites: the agricultural area in New Brunswick where the terrain is rolling and many GCPs are available, and the forest area in British Columbia where the terrain is very rugged and GCPs are few. In order to estimate the overlaying accuracy of the flight modelling procedure, image coordinates of selected control points were measured on each of the independently rectified images. Results of overlaying accuracies are given in Table 3 for various data sets. The difference in accuracy between the two test sites is clearly discernable. A considerable improvement in registration accuracy can be obtained by carrying out image-to-image registration on the rectified image channels. It is concluded that one cannot achieve positional accuracies for aircraft data of better than 10 metres in the case of rolling terrain and 20 metres in the case of mountainous terrain.

Concluding Remarks

Factors affecting geometric registration accuracy have been discussed in the context of integrating remotely sensed data by rectification to a UTM map coordinate system. The geometric correction of high resolution aircraft and satellite imagery is constrained by present map accuracies and topographical distortions to a range of 10 to 20 metres. In particular, pixel offset problems arising in high-resolution imagery because of terrain relief make it necessary to abandon procedures established for the rectification of LANDSAT data. The use of digital elevation information in the rectification scheme becomes essential.

As a consequence of these problems, as well as the vastness of Canada and the limited number of ground control points generally available, sophisticated attitude modelling procedures with as much automation as possible will have to be established to ensure geometric fidelity in satellite and aircraft imagery. The use of detailed navigation and attitude information, now being recorded during aircraft remote sensing missions and expected for forthcoming satellite systems, will become an integral part of image processing prior to analysis.

References

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Table 1
Topographically Related Distortions in Satellite and Aircraft Imagery

	LANDSAT MSS	LANDSAT-D TM	SPOT HRV*	Aircraft MSS	Aircraft SAR Steep	Aircraft SAR Shallow
Maximum scan angle off nadir (far range for SAR)	5 ^o .8	7 ^o .5	29 ^o	45 ^o	~ 55 ^o	~ 70 ^o
Pixel size (metres)	79	30	13.3	~7	3	3
At scan angle limit (or far range):						
(a) Elevation change (metres for a one-pixel offset	780	230	24	7	5.2	8.8
(b) Pixel offset for terrain elevation changes of:						
100 metres	0.13	0.44	4.2	14	19	11
2000 metres	2.6	8.7	8.4	280	382	228
Canadian Class A horizontal map accuracy (in pixels):						
1:50,000 scale	0.32	0.83	1.9	3.6	8.3	8.3
1:250,000 scale	1.6	4.2	9.4	18	42	42
Horizontal map accuracy (in pixels) for Canadian 1:50,000 map including test area at:						
Grand Falls, N.B.	1.3	3.3	7.5	14	33	33
Anderson River, B.C.	0.95	2.5	5.6	11	25	25

(* Monospectral Mode)

Table 2
 Accuracies for the UTM Topographic Maps Which
 Include the Test Areas (Surveys and Mapping Branch, 1980)

Test Site:	Grand Falls, New Brunswick	Anderson River, British Columbia
UTM Topographic Map Sheets:	21-0/4 & 21 N/1 1:50,000 scale	92 H/14, 92 H/11 1:50,000 scale
Horizontal Map Accuracy:	± 100 metres	± 75 metres
Vertical Map Accuracy:	+ 50 feet (15 metres)	+ 100 feet (30 metres)
Contour Interval:	50 feet (15 metres)	100 feet (30 metres)

Table 3
 Estimates of the Aircraft Data Rectification
 Accuracy in the Flight Path Modelling Technique

<u>Data Set</u>	Standard Deviations of Control Point Position Estimates (Metres)		
	<u>East-West</u>	<u>North-South</u>	<u>Overall</u>
<u>Grand Falls, N.B.:</u>			
- Rectified SAR channels	20	11	23
- Rectified SAR channels after subsequent image-to- image rectification	5.2	4.2	6.7
<u>Anderson River, B.C.:</u>			
- Rectified SAR channels	29	19	35
- Rectified MSS + SAR channels	33	19	39
- Rectified MSS + SAR channels after subsequent image-to- image registration	8.8	9.7	13

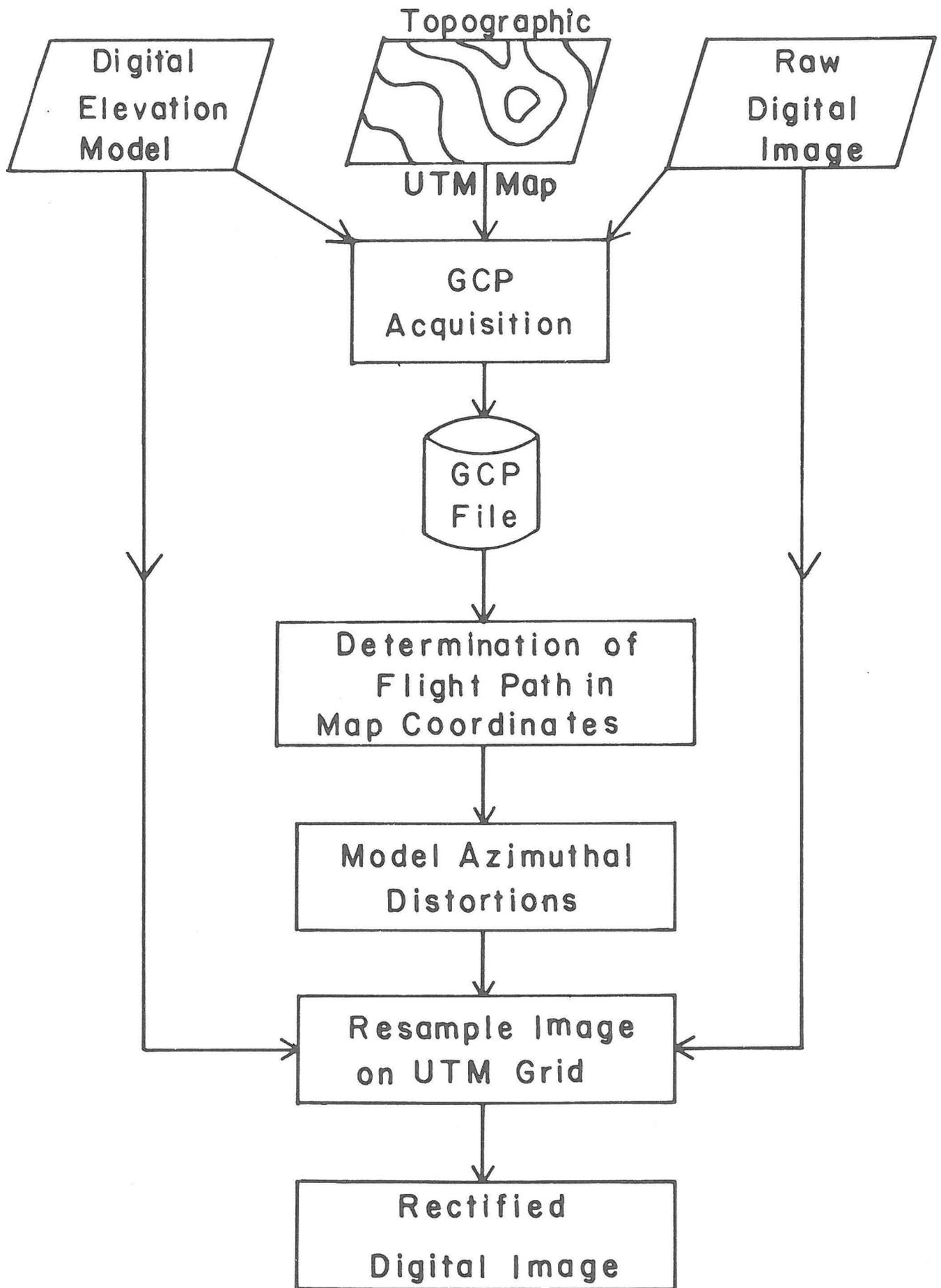


FIG. 1: Geometric Correction of Aircraft data of topographically varied terrain