CARTOGRAPHIC CONSIDERATIONS FOR THE INTEGRATION OF LANDSAT DIGITAL IMAGERY WITH EXISTING SPATIAL DATA

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I. Introduction

Anyone interested in the merger of spatial data from different sources must register the various inputs to a common projection. While the registration accuracy requirements may vary from application to application, the problems associated with data integration remain -- whether the data are merged via physical overlays or combined digitally as in a digital information system.

The rectification of Landsat Multispectral Scanner (MSS) digital data to a map projection or the scene-to-scene registration of MSS digital data requires corrections not only for the new map projection, but also for a variety of distortions. MSS digital image distortions exist due to the combined effects of sensor operation, orbit and attitude anomalies, the Earth's rotation, and atmospheric and terrain effects (1).

This report describes the procedure used to overcome the cartographic problems association with the rectification and registration of Landsat digital data to USGS 1:24000 topographic maps.

II. Background

The work reported in this paper is part of an on-going joint project between Goddard Space Flight Center (GSFC) and the Bureau of the Census (2). The program goal is to develop methods for the application of major urbanized areas in the United States (3). Current research is directed toward statistical procedures for the identification of land cover change within the urban fringe. The present investigation will use data from ten different Landsat images corrected to the universal transverse mercator (UTM) map projection and registered to each other at an accuracy better than one pixel (4).

III. Study Site

The Denver study site is an area of approximately 2975 square kilometers centered on Denver, Colorado. The area is situated in the Great Plains physiographic region to the east of the Rocky Mountains at an elevation of about 1.6 kilometers. Denver is fairly dry with an average precipitation of only 36 centimeters annually. Around the city are dry land agriculture to the east, range land to the northwest and south, wet land agriculture to the northeast and southeast. The Rocky Mountains are to the west. The city has extensive older residential areas to the west and south. This combination of land usage makes Denver a study area of considerable diversity.

IV. Registration Procedure

The Digital Image Rectification System (DIRS) (5) was selected for rectification (to UTM coordinates) and registration of the MSS imagery for the Denver Study. DIRS is a collection of programs written for an IBM 360/91 computer running with an OS/MVT operating system. DIRS runs are submitted as batch jobs and do not require special image processing hardware. The programs use up to 500K bytes of memory (larger amounts are needed to do image rotation), at least five tape drives and a moderate amount of direct access (disc) storage. Run times vary from less than one minute to eight minutes or more depending on the amount of image data being processed, the number and type of shade prints and edge correlations required, and the type of resampling used.

A. Reformatting

DIRS processing begins with reformatting standard Landsat MSS Computer Compatible Tapes (CCTs). CCT data for the four image strips are reformatted to full scene scan lines in band interleaved by pixel format. Synthetic (duplicate) pixels inserted in ground processing are deleted as are the calibration data at the end of each CCT line segment. The scene identification and annotation records are copied onto the DIRS "Composite" tape to retain scene identification.

B. GCRs

The development of ground control points (GCPs) is the most time consuming phase of the procedure. In Denver, the study area covered twenty 1:24000 topographic maps. Approximately fifty locations were considered for GCPs. However, a number of points were unusable because they were not distinct either in the Landsat image or on the ground. The twenty-seven final points chosen gave a good distribution throughout the study area. A considerable amount of time was saved during this phase through the use of an interactive color graphics display and analysis system available at GSFC. The Interactive Digital Image Manipulation System (IDIMS) made it possible to approximate rapidly the position of candidate GCPs in the image. Using these approximate coordinates, subscenes were then enlarged by a 7x7 expansion using cubic convolution resampling. This magnification procedure reduces the location error and permits sub-pixel location of image control points.

The DIRS system allows for up to 10x10 cubic convolution expansion of image data before display as line printer shade prints. Line printer products, of course, do not display the information of a three color graphics terminal nor do they allow the automatic extraction of coordinates. The DIRS approach, however, avoids the requirement for an expensive graphics display device.

C. Global Mapping Function

In order to create a mapping function DIRS requires both image coordinates and easting, northing coordinates for GCPs. Fortunately our facility includes a geographic entry system which computes geographic coordinates from topographic maps. While this procedure, too, can be done manually, it would be at a cost of considerable time and an almost certain loss in accuracy.

The GCP data developed previously are used to define functions which make transformations between map and image spaces. Three types of global mapping functions are available in DIRS: affine transformation, two-dimensional least squares polynominals, and attitude model functions. The choice of the most appropriate method depends upon the number of GCPs and their distribution over the image area.

For this project the two dimensional least squares polynominal functions were used. In this method four functions are computed using a least squares fit to the GCP data. These functions are:

$$S = f_1(E, N)$$
$$L = f_2(E, N)$$
$$E = f_3(S, L)$$
$$N = f_4(S, L)$$

where S is the sample coordinate, L, the line coordinate, N, the northing coordinates, and E, the easting coordinate. These functions are polynominals in two variables and may be defined as first-, second-, third-, fourth-, or fifth-degree polynominals. The number of GCPs available determines the maximum degree of the polynominals. The polynominals have the following general form:

$$\begin{aligned} Z = C_0 + C_1X + C_2Y + C_3X^2 + C_4XY + C_5Y^2 + C_6X^3 \\ + C_7X^2Y + C_8XY^2 + C_9Y^3 + \ldots \end{aligned}$$

These functions are continuous and global and therefore offer advantages over the affine transformation if an entire scene or a large portion of a scene is to be rectified. However, they have inherent limitations due to the need for a large number of GCPs and the requirement that the edges and corners of an image be well covered by GCPs. Since the study area for this project is much smaller than a full Landsat scene (10%), the edge problem was avoided by use of GCPs beyond the edges of the study area. Reference (5) discusses the affine and attitude model functions.

D. Rectification

The global mapping function could be used directly to transform the image data into the desired map projection. This is not practical, however, due to the enormous amount of computation required to evaluate these functions over millions of points. The solution to this problem is the creation of an interpolation grid. The global mapping functions are evaluated at each mesh point in a grid covering the image area, and then an efficient bilinear interpolation technique is used to map points within each grid cell.

The interpolation grid is composed of approximately 20 horizontal and 20 vertical grid lines. When each mesh point is known in both UTM and image coordinates, one is ready to map the image data in an efficient manner. The mapping is actually an inverse mapping; i.e., it proceeds from the map space (output coordinate system) back into the image space (input coordinate system). This arrangement has the advantage of allowing interpolation to occur in the input (image) space instead of the output (map) space. This proves to be a much more convenient approach than forward mapping.

Prior to the generation of the mapping function used in the resampling run, a test of the GCPs was made to identify points which may be inaccurately located. Test results must be reviewed carefully because a residual in the location of a point may not mean that the point is inaccurately placed. It may indicate that the point is important in the solution of the mapping function. This occurs particularly for isolated GCPs. The test run, besides evaluating the individual GCPs, provides a measure of the suitability of the order of the polynominal mapping function. Based upon test results for second and third order polynominals the third order equation was used in the actual rectification. The size of the subscene, the number of control points and the order of the mapping equation all contribute to scene registration accuracy. This test indicates the accuracy of the combination of these parameters.

E. Resampling

With the mapping function established, resampling can proceed. Resampling refers to the determination of an image intensity value at a given location. Typically, this location falls between and not on exact pixel centers and some form of interpolation is required. Two interpolation techniques are available in DIRS. The simplest and most efficient method is nearest neighbor. In this method the pixel whose center is nearest to the resample location is used to supply the intensity value at the resample location. This method introduces up to one half sample and line of geometric error. The second resampling technique provided in DIRS is cubic convolution. This method was developed by TRW and is an efficient approximation to the theoretically optimum interpolation using sin(x)/x. (6) While cubic convolution is much more efficient than sin(x)/x, it is a great deal slower than the nearest neighbor method.

Before resampling all four bands using cubic convolution, a test run was made for MSS 5 using nearest neighbor resampling. This product displayed via a film recorder confirmed that the desired subimage area was extracted. A second resampling run using cubic convolution was made to extract a rectified and rotated image of all four MSS bands with scan lines oriented in an east/west direction.

F. Registration

A primary advantage of DIRS is a convenient edge correlation method for the registration of subsequent scenes. The labor of GCP location for image rectification to a map projection is only required for the first scene in the sequence. Subsequent scenes are then registered to the first. This means that points common to the two images must be identified but it does not require that they be located on maps. Therefore, one may use the original GCPs as possible correlation candidates and one is free to try any other features common to the images. This procedure demands little effort from the user and, thus, makes the processing of a large number of potential correlation points possible.

The correlation technique used for scene-to-scene registration was developed for NASA by the Computer Sciences Corporation for the large area crop inventory experiment (LACIE) and is a very reliable technique (7). It is based on the generally valid assumption that image edges are invariant with time.

The edge extraction process begins with the computation of a reflectance gradient value at each pixel location. This is done over the target subimage area and the search area in the second scene. A gradient histogram is then constructed for each of the subareas. The user specifies a threshold to determine the percentage of edge pixels, generally about 20 percent. The resulting edge images are then cross-correlated and the point of maximum correlation is identified. The GCP coordinates in the target subimage are then mapped into the search area and this point represents the image coordinates of the GCP in the second scene. Accuracies of plus and minus one sample and line are achieved with edge correlation. The reliability of the method is in excess of 80 percent.

The correlation points found in a pair of scenes provide a basis for creation of a mapping function just as GCPs did in rectifying the first scene. By transforming the correlation points in the subsequent scenes through the global mapping function of the first scene a relationship between image coordinates and map coordinates is established and the geometric transformation proceeds just as before.

This process produces a set of registered, rectified subscenes which can be digitally overlayed and used for change detection analysis.

V. Results

To evaluate the rectification of the scenes, shade prints scaled to 1:24000 were generated for an area of downtown Denver containing a number of prominent roads and lakes. These prints were overlaid upon the USGS topographic map for the same area. Features aligned very well over the entire area. Since the purpose of the rectification was to investigate change detection techniques and not to evaluate DIRS, a quantitative measure of rectification was not attempted.

However, scene-to-scene registration was evaluated quantitatively using a gray level correlation scheme available on the VICAR System (8) at GSFC. To test the registration sixteen points evenly distributed across the image were chosen. Except where clouds were present (or, as in one image, data was missing) each point in all of the registered scenes was correlated to the master scene which had been rectified to the map projection. Typical registration errors were less than 0.20 pixels. Several scenes had points with errors greater than 0.75 pixels. In all cases with errors over 0.70 pixels the areas contained land cover which was highly variable due to seasonal or climatic conditions. Streams or lakes were present and/or field borders were not well defined. These factors tend to affect the gray level correlation more than they would the binary edge technique used to achieve the scene-to-scene registrations. In all areas where reliable correlation features existed, the images correlated to within less than 0.70 pixels.

VI. Conclusions

Anyone working with Landsat MSS digital data generated prior to the routine geometric corrections planned for Landsats C and D must contend with various distortions in the data. If a close rectification is required, some correction will be necessary.

The Digital Image Rectification System offers a number of advantages to the user. The software is readily available at a nominal fee through COSMIC (the NASA software distribution facility at the University of Georgia). The software does not require specialized hardware such as a graphics terminal. Rectification of a scene to a map is time consuming, but subsequent scene-to-scene registrations proceed rapidly. Finally, DIRS is capable of producing images registered to subpixel accuracy as demonstrated by the Denver, Colorado, work.

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