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REGISTERING THEMATIC MAPPER IMAGERY TO DIGITAL ELEVATION MODELS

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ABSTRACT

Several problems arise when attempting to register Landsat Thematic Mapper (TM) data to U.S. Geological Survey digital elevation models (DEMs). Chief among these are:

* TM data are currently available only in a rotated variant of the Space Oblique Mercator (SOM) map projection. Geometric transforms are thus required to access TM data in the geodetic coordinates used by the DEMs. Due to positional errors in the TM data, these transforms require some sort of external control.

* The spatial resolution of TM data exceeds that of the most commonly available DEM data. Oversampling DEM data to TM resolution introduces systematic noise. Common terrain processing algorithms (e.g., slope computation) compound this problem by acting as high-pass filters.

I. INTRODUCTION

Many applications of Landsat Thematic Mapper (TM) data are contingent upon the image data being registered with a geographic database. In particular, the use of TM data to derive surface reflectance information requires knowledge of the terrain characteristics (elevation; attitude; relation to surrounding terrain) of each image pixel (Dozier, 1984). Digital terrain information for areas in the United States is readily obtained from the "digital elevation models" (DEMs) distributed by the National Cartographic Information Center (NCIC, 1982). This paper will therefore examine some of the problems inherent in coregistering TM and DEM data.

II. BACKGROUND

A. GEOMETRIC CHARACTERISTICS OF TM AND DEM DATA

The instantaneous-field-of-view (IFOV) of the TM, at a nominal spacecraft altitude of 705.3 km, yields a spatial resolution of 30 m (120 m for band 6) at the Earth's surface (Engel, 1980). The geometry of an unprocessed TM scene is quite complex (Beyer, 1980) and will not be discussed here, since almost all investigators utilize geometrically preprocessed ("P"-level) TM images (NASA, 1982; 1983). P-level TM data are resampled to a 28.5 m pixel size and are cast into the Space Oblique Mercator (SOM) map projection, a cylindrical projection whose centerline is the satellite groundtrack (Snyder, 1981). Other map projections, notably Universal Transverse Mercator (UTM) and Polar Stereographic, are to be provided in the future.

NCIC DEM data are currently provided in two formats. The higher resolution data are 30 m grids in the UTM projection, registered to standard U.S. Geological Survey 7.5 minute 1:24000 scale map quadrangles. The lower resolution data are 3 arc-second (approximately 90 m at the equator) geodetic grids, derived from and registered to USGS 1 degree by 2 degree 1:250000 scale map quadrangles. Low resolution DEM data are available for the entire United States. High resolution data are presently available only for selected areas.

B. DATA USED IN THIS INVESTIGATION

The DEM data source for this investigation was a 3 arc-second resolution geodetic grid corresponding to sheet NJ11-10 (Fresno, CA) of the USGS 1:250000 scale map series. A subset equivalent to the Mt Tom, CA quadrangle of the USGS 1:62500 scale map series was extracted for a study area. Higher resolution DEM data were not available for this area.

The TM data source was a P-level tape of scene E-40186-18024 (path 42, row 43, 18 January 1983), in the SOM projection with 28.5 m pixels. A subscene encompassing the Mt Tom quadrangle was extracted.

Coregistering these data sets thus involved the following operations:

* a geometric transformation between SOM and geodetic coordinates

* resampling one of the data sets to the resolution of the other

III. GEOMETRIC TRANSFORMATIONS

Image geometric transformations are generally run in reverse (Bernstein, 1975); that is, locations in a target image are mapped into a source image, from which pixel values are selected to be placed in the target image. This guarantees that every location in the target image will be assigned a value. For this investigation, the target image was selected to be the TM image; i.e., the DEM data were to be registered to the TM data. Selection of the TM image as the target was based on two considerations: retention of spatial resolution, and avoidance of double-resampling.

Mapping TM image locations into the DEM grid is a 3-step process:

[1] convert TM image coordinates ($line_T$, $sample_T$) to SOM coordinates (x, y); then

[2] convert (x, y) to geodetic coordinates (ϕ, λ); then

[3] convert (ϕ, λ) to DEM grid coordinates ($line_D$, $sample_D$)

Step [1] is complicated by the fact that the TM image grid is rotated and shifted with respect to the Landsat SOM coordinate system. Presumably, the image grid is rotated so as to align as closely as possible with the raw TM scan lines, and thus minimize the line-buffering required to construct a corrected TM scan line. The rotation and offset information necessary to perform step [1] is obtained from the HAAT (header, ancillary, annotation, and trailer) data file on the TM P-tape.

Step [2] performs the transformation from UTM to geodetic coordinates. For this investigation, routines from the USGS General Map Projection Package were used (Thormodsgard and DeVries, 1982). Step [3] is trivial, since the DEM grid is aligned with the geodetic coordinate system.

Instead of evaluating steps [1-3] above for each point in the TM image, a regularly spaced mesh of 300 TM locations were transformed. The resulting list of $line_T$, $sample_T$, $line_D$, $sample_D$ was fed into a stepwise regression program, which generated the coefficients of two polynomial mapping functions. For the study area selected, all terms higher than first order were insignificant. A general-purpose image warping program evaluated these polynomials to assign each TM grid location a counterpart in the DEM grid. The revised geometric processing sequence is thus:

[a] Evaluate the complete TM-SOM-geodetic-DEM coordinate transform sequence for a sparse mesh of TM grid locations.

[b] Perform a stepwise regression on the location pairs generated in step [a] to determine a the coefficients of simple polynomial transforms.

[c] Substitute the polynomials from step [b] for the transforms in step [a], and compute the TM-DEM transform directly.

Steps a-c are computationally much faster than steps 1-3, since the SOM-geodetic transforms in particular require extensive trigonometric calculations.

The procedure outlined so far assumes that both the TM and DEM data are precisely located in their own coordinate systems. The DEM data have been planimetrically edited, but the TM data still contain gross linear positional errors, apparently due to uncertainties in the satellite position. That the errors are positional rather than attitudinal is inferred by the fact that a simple translation may bring the TM and transformed DEM grids into registration. In our investigation, this final translation was accomplished by displaying the instantaneous difference between the two images on a video display processor (IIS, 1979) while moving one of them under trackball control.

IV. RESAMPLING

The DEM data must be resampled to assign elevation values to any non-integral DEM locations selected by the above transforms. Two resampling algorithms were tried: nearest neighbor (zero-order) and "cubic convolution" (Simon, 1975). To match the spatial resolution of the TM data, the DEM data must be oversampled - a single DEM pixel will map into several TM locations. For this reason, nearest neighbor resampling produced an unacceptably "jagged" output image (essentially, a zoom-by-replication operation), and cubic convolution became the preferred resampling method.

An unfortunate side effect of the scale change in the elevation data was apparent with both resampling methods. The oversampling caused the orientation of the raw DEM grid to be visible as a regular pattern in the "jagged" edges. The effect was naturally more noticeable with nearest neighbor resampling, but was also present when cubic convolution resampling was used.

The presence of regularities in the resampling-induced discontinuities had a severe impact on the generation of terrain slope information. Our standard terrain processing involves the generation of two gradient images, one representing the magnitude (slope), and the other the direction (exposure). Since the gradient operation acts as a high-pass filter, the resampling-induced grid pattern was accentuated in the slope and exposure images, essentially swamping them with high-frequency systematic noise.

Various approaches were tried to mitigate this problem. Cubic convolution produced less noise than nearest neighbor resampling. The slope image was less noisy when computed from the raw DEM data and then resampled to TM resolutions, than when computed from the resampled elevation data. This approach could not be used for the exposure image; since exposures are stored azimuthal angles, values which overflow or underflow are handled incorrectly.

V. CONCLUSIONS

Three problems currently impede the integration of TM and DEM data:

- In most circumstances, TM and DEM data are not available in the same map projection, necessitating geometric transformation of one of the data types. This problem should be alleviated by the forthcoming general availability of TM and DEM data in the UTM projection.
- The TM data are not accurately located in their nominal projection. Human intervention is required to fine-tune image locations. Introduction of ground control points into the P-tape generation process, already in progress, should improve this situation.
- TM data have higher resolution than most DEM data, but oversampling the DEM data is not practical. The full resolution of TM data thus cannot be expoited over areas where high-resolution DEM data are unavailable.

A. FURTHER WORK

When TM and DEM data which meet the above criteria are available for a mountainous region, relief displacement effects should be investigated. Simple "back-of-the-envelope" calculations indicate that relief displacements of up to 10 pixels could be expected in a study area like that used in this investigation.

Given TM and DEM data of equivalent spatial resolutions, the desirability of registering the TM data to the DEM grid, rather than the reverse, should be investigated. While this approach involves re-resampling the TM data, it allows the use of an unrotated grid as the geographic reference.

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VI. REFERENCES

Bernstein, Ralph, 1975, Digital image processing. Photogrammetric Engineering and Remote Sensing, vol. 41, pp. 1465-1476.

Beyer, Eric, 1981, An Overview of the Thematic Mapper Geometric Correction System (draft). General Electric Company.

Dozier, Jeff, 1984, Reflectance Measurements from Landsat Thematic Mapper Data over Rugged Terrain. Tenth International Symposium, Machine Processing of Remotely Sensed Data (this volume).

IIS, 1979, Product Description: Model 70/E Image Computer and Display Terminal. International Imaging Systems, Milpitas, CA.

Engel, J.L., 1980, Thematic Mapper - an Interim Report on Anticioated Performance. American Institute of

Aeronautics and Astronautics.

NASA, 1982, LASLIB-CCT/LAS-CCT Tape Format Document for Thematic Mapper.

NASA, 1983, Thematic Mapper Computer Compatible Tape (CCT-AT, CCT-PT).

National Cartographic Information Center, 1982, User Guide to Digital Elevation Models (draft).

Simon, K.W., 1975, Digital image reconstruction and resampling for geometric image manipulation. _Symposium on Machine Processing of Remotely Sensed Data_, pp. 3A-1-3A-11.

Snyder, John P., 1981, Space Oblique Mercator Projection Mathematical Development. _Geological Survey Bulletin 1518_, Washington, DC.

Thormodsgard, June, and Darla De Vries, 1982, Georeferencing Landsat-4 - test program xlocat. EROS Data Center, Sioux Falls, SD.

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