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7.9 GEOMETRIC VERIFICATION

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Before proceeding with a discussion of geometric verification methods, a brief review of present Landsat data formats will clarify how both geodetic location and registration capabilities were defined. Since February 1979, Landsat multispectral scanner (MSS) data has been processed through the master data processor (MDP). The definition of the fully processed output image arrays (P-tape products) was intended to facilitate both geodetic location and temporal registration of image pixels. The world reference system (WRS) nominal image centers defined in degrees and integer minutes of latitude and longitude were selected as the reference points in output images. Framing of MSS images was defined to locate the WRS nominal image center on the center line (line 1492) of the output array. The phasing of the geometric resampling process was defined to locate the WRS center exactly on a pixel (not necessarily the center pixel) of the center line. Finally, at the WRS pixel the orientation of the center line relative to rectangular map coordinates was specified for each WRS.

By the above definitions, the geodetic location of pixels in a P-tape image lie on a 57 x 57 meter grid rotated by a specific angle (about the WRS pixel identified in P-tape header) relative to the rectangular coordinates of the map projection used. Two images for a given WRS can be registered by simply shifting one of the arrays in the along scan line direction to account for the difference in pixel locations of the WRS center.

As an aside, fully processed output arrays for return beam vidicon (RBV) data were defined as 19 x 19 meter grids overlaying the MSS grids (3 x 3 array of RBV pixels for each MSS pixel). A pixel and line number referencing each RBV subframe relative to a WRS pixel are given in the header of an RBV P-tape. This definition of RBV arrays was intended to provide a registration capability between RBV and MSS.

The accuracy of a P-tape image is a function of the geometric modeling which determines where image data are located in the P-tape array. Since there is only one geometric model used in the MDP, geometric location accuracy depends on the absolute accuracy of the model and registration accuracy is determined by the stability of the model. Due primarily to inaccuracies in data provided by the Landsat attitude measurement system (AMS), desired accuracies are attainable only by using ground control points (GCP) and a correlation process.

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Control points consist of 32 x 32 arrays of MSS data with locations defined by latitude and longitude. When maps are available, the locations are derived from the maps and both location and registration accuracy will be improved. Without maps, locations are derived from a reference P-tape image using the array location definition previously discussed. In these cases only the stability of the geometry and, therefore, the registration accuracy is improved.

The performance specifications for MSS P-tape data were .5 pixel (per axis) geodetic location and .3 pixel (per axis) registration. In the development of the MDP, this specification was taken with reference to input pixel instantaneous field of view (IFOV) of approximately 80 meters. In terms of the 57 meter pixel spacing of output P-tape arrays, these specifications convert to .7 pixel (per axis) geodetic location and .4 pixel (per axis) registration. This performance requires successful correlation of 20-25 well distributed control points in an MSS image. The geodetic location specification also requires the control points to have location errors less than 35 meters (rms) relative to refence maps.

The verification of system performance with regard to geodetic location requires the capability to determine pixel positions of map points in a P-tape array. Verification of registration performance requires the capability to determine pixel positions of common points (not necessarily map points) in 2 or more P-tape arrays for a given WRS scene. It should be noted that registration measurements will identify changes in location, while the difference between location measurements yields the registration error. Thus an accurate geodetic location verification provides registration data and registration verification can provide location data if one of the P-tapes has been verified geodetically. This relationship offers the opportunity for alternate (or mutually checking) implementations for verification of geometry.

Since the building of a GCP library for the MDP consisted of accurately identifying the locations of 32 x 32 MSS arrays relative to maps, the library build function demonstrated a method for location verification. The location funtion was accomplished by a manual overlay of a map feature and a cathode ray tube (CRT) display of MSS data. The overlay was accomplished using a Bausch and Lomb zoom-transfer scope which provides an optical superposition of 2 inputs through a binocular viewer. The inputs were a CRT display of MSS data (scaled according to available map scale) and the actual map with a feature identified. The manual overlay of the superimposed binocular view consisted of simply moving the map to give the best fit to the displayed MSS data. The specific point on the map for which latitude and longitude had been defined was then identified by moving a cursor on the CRT display. The cursor position identified the center of the 32 x 32 GCP array to be stored in the MDP library and the fractional pixel location of the defined latitude and longitude within the 32 x 32 array.

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Using this technique f r geodetic location verification is straightforward. For a selected map feature, the expected pixel and line number location in a P-tape image can be calculated from the latitude and longitude using the appropriate map transformation and rotation of coordinates previously described. This calculated location identifies the area of MSS data to be displayed on the CRT. The cursor position after manual superposition identifies the measured pixel and line number location of the map feature. The location error is simply the difference between the expected and measured locations.

An improved version of this technique can be developed by converting the selected area of a map to a digital video signal and combining the map and MSS displays directly onto the CRT display. A short study by IBM demonstrated that this superimposed display facilitates the manual overlay function.

Techniques for registration verification can be more varied and automated since map data are not required. Although correlation of common features would be possible, edge detection and correlation of arbitrary areas is probably preferable. Goddard's Large Area Crop Inventory Experiment (LACIE) processor used edge detection and matching to extract sample segments (117 lines, 160 pixels) registered to a reference segment. This system met its specified registration goal of 1 pixel (rms). However, all LACIE extractions were verified by manually comparing film images of the extracted segments with the reference segment and a small percentage were rejected due to registration errors. This experience demonstrated the need for a manual backup test. Rather than using film images, a CRT display with the capability to flicker between 2 test areas is recommended for verification testing. This manual mode would not have a strict accuracy requirement since it would only be used to assure that a correlation should exist.

One additional lesson can be learned from the LACIE System. During the development effort, experiments showed that edge data of a single MSS band were not necessarily invariant with seasonal changes. In fact, edges appearing in one band for one season occasionally appeared in another band for another season. This effect lead to the use of composite edge images using MSS bands 5 and 7. Similar considerations may be required in a registration verification system.

Although automated verification methods are highly desirable, manual processes are presently necessary when dealing with maps and advisable for verifying registration correlations. Manual processes offer an additional verification capability in terms of exposing higher frequency distortions in image data. Automated correlation functions produce mean results for the areas correlated and may be insensitive to registration errors in smaller areas.

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The implementation of a verification system will depend on the number of measurements required per image and the number of images to be verified. In turn, these requirements depend on user expectations implied by performance specifications. The final question is: which of the following verification levels are required by data users?

a) 100 percent of pixels in an image within specifications

b) Less than 100 percent, but some minimum percent of pixels in an image within specifications

c) A probability that an image meets specification

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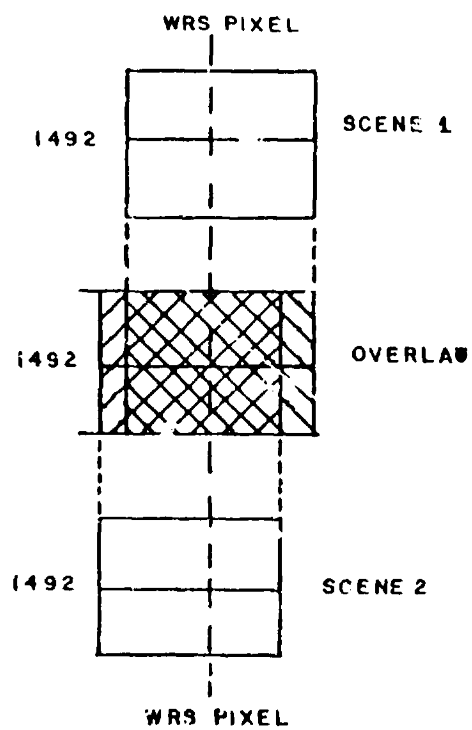

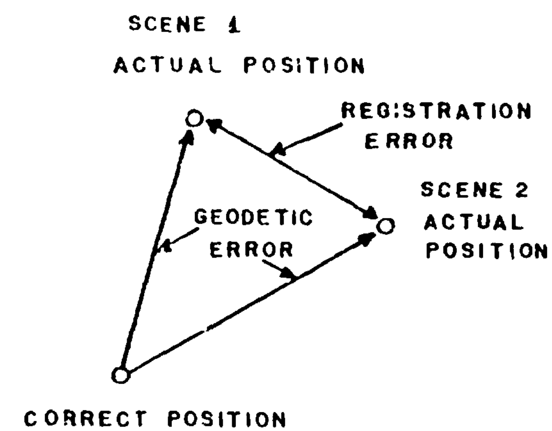

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