Geocoding and Stereo Display of Tropical Forest Multisensor Datasets

R. Welch and *T. R. Jordan*
Center for Remote Sensing and Mapping Science, The University of Georgia, Athens, GA 30602
J. C. Luvall
National Aeronautics and Space Administration, Science & Technology Laboratory, Stennis Space Center, MS 39529

ABSTRACT: Concern about the future of tropical forests has led to a demand for geocoded multisensor databases that can be used to assess forest structure, deforestation, thermal response, evapotranspiration, and other parameters linked to climate change. In response to studies being conducted at the Braulio Carrillo National Park, Costa Rica, digital satellite and aircraft images recorded by Landsat TM, SPOT HRV, Thermal Infrared Multispectral Scanner (TIMS), and Calibrated Airborne Multispectral Scanner (CAMS) sensors were placed in register using the Landsat TM image as the reference "map." Despite problems caused by relief, multitemporal datasets, and geometric distortions in the aircraft images, registration was accomplished to within ±20 m (±1 data pixel). A digital elevation model (DEM) constructed from a multisensor Landsat TM/SPOT stereopair proved useful for generating perspective views of the rugged, forested terrain.

INTRODUCTION

THE ACQUISITION AND USE of image data for the study of tropical forests is handicapped by cloud cover, dense foliage, relief, an absence of distinct features that can be used as ground control points (GCPs), and map coverage which is often incomplete, of small scale, and/or of poor quality. These problems become particularly significant when the goal is to monitor changes in forest cover, structure, density, and use over time. Such a goal requires sequential images that form a geocoded database.

By definition, a geocoded database necessitates that all data sets register to each other and to a standard map coordinate system such as the Universal Transverse Mercator (UTM) grid. With image data in raster format, an attempt is usually made to ensure that the pixels have an integer dimension and that multiresolution datasets are nested in integer multiples. Thus, the geometric fidelity of the database is dictated by the image registration and the accuracy to which the map coordinates of any pixel or feature can be determined. For the remote, poorly mapped tropical forest areas of Central and South America, orthoimages can provide the coordinate base to which other datasets are registered.

This paper addresses methods which have proved useful for creating geocoded datasets of the Braulio Carrillo National Park in northern Costa Rica from multispectral aircraft scanner, Landsat, and SPOT image data in digital formats. The availability of monoscopic Landsat and SPOT images for this area also presented a unique opportunity to create a multisensor stereo dataset that has proved useful in relating tropical forest characteristics to elevation and implementing relief displacement corrections for aircraft scanner images.

STUDY AREA

The area selected for this study is located within the recently designated (by UNESCO) Cordillera Volcanic Central Biosphere Reserve in Costa Rica. The study area includes the La Selva Biological Station as well as the Braulio Carrillo National Park (Figure 1). It encompasses the watersheds of the Rivers Sarapiqui and Sucio, and major volcanoes such as Volcan Barba. Elevations range from 30 m near La Selva Biological Station to about 3,000 m in the vicinity of Volcan Barba. Two instrumented towers lying at elevations of approximately 200 and 2,600 m mark field study sites covered during the aircraft scanner overflights. These towers are focal points for the collection of meteorological data and information on forest types. A third study site is located near La Selva Biological Station. Because the Braulio Carrillo National Park contains four life zones and two transition zones of the Holdridge Life Zone system, and encompasses a range of elevations, it is an ideal area for developing temperature and evapotranspiration models for tropical forests (Holdridge, 1967).

DATASETS

In February 1988, multiple flight lines of Thermal Infrared Multispectral Scanner (TIMS) and Calibrated Airborne Multispectral Scanner (CAMS) data of 5-m to 10-m pixel resolution were acquired over the study area (Luvall *et al.*, 1990). As the purpose of the data acquisition was to provide scanner imagery to model thermal response and rates of evapotranspiration for tropical forests, repetitive flights separated by time intervals of 5 to 20 minutes were made along the designated flight lines. The conceptual basis for thermal modeling of forest areas has been described by Luvall and Holbo (1989), and requires that multiple data sets of thermal imagery be in exact register to permit derivation of changes in temperature at pixel intervals over the study area. In addition to the TIMS and CAMS coverages, multispectral satellite image data recorded by the SPOT High Resolution Visible (HRV) cameras (20-m resolution) in 1988 and by the Landsat Thematic Mapper (TM) (28.5-m resolution) in 1986 were obtained for the study (Figure 2 and cover). Topographic maps of 1:50,000 scale (20-m contour interval) were available for the Braulio Carrillo area. These maps were produced by the Instituto Geografico Nacional from aerial photographs recorded between 1956 and 1961. They are cast on the Lambert Polyconic projection referenced to the Clarke Spheroid of 1866, and are gridded at 1000-m intervals in the North Costa Rica Lambert Grid Zone.

For the purposes of this project, the latitude and longitude values for the map sheet corners were converted to Universal Transverse Mercator (UTM) grid coordinates, and the positions of all ground control points (GCPs) digitized in the UTM system. The estimated root-mean-square error (RMSE) in planimetric location for the GCPs is about ± 15 m to ± 25 m – depending on the location and quality of the control points.

In February, 1990, the latitude and longitude of identifiable control points (riverbends, edges of clearings, bridges, etc.) were determined with the aid of a Trimble GPS Pathfinder™ portable

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Global Positioning System (GPS) receiver. Acquisition of GPS points was made difficult by overhanging canopies, rugged terrain, and a dearth of points identifiable on both the ground and image data (Wilkie, 1989). The GPS data are referenced to the World Geodetic System, 1984 (WGS 84) and must be converted to UTM coordinates referenced to the Clarke Spheroid in order to obtain compatibility with the GCPs taken from the map.

Specifications for the GPS remote mode indicate that the accuracy of coordinates is about ±25 m, or roughly ±1 TM pixel (Trimble Navigation Limited, 1989). Consequently, portable GPS receivers used in the remote mode are probably best suited for work in rugged, remote areas for which no map coverage of 1:50,000 scale or larger conforming to map accuracy standards currently exists.

The GCPs used in this study for rectifying the satellite image data were, for the most part, digitized from existing maps. Most are located at farmland fringes or along rivers, main trails, and clearings in forested areas. Identification of GCPs in the broad expanses of tropical forest covered by the aircraft scanner data, however, is virtually impossible. Thus, in the absence of a dense control network, the rectification of aircraft data, which contains distortions due to variations in aircraft attitude and terrain relief, becomes a seemingly impossible task.

FIG 1. The study area is located in Braulio Carillo National Park in Costa Rica. It is bounded on the east and west by the rivers Sardinal and Peje, respectively, and ranges in elevation from 30 m to 3000 m above mean sea level.

METHODOLOGY

After examining the control distribution, and taking the 3000-m relief into consideration, it was evident that the most direct approach to geocoding aircraft imagery of the forest was to use the satellite image datasets as the "map" reference (Rickman *et al.*, 1989). Consequently, a strategy was defined to rectify the Landsat TM image to UTM map coordinates, and to successively register the higher resolution aircraft images to the SPOT scene and the SPOT scene to the Landsat image (Figure 3). This strategy was dictated by the following factors.

- Landsat TM images provide a more accurate coordinate reference than do maps of 1:50,000 scale and smaller (Welch, Jordan and Ehlers, 1985).
- There are few identifiable map features in the forested area, but a number of good GCPs (roads, etc.) could be found in the relatively flat agricultural areas surrounding the study area.

FIG 2. SPOT XS Band 3 (0.79 to 0.89 μm) image subset of 20-m resolution of the area south of La Selva Biological Station. Cleared areas of the forest appear as bright white patches while the major rivers bounding the study areas appear black. The tropical forest of Braulio Carillo National Park is surrounded by lowlands where agriculture is the dominant land use.

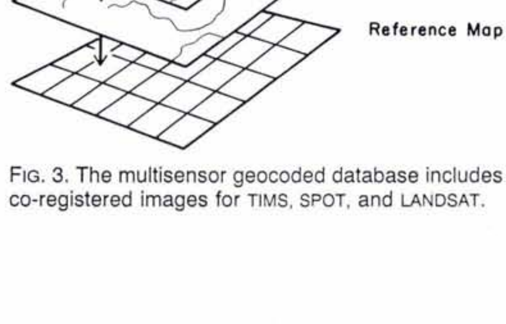

FIG. 3. The multisensor geocoded database includes co-registered images for TIMS, SPOT, and LANDSAT.

- Relief displacements were negligible for the Landsat TM image which is centered over the study area.
- The level 1A SPOT multispectral image with a look angle of 23.4 degrees presented relief displacements of up to 60 pixels in the rugged areas.
- Potential control points for registering the aircraft scanner data could be more readily identified on the SPOT images.

For areas of moderate relief, the effects of scan angle, terrain relief, and sensor attitude variations on the geometry of the TIMS data were minimized during the rectification/registration process by resampling the TIMS data (with a cubic convolution algorithm) to match the satellite image pixel dimension of 20 m. In this process, the TIMS band 4 image (9.40 to 10.15 μm) was first registered to the unrectified multispectral SPOT image using 20 GCPs to create a TIMS/SPOT image file containing four bands – i.e., SPOT bands 1,2, and 3 *and* TIMS band 4. The residual registration error was approximately ± 17 m (± 0.85 pixels). As SPOT bands 1 and 2 were extremely noisy, band 3 (0.79 to 0.89 μm) was selected to implement a rectification of the TIMS/SPOT file to the UTM coordinate system using eight GCPs obtained from the 1:50,000-scale topographic maps. A first degree polynomial rectification yielded an RMSE of ± 13 m (± 0.64 pixel), ensuring that registration of the TIMS/SPOT datasets was maintained and that locations could be defined to sub-pixel accuracy.

Next, Landsat TM band 4 (0.76 to 0.9 μm) was rectified to the UTM coordinate system using 13 GCPs, many of which were common to the TIMS/SPOT dataset. The RMSE of about ± 17 m (± 0.85 pixels), placed Landsat TM band 4 in register with the TIMS/SPOT dataset. The TIMS/SPOT and TM image files were then combined to create a single file containing co-registered Landsat TM band 4, SPOT HRV band 3, and TIMS band 4 images. Registration of these images was subsequently refined, using a second-degree polynomial algorithm. A color coded TIMS/SPOT/TM image product is shown in Plate 1. Planimetric locations can be recovered from this registered dataset to better than ± 20 m (± 1 pixel).

For areas of high relief, more rigorous corrections must be applied before merging the datasets. These corrections are based on elevations derived from a multisensor stereopair, or from existing maps.

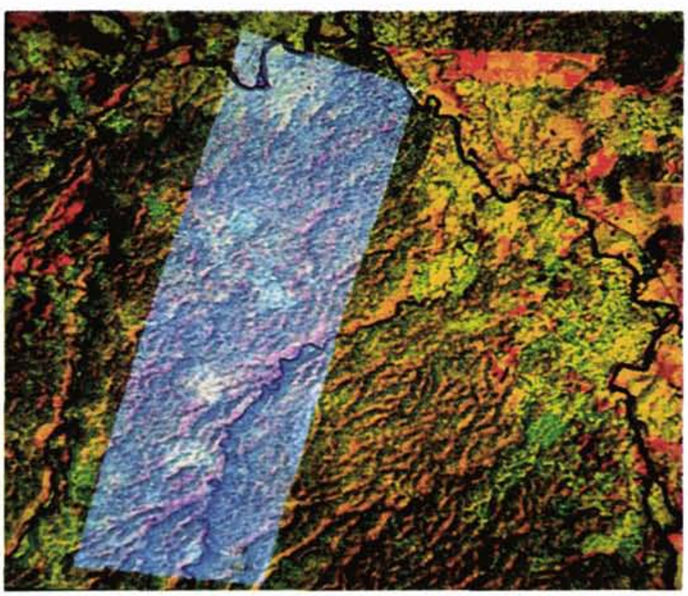

PLATE. 1. This co-registered image dataset includes TM Band 4 (red), SPOT XS Band 3 (green), and TIMS Band 4 (blue), and can be viewed in stereo with anaglyph glasses. Forest areas cleared of trees appear bright.

MULTISENSOR STEREO

The Landsat TM band 4 and SPOT HRV band 3 infrared images cover the same area, but were recorded from observation points aligned parallel to the *X*-axis (as related to image space) and separated by approximately 360 km to yield a base-to-height (*B/H*) ratio of 0.4. This favorable geometry permitted a multisensor (Landsat TM/SPOT HRV) stereo pair to be generated.

A datum was established by ensuring that the control points used for the registration of the two datasets were of about the same elevation. The stereopair was then displayed as an anaglyph image by assigning the TM band 4 image to the red gun and the SPOT band 3 image to the blue gun. An anaglyph stereo display was also generated using the TIMS and SPOT images. The advantages of stereo include improved visualization and interpretability of the terrain features, location of control points within the forest, derivation of elevations, and the possibility for creating orthoimages for areas of rugged terrain.

It is anticipated that the multisensor stereo images will prove most useful for studies of forest areas on the steep slopes of the cinder cones. A digital elevation model (DEM) was prepared from the digital multisensor dataset using the stereocorrelation capability of the Desktop Mapping System (DMS)™ (Welch, 1989). A comparison of profiles for this DEM with the existing 1:50,000-scale topographic sheets indicates an RMS difference of about ± 100 m between elevations derived from the images and those obtained from the map. A vertical accuracy of ± 50 to ± 100 m is adequate for generating orthoimages from SPOT data, and for deriving corrections for relief displacement that can be applied to the TIMS data. Most significantly, however, the stereo display gives a clear perception of the terrain and forest cover, and of the rugged clearing that has occurred along the margins of the study area between 1986 (Landsat TM) and 1988 (SPOT) (see Plate 1). The DEM created from the multisensor stereo data also can be draped with the Landsat TM pixels to give a dramatic perspective view of the Volcan Barba area (see cover).

CONCLUSION

Concerns about deforestation have lead to an upsurge in scientific studies to document the relationships between tropical forest cover and global climate. Because much of the area covered by tropical forests occupies remote, poorly mapped areas frequently covered by dense clouds, techniques that allow geocoding and stereo display of multisensor datasets will greatly facilitate the development of databases that can be used to assess deforestation, thermal response, evapotranspiration, and other parameters linked to climate change.

The methodologies developed for this study illustrate how digital satellite and aircraft imagery can be employed in concert to derive *X, Y, Z* terrain coordinates, stereo images, perspective displays, and representative thematic information about tropical forest areas. In particular, it is anticipated that maps of thermal response and evapotranspiration can be generated for Braulio Carrillo National Park and La Selva Biological Station, and that these data can be applied to future studies of tropical forest environments.

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