GPS, IMAGE PROCESSING AND GIS TECHNIQUES FOR COASTAL WETLAND MAPPING APPLICATIONS

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ABSTRACT:

Global Positioning System (GPS), image processing and geographic information systems (GIS) techniques were employed to establish a database for South Florida wetland environments threatened by urban expansion, agriculture, exotic plant invasion and hurricanes.

1. INTRODUCTION

Geographic information systems (GIS) are currently an integral component of natural resource monitoring and management operations worldwide. Useful not only for data storage, manipulation and map production, the strength of GIS is spatial data analysis and predictive environmental modeling (Remillard and Welch, 1993; Cowen, et al., 1995). Remotely sensed satellite image data and aerial photographs serve as an excellent reference base for GIS data layers, provide ground control and up-to-date thematic information. The integration of GIS with image processing and Global Positioning System (GPS) techniques has proved particularly useful for resource mapping applications.

In compiling resource databases, thoughtful consideration must be given to: 1) project and end-product requirements; 2) coordinate systems and ground control; 3) GPS; 4) mapping and database assembly techniques; and 5) GIS analysis procedures. In the following discussion, a project is presented that combines GPS, image processing and GIS technologies that are particularly useful in preparing databases for coastal wetland mapping applications.

2. DIGITAL DATABASES FOR SOUTH FLORIDA NATIONAL PARKS/PRESERVES

The University of Georgia's Center for Remote Sensing and Mapping Science (CRMS) is working in conjunction with the U.S. Department of Interior's National Park Service (NPS) to construct a GIS database and associated detailed vegetation maps for ecologically unique wetlands in South Florida, including Everglades National Park, Biscayne National Park, Big Cypress National Preserve and the Florida Panther Refuge (Welch, et al., 1995). This 6,000 mi^2 area, collectively referred to as the "Parks", is threatened by urban expansion, nutrient runoff from agricultural lands, invasive exotic plant species, increased recreational use and episodic disturbances such as hurricanes (Davis and Ogden, 1994). Extending roughly from Miami on the east to Naples on the west, southward to Florida Bay, the Parks represent the remaining lands of the greater Big Cypress Swamp and Everglades ecosystems that once covered approximately one-third of the Florida peninsula (Figure 1).

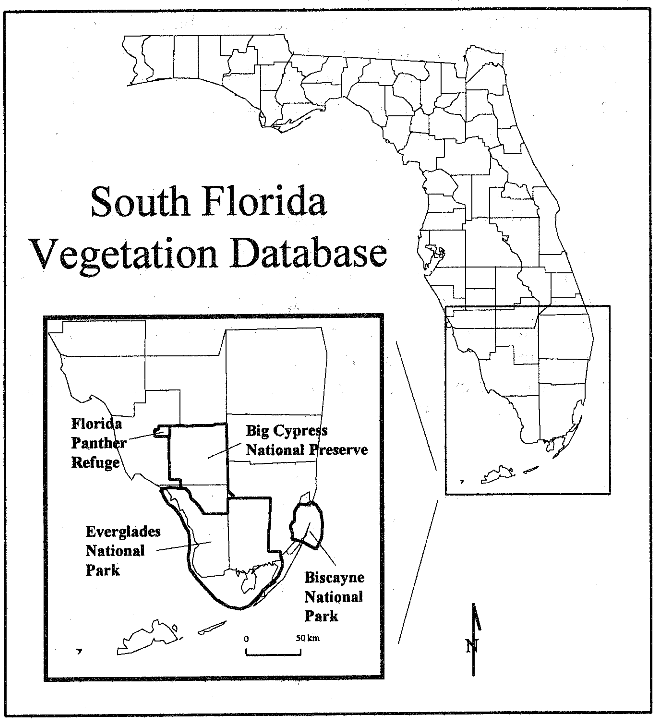

Figure 1. South Florida vegetation database study area.

Preservation of the natural vegetation within these parks is of national concern and requires detailed information on vegetation distributions, along with planimetric features such as roads, rivers and canals. In order to meet these objectives and construct a GIS database in digital format, it was necessary to: 1) develop techniques for using control transferred from geocoded satellite images to rectify several hundred aerial photographs; 2) establish efficient photo-interpretation and feature encoding procedures compatible with a vegetation classification system that takes into account vegetation species, human impacts and hurricane damage; and 3) integrate GPS surveys with attribute recording and digital image processing on a laptop computer to facilitate the real time collection of ground truth information by helicopter surveys.

2.1 South Florida GPS Surveys and Satellite Image Mosaic

To ensure the registration of vegetation, transportation and hydrographic features in a GIS database, it was first necessary to establish a network of ground control points (GCPs) adequate for rectifying eight SPOT panchromatic images (10-m resolution) of the study area. Past experience has shown that because of their excellent internal geometry, only 4 to 6 GCPs per image are required to geocode a SPOT satellite image to a planimetric accuracy of $\pm$ 0.5 to $\pm$ 1.0 pixel - or $\pm$ 5 to $\pm$ 10 m on the ground. Such accuracies are compatible with U.S. National Map Accuracy Standards for 1:24,000 scale maps and were considered acceptable for densifying the horizontal control points needed to rectify the aerial photographs from which the database would be constructed.

The survey to establish GCPs was influenced by the existing road network and by the availability of 1:24,000 scale topographic line maps of recent vintage for the lands adjoining the Parks. Thus, it was decided to use the existing maps for perimeter control and to conduct the GPS survey along the few roads through the middle of the study area to provide the interior control necessary to rectify the satellite images. Control points included the intersections of roads and of roads and canals, both of which are easily located on the SPOT 10-m panchromatic images. In addition, the survey included eight monumented National Geodetic Survey (NGS) and Florida GPS (FLGPS) base points of Order B (1:1,000,000) accuracy (or better) which were used to adjust the network. Based on checks conducted in the post-processing adjustment of the GPS observations, the accuracy to which the UTM coordinates of the 23 points were established as referenced to NAD 83 was about $\pm$ 0.05 m ($RMSE_{xy}$).

The SPOT image mosaic was created from individual SPOT scenes using the Desktop Mapping System (DMS)™ software package. Each digital SPOT image (or tile) was rectified to the UTM coordinate system using 6 to 15 GCPs per image and then placed at its correct location (according to the UTM coordinates of the upper left corner pixel) within a coordinate box for the entire study area. In order to facilitate its use, a UTM grid (NAD 83) with 5,000 m spacing was registered to the mosaic. The planimetric accuracy of the geocoded mosaic was evaluated at 29 withheld control points (check points) and found to be better than $\pm$ 1.5 pixels. The mosaic occupies slightly more than 200 Mbytes of disk space.

2.2 Interpretation of CIR Aerial Photographs

Development of an accurate, detailed vegetation database for the Parks requires the use of remotely sensed data of sufficient resolution to allow the identification of plant species/associations, the delineation of one-hectare or larger vegetation plots and classification accuracies of 90 percent of better. These requirements precluded the use of Landsat TM (28.5 m) or SPOT (20 m) multispectral imagery for the construction of the vegetation database. Instead, the use of aerial photographs was deemed essential for the project. Color infrared (CIR) aerial photographs of 1:40,000 scale acquired as part of the U.S. Geological Survey (USGS) National Aerial Photography Program (NAPP) in 1994 and 1995 were purchased for the entire South Florida study area. In order to facilitate the interpretation of these photographs and the construction of vegetation coverages in digital format, vegetation classes were delineated directly on CIR paper print enlargements (4x) produced from the CIR film transparencies. Point features common to both the SPOT images and the analog air photo enlargements were annotated, numbered and their UTM coordinates determined from the geocoded SPOT images to establish a GCP file for each CIR photograph.

The GCPs transferred to the photographs were then digitized, along with the vegetation polygons and other point and line features. By digitizing the GCPs first, a set of photo rectification coefficients were generated that allowed x,y digitizer coordinates for the vegetation polygons to be transformed to UTM map coordinates (Easting, Northing). This procedure permitted a segregation of tasks (interpretation, digitizing, editing) and greatly facilitated the development of the vegetation database. To further improve digitizing efficiency in areas of complex vegetation patterns, clear plastic overlays with annotated vegetation boundaries were scanned at 65 µm and accessed by the VTRAK® software package (Laser-Scan, Inc.) for automatic vectorization and input to ARC/INFO®. Tests conducted to assess the accuracy to which the features were digitized yielded $RMSE_{xy}$ values of between $\pm$ 5 and $\pm$ 10 m.

2.3 Field Verification with GPS Assisted Helicopter Surveys and Vegetation Classification

A new Everglades Vegetation Classification System was developed in conjunction with personnel from both the NPS and South Florida Water Management District (SFWMD) because existing vegetation classification schemes did not contain the level of detail required for this vegetation mapping project. This classification system includes hierarchical vegetation classes at the individual species or species association level that can be identified from the CIR aerial photographs. In addition to the floristic characterization of the naturally occurring Everglades plant communities, the classification system includes categories of human impacts and episodic disturbances that influence vegetation species distributions. For example, invasive exotic plants, indicators of human influence such as agriculture or off-road vehicle (ORV) trails and three hurricane damage classes are added as modifiers to the vegetation class.

Fieldwork to verify the image interpretation was greatly facilitated by the use of NPS Bell Jet Ranger 206 helicopters that are available for ground truth collection. Since helicopter flight time is expensive (~ $ 650.00/hr), a procedure involving use of the SPOT image mosaic and the latest technology in laptop computers, GPS receivers and image processing/positioning/display software was developed to expedite data collection and verification. The helicopters are equipped with GPS receivers that enable the pilots to pre-define their flight track, conduct real time navigation guided by the GPS unit and to record the coordinates of landing points or features of interest. The SPOT mosaic was loaded into a Pentium laptop computer (100 Mhz) along with the DMS and Field Notes (Pen Metrics, Inc.) software packages. A Trimble Pathfinder Pro XL (8- channel) GPS receiver with an external antenna mounted on the forward hull of the helicopter was then connected to the serial port of the laptop computer. This set-up enables a person in the rear seat of the helicopter to hold the computer on his or her lap, display the satellite image mosaic and track in real time the flight path of the helicopter. Most importantly, it provides a means of collecting ground truth information that is linked to coordinates provided by the GPS receiver. Upon reaching an area of interest, the helicopter circles at low altitude and/or lands to allow identification of plants. Species attribute information and additional notes pertaining to fire history or exotic control measures that may have influenced the area are entered into the computer and linked with the GPS coordinates. This procedure also can be used with vehicle or foot surveys.

A handheld digital camera, the Kodak Professional DCS 420 (1500 x 1000 pixels) is also being used to capture digital CIR and true-color images of plant species. Resulting images are directly accessible by software packages such as the DMS and Adobe Photoshop for display and enhancement. Positional information (via a Trimble Ensign GPS unit) and voice annotation also can be linked with individual images for location recovery and the addition of attributes. In South Florida, the digital camera was used both on the ground and in the helicopter to document representative plant species and build a digital photo key corresponding to classes of the Everglades Vegetation Classification System.

The data gathered during the ground and helicopter surveys are used to verify vegetation interpretations from the 1994/1995 USGS NAPP air photos. After verification, the digital vegetation boundary files, along with transportation and hydrographic data in digital format, are input to the ARC/INFO software package resident on SUN SPARCstation 10 and IBM RISC System 6000 workstations, edited, attributed and edge matched to create the GIS database. Tiles corresponding to the USGS 1:24,000 scale topographic quadrangle series are then plotted as hardcopy maps.

3. CONCLUSION

Development of a resource database for the national parks and preserves of South Florida has demonstrated the advantages of using GPS, image processing and GIS to facilitate rectification, analysis and verification of data. For example, GPS derived control was used to rectify satellite images and to create a satellite image mosaic that, in turn, served as a source of ground control for aerial photographs. Once georeferenced to a standard ground coordinate system within a high degree of positional accuracy, the aerial photographs provide source information for the derivation/revision of thematic data layers such as vegetation and land use.

The efficient collection of field data via ground, vehicle and helicopter surveys for attributing database features and/or verifying the interpretation of remotely sensed data also is made possible by GPS. Innovative techniques that integrate GPS, image processing and GIS on laptop computers provide resource managers full mobility in the field and allow the rapid collection of ground truth information. It is expected that routine use of these techniques will lead to improvements in the thematic accuracy of resource databases. The increased use of GPS, image processing and GIS technologies also will allow managers of natural resources to evaluate existing strategies and make ecologically sound decisions.

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