Control Extension and Orthorectification Procedures for Compiling Vegetation Databases of National Parks in the Southeastern United States

Thomas R. Jordan
Center for Remote Sensing and Mapping Science (CRMS)
Department of Geography, The University of Georgia Athens, GA 30602 USA
tombob@uga.edu

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ABSTRACT:

Vegetation mapping of national park units in the southeastern United States is being undertaken by the Center for Remote Sensing and Mapping Science at the University of Georgia. Because of the unique characteristics of the individual parks, including size, relief, number of photos and availability of ground control, different approaches are employed for converting vegetation polygons interpreted from large-scale color infrared aerial photographs and delineated on plastic overlays into accurately georeferenced GIS database layers. Using streamlined softcopy photogrammetry and aerotriangulation procedures, it is possible to differentially rectify overlays to compensate for relief displacements and create detailed vegetation maps that conform to defined mapping standards. This paper discusses the issues of ground control extension and orthorectification of photo overlays and describes the procedures employed in this project for building the vegetation GIS databases.

INTRODUCTION

The Center for Remote Sensing and Mapping Science (CRMS) at The University of Georgia has been engaged for several years in mapping vegetation communities in national parks in southeastern United States (Welch, et al., 2002). In this project, vegetation polygons delineated on overlays registered to large-scale (1:12,000 to 1:16,000 scale) color-infrared (CIR) aerial photographs are converted to digital format and integrated into a GIS database. To maximize vegetation discrimination, the aerial photographs are acquired during the autumn (leaf-on) season when the changing colors of the leaves provide additional indicators for species and vegetation community identification. It is critical that the polygons transferred from overlay to GIS database be accurate in terms of position, shape and size to ensure that analyses that depend on the interaction of layered data sets, such as fire fuel modelling and data visualization, can be performed with confidence (Madden, 2004). As many of these parks are located in remote and rugged areas where conventional sources of ground control are lacking, streamlined aerotriangulation procedures have been developed to extend the existing ground control and permit the production of orthophotos and corrected overlays for incorporation into the GIS database.

STUDY AREA AND METHODOLOGY

The overall project area encompasses much of the southeastern United States and includes U.S. National Park units located in the states of Kentucky, Tennessee, North Carolina, South Carolina, Virginia and Alabama (Figure 1). The parks differ greatly in size, location, relief and origin. Some of the smaller (100-400 ha) historical battlefield parks and national home sites in the project are located in or near urban areas with little relief and ample roads, field boundaries and other features that can be used for ground control. In these cases, ground control coordinates are extracted from U.S. Geological Survey (USGS) Digital Orthophoto Quarter Quadrangles (DOQQ) and simple polynomial techniques are applied to create corrected photos. Interpretation is then performed directly on the rectified CIR photographs and the polygons transferred into the GIS.

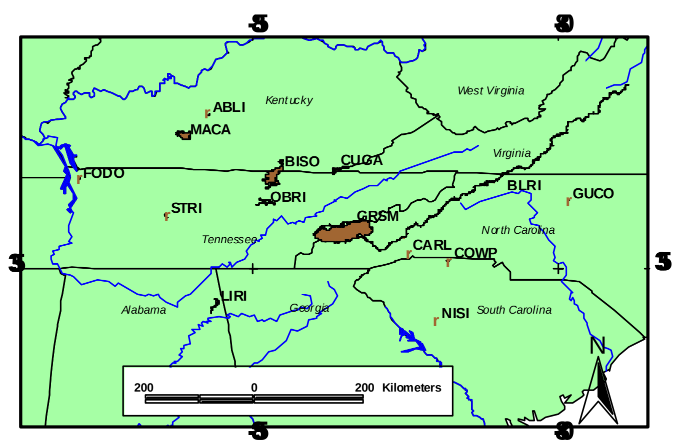

Figure 1. U.S. National Park units being mapped by the UGA-CRMS. See Table 1 below for park name abbreviations.

Many of the parks, however, are set aside to protect natural areas ranging from 80 to over 2000 sq. km in size and require a large number of aerial photographs for complete coverage (Table 1). In the more remote areas, a recurring problem is the lack of cultural features suitable for use as the ground control required to restitute the aerial photographs and associated overlays. This issue is frequently exacerbated by the presence of extensive forest cover and high relief. The result is that the locations and shapes of vegetation polygons interpreted for

Table 1: U.S. National Parks being mapped by the UGA-CRMS

Park Name	Abbrev-iation	Location	Size (Ha)	# Photos	Photo Scale
Abraham Lincoln National Historic Site	ABLI	Kentucky	140	3	12,000
Big South Fork National Recreation Area	BISO	Kentucky/Tennessee	50,733	309	16,000
Blue Ridge Parkway	BLRI	North Carolina/Virginia	37,408	768	16,000
Carl Sandburg Home National Historic Site	CARL	North Carolina	107	1	12,000
Cowpens National Battlefield	COWP	South Carolina	341	4	12,000
Cumberland Gap National Historical Park	CUGA	Kentucky	8,285	76	16,000
Fort Donelson National Historic Site	FODO	Tennessee	223	3	12,000
Great Smoky Mountains National Park	GRSM	Tennessee/North Carolina	209,000	1,200	12,000
Guilford Courthouse National Military Park	GUCO	North Carolina	93	1	12,000
Little River Canyon National Preserve	LIRI	Alabama	5,519	89	12,000
Mammoth Cave National Park	MACA	Kentucky	21,389	124	16,000
Ninety-Six National Historic Site	NISI	South Carolina	400	2	12,000
Obed Wild and Scenic River	OBRI	Tennessee	2,156	106	16,000
Stones River National Battlefield	STRI	Kentucky	288	3	12,000

these areas tend to be more highly influenced by geometric errors caused by improper rectification techniques or poor control. A full photogrammetric solution and orthorectification is required in these instances.

Control Extension

Extension and simplification of ground control identification and aerotriangulation procedures developed for mapping Great Smoky Mountains National Park has dramatically improved the speed and accuracy with which aerial photographs and overlays can be prepared for use in building the GIS database (Jordan, 2002). These methods permit the use of non-traditional features such as tree tops to be used for ground control. In addition, the procedures can be undertaken by non-photogrammetrists to achieve accuracies required to meet the project goals and deadlines that would be difficult under normal circumstances. Using low cost softcopy photogrammetry tools provided by the DMS Softcopy 5.0 software package and standard aerotriangulation point distribution and numbering practises, pass points are identified on scanned (42 μm) color infrared aerial photographs (R-WEL, Inc., 2004). Although well-defined cultural features are chosen as pass points whenever possible, it is frequently the case that natural features such as corners of clearings or even tree tops must be employed when the tree canopy is extremely dense.

Well-defined features suitable for use as ground control points (GCPs) are identified on USGS DOQQs and the scanned aerial photos. Their X,Y Universal Transverse Mercator (UTM) planimetric coordinates are measured directly from the DOQQ. Elevation values for GCPs are extracted from USGS digital elevation models (DEMs) using a bilinear interpolation algorithm. In general, the accuracy of the GCP coordinates recovered from these data sets is on the order of ± 3-5 m in XY and ±4-7 m in Z.

Photo coordinates are organized into flight line strips within DMS Softcopy 5.0 and automatically employed with the AeroSys 5.0 for Windows aerotriangulation (AT) package to compute map coordinates for the pass points (Stevens, 2002). The process is quick and typical errors are comparable in magnitude to the GCP coordinate errors. Experience has shown that a person familiar with aerial photographs and the fundamental concepts of photogrammetry quickly can be trained to do productive aerotriangulation work with this system in just one or two days. This is a vast improvement on previous AT software which required weeks of experience and a strong photogrammetric background to achieve adequate results.

Rectification of Overlays

Overlays first must be scanned and rectified to the map coordinate system before the vegetation polygons can be incorporated into the GIS database. It is difficult, however, to accurately transfer ground and image coordinates directly from the aerial photographs to the overlays using manual methods. Therefore, the fiducial marks on the photos and scanned overlays are employed as registration points. Image coordinates identified during the AT process are transformed into the overlay coordinate system and used with an appropriate rectification algorithm to create a corrected overlay that is in register with the underlying GIS database. The raster polygons are converted to vector format using R2V program from Able Software, Inc. (Cambridge, Massachusetts, USA) and imported to ESRI ArcGIS for editing.

In areas of little relief, it is appropriate to apply simple polynomial correction techniques to create rectified photographs. For smaller parks, these rectified photos are tiled, overlaid with coordinate grids and printed on a high quality color printer for use in the field. Interpretation is performed on overlays registered to the hard copy prints. The overlays are scanned and converted to vector format for input to the GIS. There the polygons representing vegetation communities are edited and assigned attributes. The vegetation map of Guilford Courthouse National Military Park was created in this manner (Figure 2). In the Guilford Courthouse map product, the top portion in a rectified color infrared aerial photograph annotated with the park boundary. In the bottom section of the product, the detailed vegetation map is presented at the same scale and area coverage as the aerial photograph.

Figure 2. The vegetation map product or Guilford Courthouse National Military Park.

For areas of high relief such as Great Smoky Mountains National Park, Blue Ridge Parkway and Cumberland Gap, the overlays must be differentially rectified using a DEM to remove the effects of relief displacement, which at times can be quite significant (see Jordan, 2002). Improper corrections can lead to major difficulties in edge matching detail in the overlap areas of adjacent photographs along a flight line. The mountainous terrain in Great Smoky Mountains National Park is the source of major relief displacements in the large (1:12,000) scale aerial photographs. These relief effects greatly influence the apparent shapes of objects appearing on adjacent photos as well as their map positions and areas. Thus, it is important that the polygons are corrected properly in shape and position to facilitate edge matching during its incorporation into the GIS database. For example, a distinct area appearing on the aerial photographs in the Thunderhead Mountain area in the central portion of the park near the Appalachian Trail occurs on a steeply sloping mountainside. Elevation ranges from 1549 m in the lower left corner of the image chip to 1214 m in the upper right – a range of 335 m over a distance of about 600 m. When viewed on the three overlapping photographs, the area appears to be vastly different sizes and shapes (Figure 3). Thus, mapping the area from each of the three uncorrected photos would potentially give different results.

(a) (b) (c)

Figure 3. The dark shadowed area in the above image chips appears to be very different in shape and size in these three overlapping photographs. The image chip (a) is from the lower right corner of Photo 10063; b) near the bottom center of Photo 10062; and c) lower left edge of Photo 10061.

COMPARISON OF RECTIFICATION METHODS

There are a number of well-known image rectification methods available that can be used for converting vegetation overlays in raster format to a vector map base. Three of these are 1) polynomial (affine) based on a least-squares fit to two-dimensional GCPs; 2) single-photo projective rectification referenced to a mean datum elevation using a photogrammetric solution and 3-D GCP coordinates; and 3) rigorous differential correction (orthocorrection) using the photogrammetric solution and a DEM (Novak, 1992; Welch and Jordan, 1996). To compare the effectiveness of the techniques, Photo 10063 from Thunderhead Mountain was rectified using each of the three methods and then overlaid with the completed vegetation map (Figures 4a-d). In the following examples, the darker shadowed area and corresponding vegetation polygon indicated by the black arrow in Figure 4a will be used to illustrate the effects of the different rectification methods. In the GIS database, this polygon has an area of 5.97 ha (Table 2).

After aerotriangulation, 14 GCPs were available for Photo 10063. The affine transformation coefficients were computed using the method of least squares and resulted in an RMSE at the 14 GCPs of 106 pixels or 53 m. Most of this error is due to relief displacements in the image. The aerial photograph was then rectified using the polynomial method. The resulting image is approximately in the correct geographical location but relief displacements have not been corrected (Figure 4a). Although the general correspondence between the vegetation polygons and the underlying image can be seen (point A on the photo), it is clear that the overall registration accuracy is poor: the lines from the vegetation coverage do not fit this rectified air photo well and the shape distortions in the image are clearly visible. In this case, the dark shadowed area in the photo corresponding to the polygon (indicated by the arrow) appears to be longer, wider and in a different position than the actual polygon in the vegetation coverage. In this figure, the polygon measured directly from the image has an area of 8.34 ha, which is 2.4 ha (40 per cent) greater than the actual area of the polygon taken from the GIS database.

The overall geometry of the image rectified using the single photo projective transformation was not improved significantly over the polynomial rectification (Figure 4b). The photogrammetric solution used to determine the exterior orientation parameters, however, was excellent and yielded a RMSE of 3.34 pixels or 1.67 m at the 14 GCPs. The image was then rectified to an elevation datum value of 1380 m using a method which enforces the scale at the datum and corrects for tilt but does not correct for relief effects. Note that although the vegetation polygons generally do not fit the image exactly, there is a good fit in the areas near the 1380 m contour (shown in yellow) where scaling is exact using the photogrammetric solution. Overall, the shapes of the target polygon and other features are still distorted and this solution is not satisfactory. The area of the sample polygon measured from this image is 7.9 ha.

Orthocorrection was performed on the photo using the same exterior orientation parameters computed above, but this time using the USGS DEM to provide elevation values to correct for relief displacement at each pixel location (Figure 4c). Polygons in the completed vegetation coverage are aligned perfectly with the underlying orthophoto (see point A) and the shadowed area indicated by the arrow has an area of 5.98 ha which corresponds well with the value in the GIS database for the polygon. This high level of correspondence clearly demonstrates the requirement for a full softcopy photogrammetric solution to rectifying vegetation overlays.

Finally, as a logic check, the vegetation vectors were overlaid on the USGS DOQQ (Figure 4d). It is reassuring to see that the GIS database created by orthocorrection techniques described in this paper lines up very well with the USGS DOQQ product of the same area.

Table 2. Results of different image rectification methods on Photo 10063 (Great Smoky Mountains: Thunderhead Mountain Quadrangle).

Rectification Method	# GCPs	RMSE (pix)	RMSE (m)	Area of Target Polygon (ha)	Difference
DOQQ (Reference Image)	N/A	N/A	N/A	5.97	--
Affine Polynomial	14	106.3	53.1	8.34	40%
Single Photo Projective	14	3.34	1.67	7.90	32%
Orthocorrection	14	3.34	1.67	5.98	0.2%

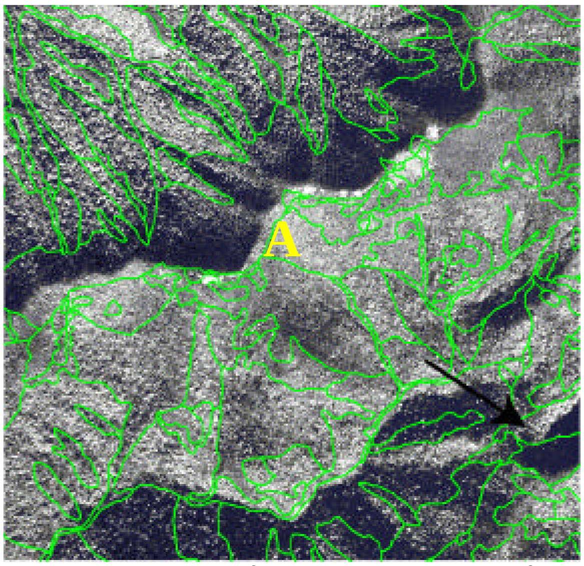

Figure 4a. Portion of Photo 10063 resulting from the polynomial rectification. Polygons in the completed vegetation coverage are shown in green. The sample polygon in the lower right portion of the photo (indicated by the black arrow) has an area of 5.97 ha according to the GIS database but 8.34 ha when measured directly from the image.

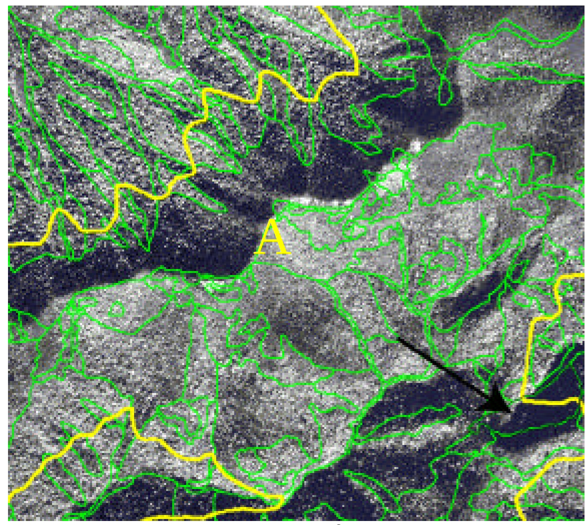

Figure 4b. Photo 10063 rectified using the single photo projective transformation. In this image, the contour representing the datum elevation of 1380 m employed for the rectification is shown in yellow.

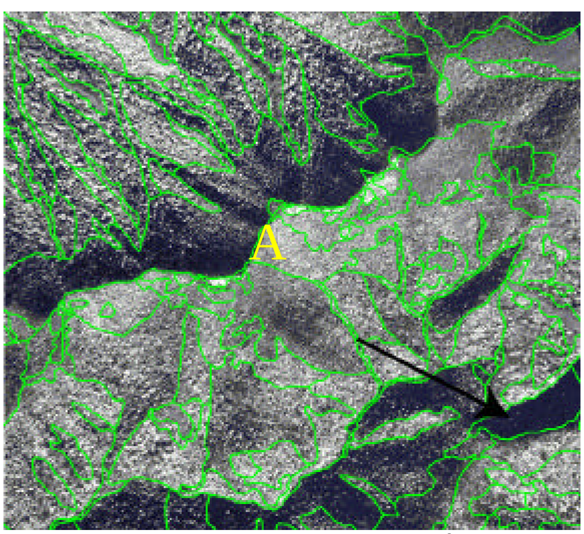

Figure 4c. The digital orthophoto created by from Photo 10063 and the USGS DEM.

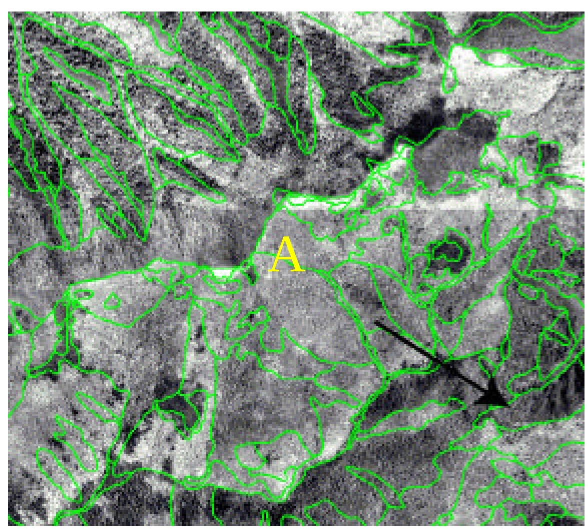

Figure 4d. A portion of the USGS DOQQ corresponding to the area covered by Photo 10063.

CONCLUSION

Experience with mapping vegetation communities in national parks units in the southeastern United States has led to the development of streamlined methods for the extension of ground control in remote areas using softcopy photogrammetry and analytical aerotriangulation techniques. Basic ground control extracted from standard USGS digital orthophoto quarterquads (DOQQs) and digital elevation models (DEMs) provide the framework with which a large number of aerial photographs of areas that have nearly continuous tree canopy cover can be controlled. Although a number of rectification methods are available, it was found that for areas of high relief, overlays delineating vegetation polygons are more accurately transferred to a GIS database if they are first orthocorrected using photogrammetric differential rectification techniques. This method improves not only positional accuracy but also ease of editing and edge matching polygons from adjacent photographs. In a test polygon, area calculation was in error by as much as 40% when simple polynomial rectification was performed on an area with very high relief.

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