



SAGUARO NATIONAL PARK

GEOREGISTERING HISTORICAL AERIAL PHOTOS TO REAL-WORLD COORDINATES FOR GIS ANALYSIS

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A cooperative project by:

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Introduction and Project Rationale

Effective long-term management of natural resources is contingent upon knowing the current status of resources and understanding the trends these resources follow through time. In order to accomplish long-term management goals, it is imperative to know the history of natural resources in an area. Consequently, spatial data sets such as current and historic aerial photography have become invaluable to resource management staff. By having natural resource information like historic aerial photographs stored digitally in a common spatial format, temporal analyses can be performed on resources sharing the same space. However, most historic aerial photographs exist only in a hardcopy format. Therefore, in order to utilize aerial photography in a Geographic Information System (GIS) it becomes necessary to scan older print photos into an electronic format and then register these photos to a common real-world coordinate system using image processing software.

Saguaro National Park has an extensive archive of historical aerial photos which can provide a number of "looks" at the Park from the 1930s to the present. However, it is currently difficult to make use of these numerous, loosely organized prints even for visual assessment of resources, and especially for true spatial and temporal analysis. Having these photos in digital format for manipulation in a GIS, and registered to a common coordinate system for overlay with other digital data layers, would greatly enhance their usefulness and value.

It is recognized that such processing of SAGU's photo archive will require a substantial commitment of time and money, but the actual size of this commitment is unknown. Before Park managers can consider the feasibility of processing the archive, an estimate is needed of the funding, time and computing resources that would be required for the job.

Objectives

The objectives of this project are to scan, georeference and mosaic a small sample of SAGU's aerial photo archive, and thereby develop an estimate of the cost, time and computing resources (software, disk space) that would be needed to process a given portion or the entirety of the archive. The goal is to produce a processing estimate per photo or per set of photos that can be reasonably extrapolated to the rest of the archive to get an idea of the overall scope of the resources that would have to be allocated should Park managers wish to pursue processing the archive.

Materials and Methods Overview

Tasks for this cooperative project have been split between the National Park Service and the Arizona Remote Sensing Center (ARSC) of the University of Arizona. Photo scanning was done by NPS staff and volunteers at SOAR, where a large-format scanner

capable of handling air photos of various sizes was available. The scanned aerial photos in .tif format and a set of reference imagery in .sid format were then provided to ARSC for georegistration and mosaicking. The set of historic photos used had been acquired on December 17, 1982 over the Rincon Mountain District of SAGU. Because, as is most commonly the case with historical aerial photos, the SAGU photos lacked any information about the camera model or imaging geometry that could be used for registration, the process we used was image-to-image registration. The scanned historical photos were registered to high-resolution reference photography flown, scanned, registered, and orthorectified by Pima County in 2002. This reference imagery provided the real-world coordinates of known locations (ground control points or GCPs) that could be discerned on the scanned aerial photographs. The registration algorithm used the network of selected GCPs to rectify the historical aerial photos by "warping" them to the 2002 orthophoto base. Typical features used as GCPs included road intersections, trail junctions, rock outcroppings, and buildings.

After the photos were individually georegistered, they were processed into a mosaic. This required subsetting each photo to remove edge annotation and excessive overlap. Creating a mosaic is an optional step, as the photos can be used individually for analysis and displayed as a virtual mosaic as desired. Because of the limited budget and staff time available for this project, only 5 historical photos were processed.

Total project budget was \$1000, which equated to about 50 hours of a graduate student's time (including all ERE and University indirect costs) to implement the image processing. Part of this time was spent on initial meetings and, importantly, on georeferencing methods development. This time does not appear in the accounting presented below, because it is not rightfully a part of the actual image processing protocol that would be implemented in a production mode. Once the methods were established, the student operator stepped through the processing and recorded the actual time needed for each step, to produce the most true and accurate production-processing estimate possible, which was the goal of this experiment.

Method Detail, Results and Discussion

Results are presented below in the context of additional methodological detail for clarity. A few points of discussion are introduced where they are relevant.

Task: Assess aerial photos and reference images. Identify which reference image(s) will be used to register each aerial photo. Copy data from CDs to a computer hard drive.

Reference image files (.sid) were too big to be imported (and uncompressed) into ERDAS Imagine (2 GB limit), so the decision was made to use ENVI for all processing.

A set of 10 contiguous photos was assessed for potential processing, and a representative 5 were selected as a suitable initial effort, which proved to be all that we could do in the

time available. With this small set, layout, assessment and development of a processing strategy took only about 20 minutes, but this step could take much longer with more numerous photo sets.

Copying data from CDs (four reference images - 1416, 1417, 1516, 1517 - and all five aerial photos) into a local hard-drive directory took 20 minutes.

Task: Display aerial photos and reference images in ENVI. Perform georegistration.

Aerial photos 15-15, 16-15, 15-14, and 16-14 were registered to reference image 1416. In order to register the other aerial photos (possibly all 10 in the set) it was necessary to mosaic the four reference images together to provide suitable coverage. To conserve disk space, the reference images were subset before mosaicking to eliminate unneeded area, as shown in the diagram below.

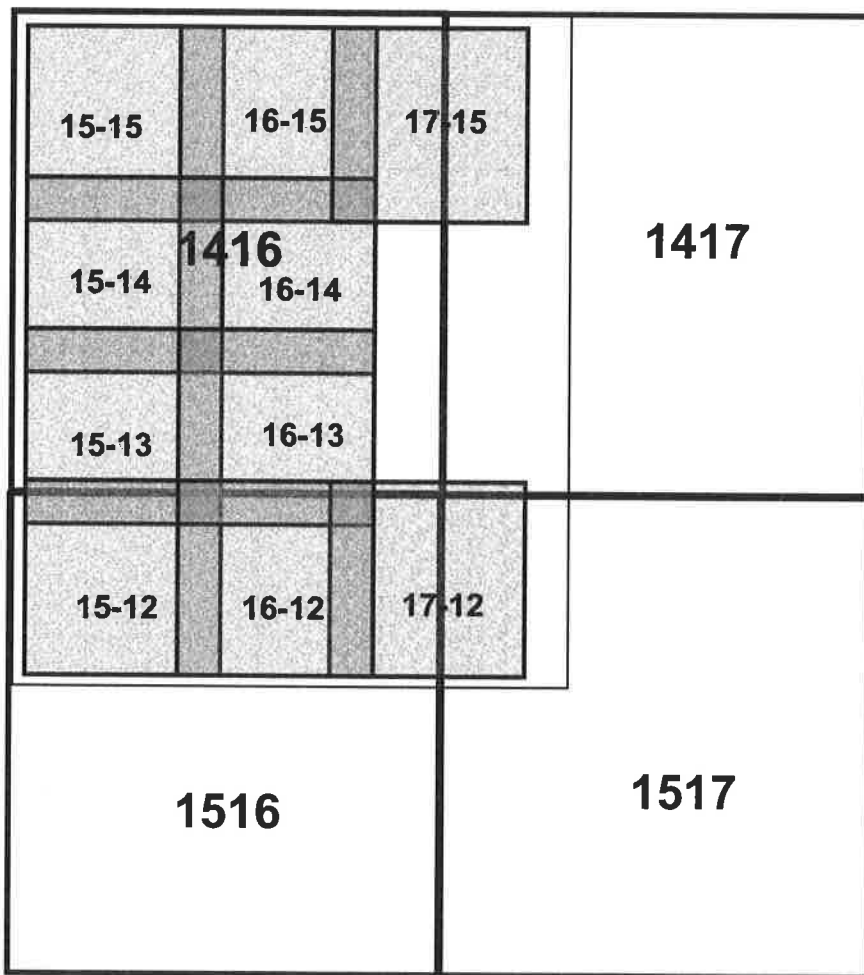


Figure 1. Diagram of reference image mosaic (no shading) indicating subset area used (light shading) and aerial photo arrangement (darker shading).

Table 1. Summary of reference image subsetting and mosaicking.

Reference Image	Subset Size (pixels)	Setup time (h:min)	Time to compute (h:min)	Time Total (h:min)
1417	11000 x 33466	0:10	0:40	0:50
1516	32122 x 16000	0:10	9:10	9:20
1517	11000 x 16000	0:10	3:50	4:00
mosaic	1416 + 3 subsets	0:10	9:50	10:00
Time total		0:40	23:30	24:10

Out of 24 hours spent to mosaic the four reference images, 23.5 hours were computer processing time and did not require human participation. The differences in processing time among the images, not related to image size, evident in Table 1 are attributable to differences in ARSC's network conditions at different times – traffic volume (thus access speed) and multiple users competing for a machine's resources. Reference image 1417 was processed at a particularly advantageous time, while image 1516 was done at a particularly disadvantageous time.

Table 2. Summary of georegistration of aerial photos.

Aerial Photo	Reference Image	Time to select and check GCPs (h:min)	# of GCPs selected	RMS Error (pixels)	Time to warp (min)	Time to check quality (min)	Time Total (h:min)
15-15	1416	4:00	42	1.41	10	10	4:20
16-15	1416	3:00	49	7.48	10	10	3:20
15-14	1416	3:30	36	3.10	20	10	4:00
16-14	1416	5:00	46	9.98	25	10	5:35
17-15	mosaic	5:00	33	10.42	25	10	5:35
Average		4:06			18	10	4:34

Total time spent to georegister 5 aerial photos was 23 hours, with the number of GCPs as shown in Table 2. Selecting GCPs requires the largest portion of processing time, and total time could be cut substantially if fewer GCPs were used. However, while using fewer GCPs does not generally result in a higher calculated RMS error, it does result in more potential spatial error within the image, particularly in regions furthest from GCPs.

In flat areas this matters less than in areas of high relief. The "optimal" number of GCPs will vary with the characteristics of each photo and may be difficult to specify.

Spatial accuracy of georegistered photos was highly dependent on the topographic relief present in the coverage area. Photos of terrain with more relief, such as 17-15 in this set, yielded higher RMS error.

Presence of houses and roads made the process of selecting ground control points faster and easier, but didn't directly affect the accuracy of georegistration for this set of photos. However, it is possible that in some older photos of SAGU and environs it could be difficult to identify an ample set of GCPs due to landscape changes over time. This could result in diminished spatial accuracy of georegistration.

RMS error is expressed in pixels of the image that is being warped (RMS of Δx and Δy expressed in pixels). Pixel size of the scanned photos was about 2 m.

The method used for warping was 2nd degree polynomial with nearest-neighbor resampling.

Task: Mosaic georegistered aerial photos.

After being individually georeferenced, the five photos were combined into a mosaic. From the ENVI tools list, selected commands were: **Map** → **Mosaicking** → **Georeferenced**. From the **Map Based Mosaic** window were selected: **Import** → **Import Files...** and aerial photos were selected in the order they should appear in the mosaic; if photos overlap, the one selected last is put on top of previous ones. The resulting mosaic looks exactly the way it looks in the "Map Based Mosaic" window.

In order to mosaic the aerial photos they need to be individually subset first to remove black edges, writing on the edges, and excessive overlap. Three out of 5 were subset in this case. Each required about 20 minutes (10 minutes setup and 10 minutes to compute).

Creating the photo mosaic required 10 minutes to set up and 2 hr 50 min to compute.

The whole mosaic process, including photo subsetting, required 4 hours.

Since the mosaic algorithm simply puts the georegistered photos together based on geographic coordinates, it is as accurate as the georegistered photos that comprise it. There are some unavoidable pixel misalignments along the seams, due to slight differences in warping of the individual photos.

Conclusions

Adding up the time required for each processing step, on a per-photo basis, gives an estimate of 4 hours 41 minutes of human operator time required and a total of 7 hours 42

minutes of computing time needed, which includes all of the human operator time plus additional unattended processing time (Table 3).

Table 3. Time required for processing steps, per photo, under the conditions of this experiment.

	Operator time per photo (h:min)	Computer time per photo (h:min)
Copying data	0:04	0:04
Layout and assessment	0:02	0:02
Basic georegistration	4:16	4:34
Subset and mosaic reference images	0:06	2:21
Subset and mosaic aerial photos	0:12	0:36
Export photos from ENVI to GeoTiff	0:01	0:05
Total	4:41	7:42

The great majority (91%) of the operator's time is needed for selecting GCPs in performing the georegistration. This factor will vary somewhat with the characteristics of each photo, particularly the presence of clear, unchanged features usable as GCPs. It can be reduced by a decision to select fewer GCPs per photo or to accept a higher RMS spatial error for a set of GCPs. In this experiment, more care was taken to minimize RMS error and develop an ample set of GCPs for each photo than would probably be the case in a production situation where many photos were to be processed. More work would be needed to determine guidelines for a minimal or optimal set of GCPs to select for an acceptable level of spatial error.

The per-photo estimate for time needed to mosaic the reference images was based on a mosaic of 4 reference images to register 10 aerial photos (Figure 1), and this factor will deviate (be reduced) from this estimate over the course of a large job registering multi-date photo sets, primarily because once a reference image mosaic is created it can be used for multiple photo sets of the same area.

The other per-photo time estimates are probably near minimums and would not be expected to vary much with the scope of the job or other factors, with the possible exception of layout and assessment time. This may be higher if large photo sets are involved or if the scanned photos had not already been through a quality-control process.

An important factor not yet discussed is the effect of large file sizes on processing work flow and potential results. This experiment showed that ERDAS Imagine, probably the most widely used image processing software, is inadequate to handle the file sizes involved, and an alternative must be found. In this case we used ENVI, but even that has practical limitations on handling very large files such as mosaics. Processing times are very long and the resultant files are slow and cumbersome to use in any software package.

For this reason, we recommend against creating large photomosaics as a matter of course. The individual georegistered photos (perhaps subset to remove edges) are more convenient to use, can be displayed in sets as desired, and can be combined into mosaics on an ad-hoc basis if necessary for spatial analyses.

Even with a fast intranet connection, we found that it was impractical to store data (particularly the reference mosaic) on a computer other than the one being used for processing. Even with data loaded on a local hard drive, the slow refresh rate of large images added considerable time, and frustration, to the process of selecting GCPs during georegistration. It was noted that the full resolution (0.3 m) of the reference imagery was not really needed for this work, and the use of coarser, resampled imagery with smaller file sizes could significantly speed up processing. Moreover, the large disparity in resolution between the reference imagery and the subject photos actually made matching GCPs more difficult than it could have been.

Storage of large files and access for processing are becoming easier with the availability of affordable, capacious external hard drives. Even so, for a large job thought must be given to storage space needs, and additional drives may need to be purchased.

To the extent that the conditions of this experiment represent the conditions of a larger undertaking to process the SAGU aerial photo archive, the figures in Table 3 can reasonably be extrapolated on a per-photo basis to gain an idea of the resources that would need to be committed. Again, the amount of time per photo to mosaic the reference images will be reduced as more photos are processed to the same reference set. In addition, due consideration should be given to the ways in which the pilot-project conditions might differ from those of a larger production-oriented project, and adjustments to the estimates made accordingly.