LOW-COST LARGE-SCALE AERIAL PHOTOGRAPHY AND THE UPLAND SOUTH FOLK CEMETERY

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THESIS APPROVED

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Abstract

Aerial Photography, normally acquired via platforms like airplanes and helicopters, is very expensive, requires significant lead-time, and lacks spatial resolution for small features. Large-scale imagery can be acquired using helium-balloon or kite platforms with consumer electronics at a significantly lower cost, at a higher spatial resolution and with more flexible temporal resolution. Increased spatial resolution allows for identification of small surface features such as cemetery headstones, power lines, and manhole covers. The spatial accuracy of images acquired through the low-cost large-scale method was assessed through identification of small spatial features common to the Upland South Cemetery. Unfortunately, the spatial accuracy of the features extracted from the imagery was relatively poor. However, the increased spatial resolutions and more flexible temporal resolutions were very useful in documenting spatial and cultural aspects of the Upland South Cemetery.

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LIST OF ABBREVIATIONS

BAP	Balloon aerial photography
CCD	Charged-couple device
DGPS	Differential Global Positioning System
FAA	Federal Aviation Authority
GPS	Global Positioning System
KAP	Kite aerial photography
LULC	Land use and land cover
NIIRS	National Image Interpretation Rating Scales
SFAP	Small-format aerial photography
USGS	United States Geological Society

INTRODUCTION

Aerial photography was first born when a camera was taken aloft in a hot-air balloon by Nadar in 1858 (Jensen 2000). In 1890, Arthur Batut developed kite aerial photography. Since then, balloon and kites continued as common platforms for acquiring aerial imagery for spatial analysis. In the early 20th century, the airplane quickly eclipsed the balloons and kites as the platforms of choice for acquiring aerial imagery. Modern airplane aerial photography has been fine tuned for very specific scientific purposes with great success. Aerial photography facilitates research in many different fields of study. However, acquiring aerial photography is very expensive, requires significant lead-time to schedule the necessary flights, and results in images in which small features cannot be easily identified.

Several metrics have been created for evaluating the quality of remotely sensed data and aerial photographs. The simplest metric is nominal spatial resolution, measured in cell-size or the ground area encompassed by a single picture element (pixel). For instance, the United States Geological Survey (USGS) High Resolution Imagery used in this study has a nominal spatial resolution, or cell-size, of 30 centimeters by 30 centimeters and is often simply stated as 30 centimeter resolution. A general rule for object identification is the nominal spatial resolution, or cell-size, needs to be at least one-half the width of the object being identified (Jensen 2000). By this standard, the USGS High Resolution Imagery is sufficient for identifying objects as small as 60 centimeters wide. Another metric is the USGS Classification Level used to establish the level of land use and land cover (LULC) classification that the imagery can be used for. In this system, Levels I and II are very small scale, less than 1:80,000, with a large cell-size, used to establish LULC at the continental level. Levels III and IV are used for LULC at state, county and municipal levels with Level IV being more than 1:20,000 in scale (Anderson *et al.* 1976). Both the USGS High Resolution Imagery and the imagery captured for this study are greater than 1:20,000 scale.

While USGS Classification Level metric is not useful for this study, the National Imagery Interpretability Rating Scale (NIIRS) provides a standard for image quality that quantifies the interpretability or usefulness of imagery (Irvine and Leachtenauer 1996). NIIRS is a 10-level task or criteria based scale that was originally developed by the intelligence community and released as the Civil NIIRS in the 1990s. For the Civil NIIRS scale, examples of criteria start with the imagery being completely obscured and undecipherable at Level 0 and then ranging from Level 1, being able to detect lines of transportation through Level 9, being able to identify individual heads on small grain (e.g., wheat, oats, barley) (see Appendix A for more details) (Brown and Aftergood 1996).

There are many fields of inquiry that are not able to benefit from aerial photography because of the high cost of acquisition, the low level of detail in the photographs (spatial resolution) and the delay time before flight or time between flights (temporal resolution). For cultural geographers studying necrogeography, the study of burial places, or genealogists documenting family cemeteries, or folk culture enthusiasts investigating burial rituals, commissioning an airplane or helicopter for an aerial flyover can be prohibitively expensive. Further, the imagery may not have the spatial resolution necessary to document the spatial arrangement of graves and headstones. Many graveyards of cultural significance are not regularly maintained limiting the use of existing imagery. Features, like grave markers and grave decorations, may be obscured by vegetation, debris, and weather.

Cemeteries are recognized by cultural geographers as a significant source of material culture, that is, physical objects from the past that provide insight into the culture that created them (Jordan 1982). The Upland South Folk Cemetery is a well-established cemetery style unique to rural parts of the Southeastern United States (see Figure 1).

According to Jeane (1989), “the folk cemetery is a complex of cultural traits significant for its association of traits rather than for any single identifying element.” Some of these elements are cultural: grave decorations expressing the art of “making do” (see Figure 2), choices of vegetation, use of grave shelters, scraping of the ground,

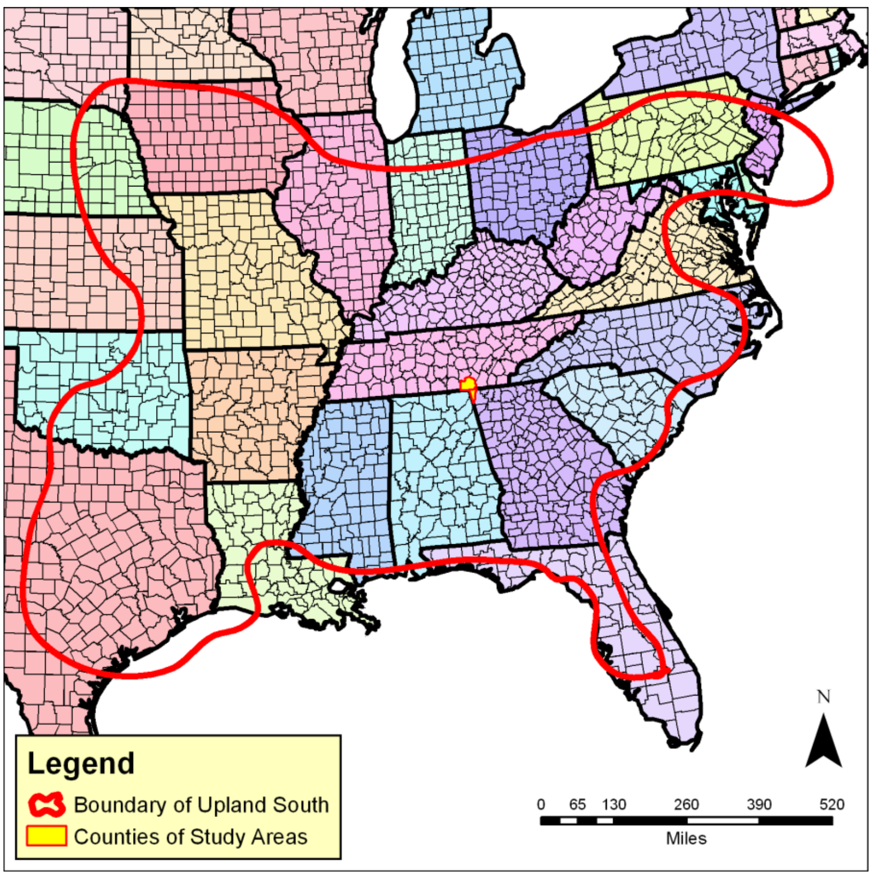

Figure 1: Boundary of the Upland South (Jeane 1989)

mounding of graves, and “Decoration Day” maintenance. Several of these elements are spatial: a hill-top location, unsanctified grounds (not on church grounds), east-west orientation of graves, and unorganized or chaotic distribution of graves. While many of these elements are present in cemeteries elsewhere in the United States and the world, it is the combination of these elements that define the Upland South Folk Cemetery (Jeane 1989).

Some of the elements that define the Upland South Folk Cemetery, like the use of grave shelters, choice of trees, and irregular distribution of graves, are easily ascertained through low-altitude aerial photography captured by airplane. However, many other features are more readily identified in imagery acquired through the low-cost technique, such as the use of shells for grave decoration, small, hand-made headstones, and choice of shrubbery and plantings (Jordan 1982). Further, the Upland South Folk Cemetery complex is marked a “cult of piety” in the practice of maintaining the grounds on

Figure 2: Grave with decorations and gravel simulating scraped earth

“Decoration Day,” “Homecoming,” or “Cemetery Work Day,” rather than the use of professional, perpetual maintenance (Ball 1975). On this day, the descendants of the interred gather to clean the graveyard, removing vegetation, replacing grave markers, and generally socializing. This is significant because “Decoration Day” is generally held near the beginning and/or end of summer. This practice impacts the temporal resolution of the desired imagery. The best time to acquire imagery of an Upland South Folk Cemetery would be immediately following a Decoration Day cleaning. The general-purpose aerial photography found in publicly available collections are acquired at widely spaced time periods (very low temporal resolution) and on a date that may not coincide well with Decoration Day. It would also be useful for the cultural geographer to be able to collect aerial photographs before and after a Decoration Day event to document the results of the ritual.

Using a tethered helium-balloon or kite platform to acquire aerial photography may provide a cost-effective way to acquire the high spatial resolution imagery with flexible temporal resolution that is best suited for the fields like necrogeography. Assuming weather conditions are favorable, mostly clear skies and windy for a kite or mostly clear skies and calm for a balloon, image acquisition can begin as quickly as desired and can continue as long as weather and daylight holds out. Image resolution can be adjusted easily by varying the altitude of the platform. Coverage area is changed by maneuvering the platform. On a very calm day, the balloon can be easily maneuvered even between trees with only a few inches of clearance. The kite, however, is limited to subjects that can be captured downwind from a clearing. The use of a high resolution digital camera allows for hundreds of images to be captured, with the best images to be saved and the others archived or discarded.

The technique of low-altitude aerial photography utilizing tethered balloons and kites is by no means novel. The first patent issued by the United States Patent Office relating to aerial photography in general was for a camera system to be suspended from a kite or balloon (Fairman 1887). The availability of desktop GIS and high-resolution digital cameras make the acquisition and geo-referencing of digital imagery significantly simpler than ever before opening the door to widespread growth in this technique. While many studies have utilized low-altitude aerial photography and have examined the efficacy of the imagery compared to other platforms, few have critically examined the accuracy and quality of the imagery using established metrics. To this extent, this study will establish a level of spatial accuracy and quality for imagery acquired using this technique. Further, this study will utilize this process to document some of the spatial features unique to the Upland South Folk Cemetery.

Research Objectives

The purpose of this study is to determine the accuracy of aerial imagery acquired using a low-cost technique employing consumer digital cameras and a tethered helium balloon or kite platform with limited access to expensive software and differential global positioning system (DGPS). In particular, the spatial accuracy of features extracted from such imagery of three cemeteries exhibiting aspects of an Upland South Folk Cemetery will be examined.

In order to determine the accuracy, imagery acquired by the low-cost technique will be geo-referenced using two different techniques. In the first technique, imagery will be combined into a single mosaic and then geo-referenced to common features identifiable in the USGS High Resolution Imagery. In the second technique, each individual image will be separately geo-referenced to common features in the USGS High Resolution Imagery. Features in the geo-referenced images resulting from each method will be extracted using heads-up digitization. A random sample of these features will be selected and their actual location determined using a DGPS receiver capable of sub-centimeter accuracy. In order to maintain the low-cost technique, the USGS High Resolution Imagery with coarser spatial resolution will be used to geo-reference the relatively finer spatial resolution aerial photography acquired in this study. This is contrary to standard photogrammetric practices in which geo-referencing usually is accomplished by matching lower-resolution imagery to already geo-referenced higher resolution imagery. The USGS High Resolution Imagery is the best freely available imagery for the extents studied and is freely available through the USGS National Map (USGS 2004).

Three cemeteries have been selected that exhibit various aspects of the Upland South Folk Cemetery. These cemeteries are within the coverage of the USGS High Resolution Imagery for Chattanooga, Tennessee. The Federal Aviation Authority (FAA) limits the operation of kites and balloons within an 8 kilometer buffer around any airport. The cemeteries selected are outside such a buffer, as illustrated in Figure 3.

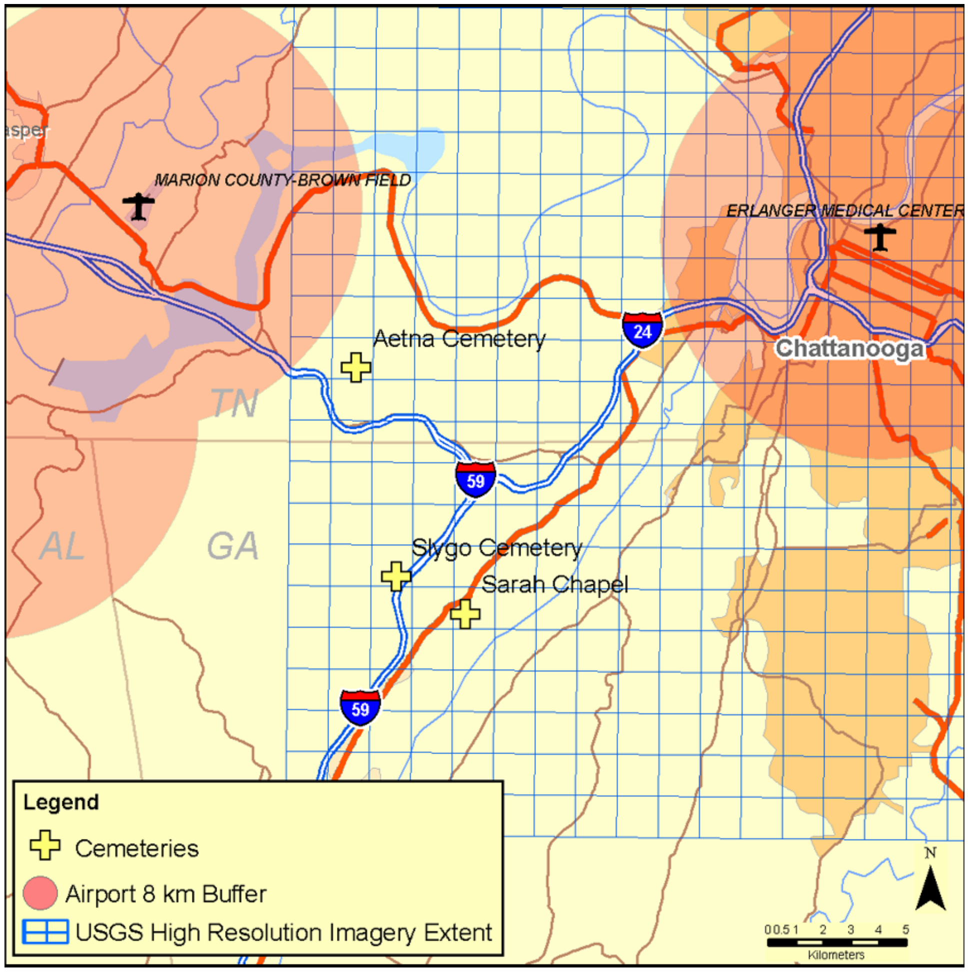

Figure 3: Overview of Cemeteries

LITERATURE REVIEW

Balloon and Kite Aerial Photography

Remote sensing and aerial photography originated with balloon-based platforms. Modern systems involving airplanes and satellites provide very high quality data but at very high costs. Though the image quality of such modern systems is high, the spatial resolution and temporal resolution are limited to manufactory-set default settings making it not practical for small feature and time-sensitive events (Buerkert *et al*. 1996). For many studies helicopters create too much disturbance when flown at low altitudes (Trathan 2004). Several researchers have recently explored both balloon-based aerial photography (BAP) and kite aerial photography (KAP) for alternative aerial imagery.

Andrew Baker and colleagues (Baker *et al.* 2004) published a cost and functionality comparison of three methods of capturing aerial photography including a fixed cable suspended platform, a balloon platform and airplane based platform. They found the balloon platform to be very flexible, providing greater image resolution while providing rapid response to triggering events.

Dr. James S. Aber and colleagues have published several recent entries in the Transactions of the Kansas Academy of Science mostly focusing on KAP. Aber *et al.* (2002c) established that kite aerial photography is highly portable and that low cost makes the method feasible for routine operation by small organizations. They concluded that kite and balloon aerial photography "could be utilized to document important or special geological sites throughout the state" of North Dakota (Aber 2003). Their continued "field experiences demonstrate that kite aerial photography may provide a basis for microstructural mapping and analysis of complex bogs" (Aber *et al.* 2002a) Aber evaluated the use of a tethered helium blimp, finding that "the helium blimp is relatively inexpensive and easy to operate in the field in calm to light wind conditions" (Aber 2004). Aber *et al.* (2003) found that KAP "proved successful for identifying effects of irrigation and for quantifying turf conditions" on a golf course.

J.B. Ries and I. Marzolff utilized a remotely controlled hot-air blimp for monitoring erosion in the Central Ebro basin (Ries and Marzolff 2003). Hot-air was utilized because they could not get a source for hydrogen or helium. Buerkert *et al.* (1996) used a hot air filled zeppelin tethered to a camel to capture imagery of millet fields in the Sahel. They found that "compared to flying ultra-light aircraft which was used to take high resolution photographs from the same experimental areas in 1993, the balloon set-up was much more flexible." This echoed the findings of Boike and Yoshikawa (2003) in their mapping of periglacial geomorphology that "BAP is easier to operate than kite-borne," however, with the limitations that "it requires an environment with little or no wind" and "transporting helium to remote areas is difficult, and the helium itself is expensive."

Starting in 1973 and continuing through the 1970s, the Whittlesey Foundation completed several successful aerial surveys of archaeological sites throughout the world. Their systems consisted of "airfoil" (kite) and tethered hydrogen-filled balloon-kite, which is essentially a small blimp (Whittlesey 1974b). These platforms were used in the United States, Europe, and the Mediterranean (Whittlesey 1974b, Whittlesey *et al.* 1977, Myers 1978, Cooper 1981).

Until recently most BAP and KAP researchers focused on techniques using film cameras. The limited number of exposures of a film camera (usually 36 exposures at most) meant that the effort in acquiring each photograph was significant. In most cases, researchers would acquire mostly oblique photographs for monitoring and evaluating environmental conditions rather than attempting to acquire vertical photographs for planimetric use. The recent increase in the quality of digital cameras provides the ability to take several hundred pictures an hour at resolutions comparable to 35mm film cameras. Images acquired with digital cameras do not require chemical processing and can be evaluated in the field. This allows for unnecessary or poorly exposed images to be discarded without cost and additional imagery acquired as needed. Throughout aerial photography, digital imaging systems are replacing film-based cameras (Leberl 2003). The ability to inexpensively capture large number of pictures has lead BAP and KAP practitioners to abandon the complex remote controlled camera positioning systems in favor of simpler, fully automatic systems (Leffler 2006).

GIScience and Necrogeography

Utilizing GIS for necrogeography is also not a new idea. Many state genealogical societies have online databases for finding the location of ancestral graves. The University of Pennsylvania's Historic Preservation Program in the Graduate School of Fine Arts has been working on the "Dead Space" project "focused on developing a model conservation plan beginning with the documentation, recording and analysis of the cemetery and its urban context over time" (Historic Preservation Program 2006). Numerous Lewiston, Idaho, grade-school students have been introduced to GIS through applications in necrogeography (Branting 2005).

Applications of aerial photography are also well-represented in the study of burial places. Low-altitude aerial imagery from aircraft was used to identify indigenous cemeteries in Costa Rica (Sheets 2004). The Dead Space project utilized existing aerial imagery to digitize the graves in the St. Louis Cemetery #1 (Historic Preservation Program 2006). Kite Aerial Photography has even been used in conjunction with electromagnetic ground conductivity surveying to locate unmarked graves (Wilson-Agin 2003).

The value of the material culture present in cemeteries has been well-established by archaeologists and anthropologists. However, as late as 1967, burial practices were recognized as one of “few other subjects as untouched or as promising” in geography. (Kniffen 1967) The Upland South Folk Cemetery has been well studied by anthropologists. Several of the burial practices have been traced to roots on three continents and are common in predominately Anglo-Saxon cemeteries, African-American cemeteries and Native American cemeteries. The cemeteries follow British dissenter Protestant traditions of not being on sanctified grounds. The use of grave sheds or grave shelters is of Native American tradition. The mounding of graves and use of shells and other “making-do” decorations derives from African influences (Jordan 1982). The “cult of piety” was well-documented (Ball 1975) as a common method of maintaining the graveyard along with the use of fixed tables for sharing food, a practice derived from African customs of leaving favorite foods of the dead.

Unfortunately, it has been noted that these repositories of folk practices are endangered (Jordan 1982). Urban sprawl is encroaching on the land occupied by cemeteries with little documentation of the burial practices used. Weather and vandalism continuously take their toll. Active cemeteries transition into practices of perpetual, professional care in which grass is grown and graves are leveled. While Terry Jordan (1982) encourages preservation, thorough documentation should occur first. The KAP and BAP techniques used in prior studies of geomorphology can be simplified and used for documenting the Upland South Folk Cemetery. Early KAP and BAP techniques required the camera to be lowered and reloaded with film for every shot (Birdseye 1940) Most recent research utilizing KAP and BAP rely on 35mm film-based cameras and remote shutter control and remote camera positioning (Whittlesey 1974a, 1974b, Whittlesey *et al.* 1977, Myers 1978, Badekas *et al.* 1980, Marks 1989, Warner 1996, Aber *et al.* 1999, 2001, 2002a, 2002b, 2002c, 2003, Perkins 2000, Aber 2003, Boike and Yoshikawa 2003). More recently, the digital camera has been replacing the 35mm film-based camera (Hinkler *et al.* 2002, Wilson-Agin 2003, Aber 2004, Baker *et al.* 2004, Myamoto *et al.* 2004, Trathan 2004, Aber *et al.* 2005). While airplane acquired aerial photography has been applied to necrogeography (Sheets 2004, Branting 2005, Historic Preservation Program 2006), the application of low-cost techniques like KAP and BAP to studies of burial places has been very limited (Wilson-Agin 2003) and not focused on documenting aspects of the burial practices. Further, photogrammetric standards for KAP and BAP imagery are only recently being developed (Aber 2005).

METHODOLOGY

Selected Cemeteries

Three cemeteries exhibiting several qualities of the Upland South Folk Cemetery complex were chosen for this project because of their proximity to Chattanooga, Tennessee, and distance from airports. Figure 3 in the Introduction illustrates the locations of these three cemeteries.

Figure 4 shows the extent of the Aetna Cemetery, on Aetna Mountain in Marion County, Tennessee, which is about 50 meters by 128 meters covering approximately 6400 square meters centered at 35° 0' 27.9" North Latitude and 85° 29' 57.9" West Longitude. The red-dash line follows the approximate boundary of

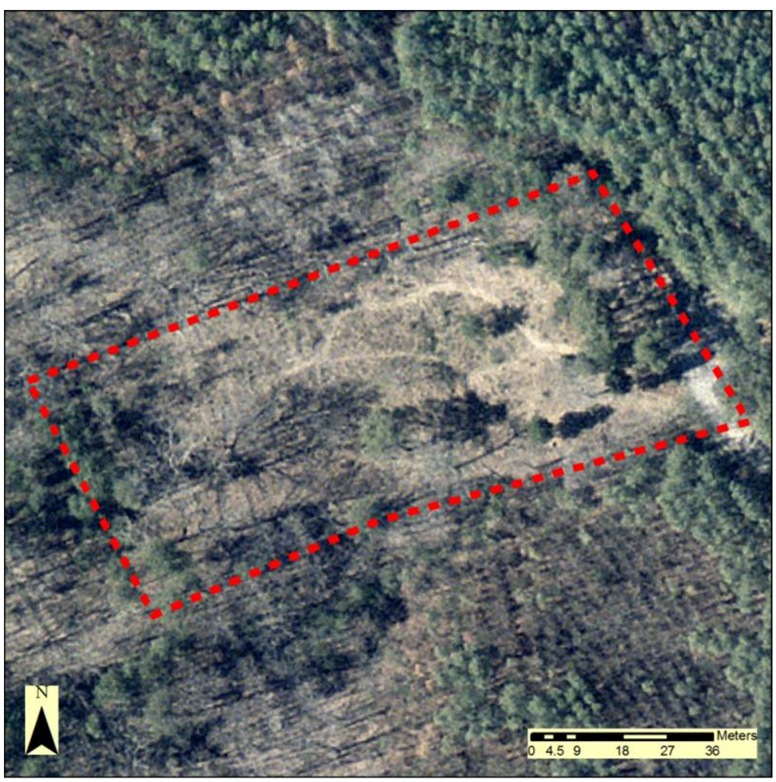

Figure 4: Aetna Cemetery from USGS High Resolution Imagery

the cemetery. The surrounding area is a Bowater Company pine tree farm, clearly visible in the USGS imagery in Figure 4. Since the USGS imagery was captured in April 2002, the pine farm had been clear-cut logged due to a Pine-beetle infestation. The cemetery itself is in poor condition with the older parts extremely overgrown with weeds and several fallen trees across older graves. The cemetery was used extensively in the late 1800s and early 1900s when Aetna Mountain had an active mining community. In accordance with the Upland South Folk Cemetery complex, the cemetery is far from any churches and exhibits no Christian symbols. Graves are randomly distributed but have a general eastern orientation. Several graves are fenced-in and some had been scraped and mounded. See plan-view in Figure 5.

Figure 6 illustrates Slygo Cemetery delineated by the red-dash line. The 25 meter by 50 meter cemetery lies on a hill behind Slygo Baptist Church in northern Dade County, Georgia, and covers about 2300 square meters centered at 34° 56' 21.4" North Latitude and 85° 29' 6.5" West Longitude . This cemetery predates the adjacent church

Figure 5: Aetna Cemetery plan-view

Figure 6: Slygo Cemetery from USGS High Resolution Imagery

and contains several unmarked stone-covered graves. The cemetery is well-maintained and in current use. Christian symbols are only present on newer headstones. Some graves are marked with “making-do” decorations in addition to the traditional flower arrangements (see Figure 7 for plan-view).

Sarah Chapel Cemetery is also located in northern Dade County, Georgia and

Figure 7: Slygo Cemetery plan-view

covers about 10000 square meters (approximately 100 meters on each side) centered at 34° 55' 35.2" North Latitude and 85° 27' 20.7" West Longitude (see Figure 8). The cemetery also predates the adjacent church. Several unmarked and marked stone-covered graves exist as well as one unmarked mounded grave, several “scraped earth” graves and a large poured-concrete table for serving food on Decoration Day. This is the largest of the three cemeteries and is well-maintained, especially in the newer areas (see Figure 9 for plan-view).

Kite and Balloon Aerial Photography

Aerial photography was acquired at each of three cemeteries using either a 2.8-square meter airfoil or a 1.5 meter diameter helium filled balloon. The kite is capable of lifting several kilograms in a steady wind of at least 4 miles per hour. The balloon is capable of lifting 2 kilograms and is easiest to use in little or no wind. A tether consisting

Figure 8: Sarah Chapel Cemetery from USGS High Resolution Imagery


Figure 9: Sarah Chapel Cemetery plan-view

of nylon Dacron with a 90 kilogram breaking force was used for both the kite and balloon. The tether was marked every 15 meters with marker tape.

A camera mount (rig) was fashioned from aluminum allowing the camera angle to be manually positioned and locked in place. The rig was suspended about 15 meters down the tether line from the kite or balloon using a Picavet suspension. This type of suspension uses a single line passing through four pulleys to maintain a constant direction relative to the tether line and allows gravity to maintain the camera position relative to the earth. The camera was mounted in a vertical position on nadir (see Figure 10).

The camera used was an Olympus Stylus 800 with a 8.1 mega-pixel charged-couple device (CCD) sensor configured with an intervalometer set to capture a 3264x2448 pixel image every 15 seconds. The camera could capture about 250 compressed images on a one gigabyte (GB) flash memory card before needing to be brought back down and reloaded. This configuration provided about an hour of image capturing, during which, the kite or balloon was maneuvered over the subject area at an altitude of 30 to 50 meters above ground level (AGL). The altitude was adjusted as needed to prevent the tether from being tangled in trees. At an altitude of 50 meters AGL,

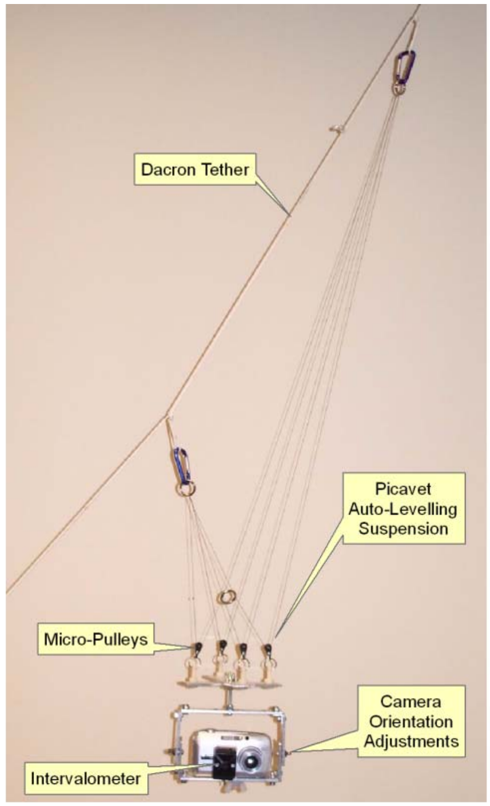

Figure 10: Camera Rig with Picavet Suspension

the image extent would cover an area 30 meters by 50 meters, or 1500 square meters, of surface area resulting in a cell size of 15 millimeters. At this resolution, features as small as 30 millimeters wide can be easily identified.

With the camera set to automatically capture an image every 15 seconds, the balloon or kite was maneuvered over each cemetery. Several hundred images were captured for each cemetery and of those about two dozen were selected as being the best. Because the camera position and exposure settings were not directly controlled, images were chosen based on three criteria: the extent of coverage in the image, the verticality of the image (usually discernable in the pitch of trees or headstones in the image), and image clarity. During analyses, the colors in the images were histogram-equalized to increase the contrast between features and vegetation. Samples of the original imagery are exhibited in Appendix B.

For two of the cemeteries, the images were mosaicked in a process similar to image to image co-registration. One image was selected as an anchor while the other images were georeferenced to common points. The resulting mosaic was converted to a single raster. The single raster was then georeferenced wholly to the 30cm spatial resolution USGS High Resolution Imagery. For the third cemetery, each image was individually georeferenced to the USGS High Resolution Imagery and not converted to a single raster layer.

The two different methods for creating the final mosaics were used because the USGS High Resolution Imagery for Aetna Cemetery and Slygo Cemetery did not provide enough visible control points to accurately georeference each image (30cm spatial resolution in the USGS High Resolution Imagery versus 15mm spatial resolution in the aerial images acquired for this study). Further, the final mosaic for Sarah Chapel Cemetery consisted of twelve individual images.

Once the mosaics were complete and georeferenced, each visible headstone was digitized resulting in a polygon feature class with 563 features stored in a geo-database. The longitude and latitude for the centroid of each polygon was saved in fields in the feature set. The angle of a normal line off the eastern-most face of the polygon was calculated and saved in a field in the feature class to represent the apparent direction of the headstones. Fields were added to the feature class for measured longitude, latitude and direction. Finally, a field was added and filled with a random number between 0 and 10 to help select the sample for analysis.

Using three of the random values in the feature class (2, 4, 8) a sample of 185 headstones out of 563 was selected. The longitude and latitude of the center of each headstone was determined using a Trimble GeoXT differential Global Positioning System (DGPS) receiver. The direction each headstone in the sample faced was measured manually with a compass. The spatial location and orientation of the headstones were chosen for comparison because of the chaotic spatial character and strict East-West orientation of the Upland South Folk Cemetery complex.

RESULTS AND ANALYSIS

A sample of 185 of the 563 digitized features was selected for manual measurement and analysis. Out of this sample, data collection errors eliminated 32 features from the analysis. Of the remaining 153, three exhibited measured error in position more than two standard deviations from the mean and were eliminated as outliers leaving a sample of 150 features. Of these features, 112 were in Sarah Chapel Cemetery (32.5% of the total in that cemetery), 22 were in Slygo Cemetery (21.6%), and 16 were in Aetna Cemetery (13.6%).

Aetna Cemetery

At the Aetna Cemetery, see Figure 11 (images are histogram-equalized, see Appendix B for samples of original imagery), 16 digitized features were selected for analysis representing 13.6% of the digitized features. The small percent of sampled features was due to a larger number of data collection errors occurring at this cemetery. This was both the first cemetery where data was collected and the most challenging because tree coverage introduced problems with GPS signal strength. Further, the cemetery had been cleaned since the aerial images were captured and many features were hard to identify on the ground. The digitized features exhibited an average difference from the DGPS collected location of 3.278 meters resulting in a root mean square (RMS) of 4.266 meters. The digitized features exhibited an average calculated facing direction of 115 degrees (standard deviation of 11.9 degrees), with 0 being true North. The features exhibited a mean measured facing direction of 80 degrees (standard deviation of 3.6 degrees), compensating with a magnetic declination of 3.5 degrees.

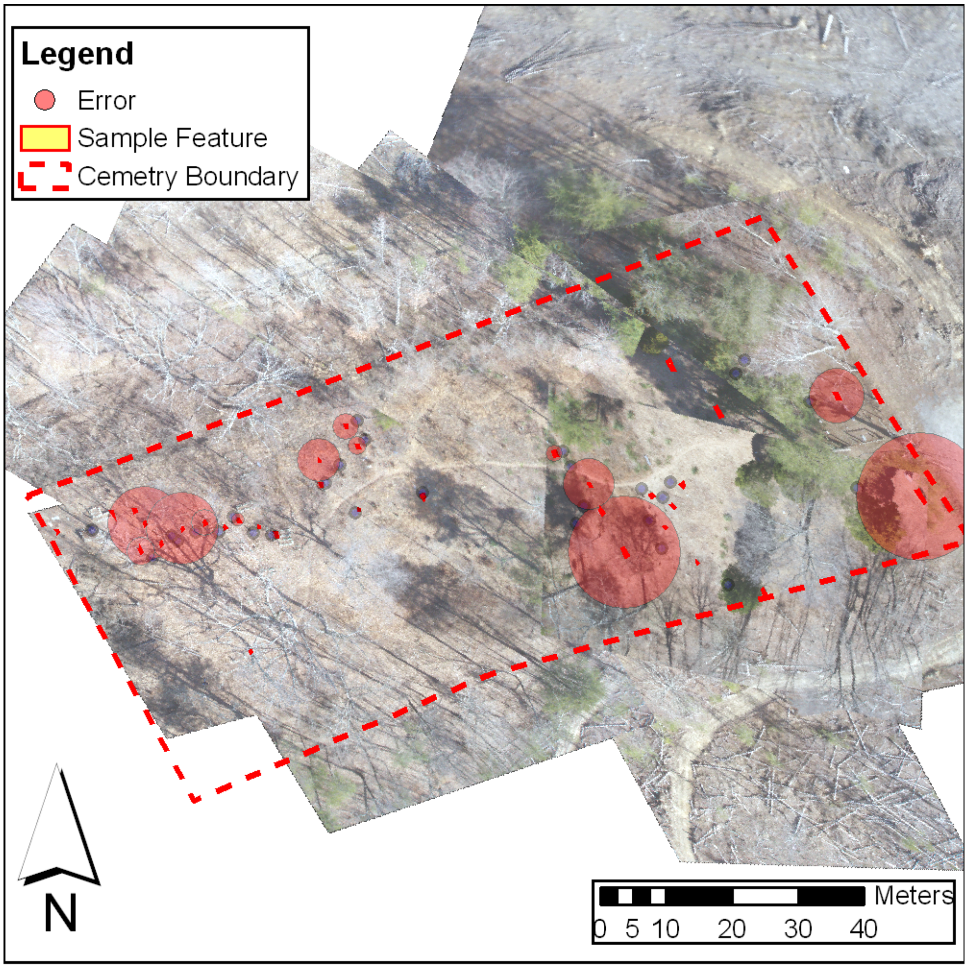

Figure 11: Aetna Cemetery showing error in digitized feature locations

Slygo Cemetery

At the Slygo Cemetery, see Figure 12 (images are histogram-equalized, see Appendix B for samples of original imagery), 22 digitized features were selected for analysis representing 21.6% of the digitized features. Slygo Cemetery was the smallest cemetery in the study. The small size of the cemetery and the strong GPS signal allowed for complete collection of all points. The digitized features exhibited an average difference from the DGPS collected location of 1.676 meters resulting in a root mean

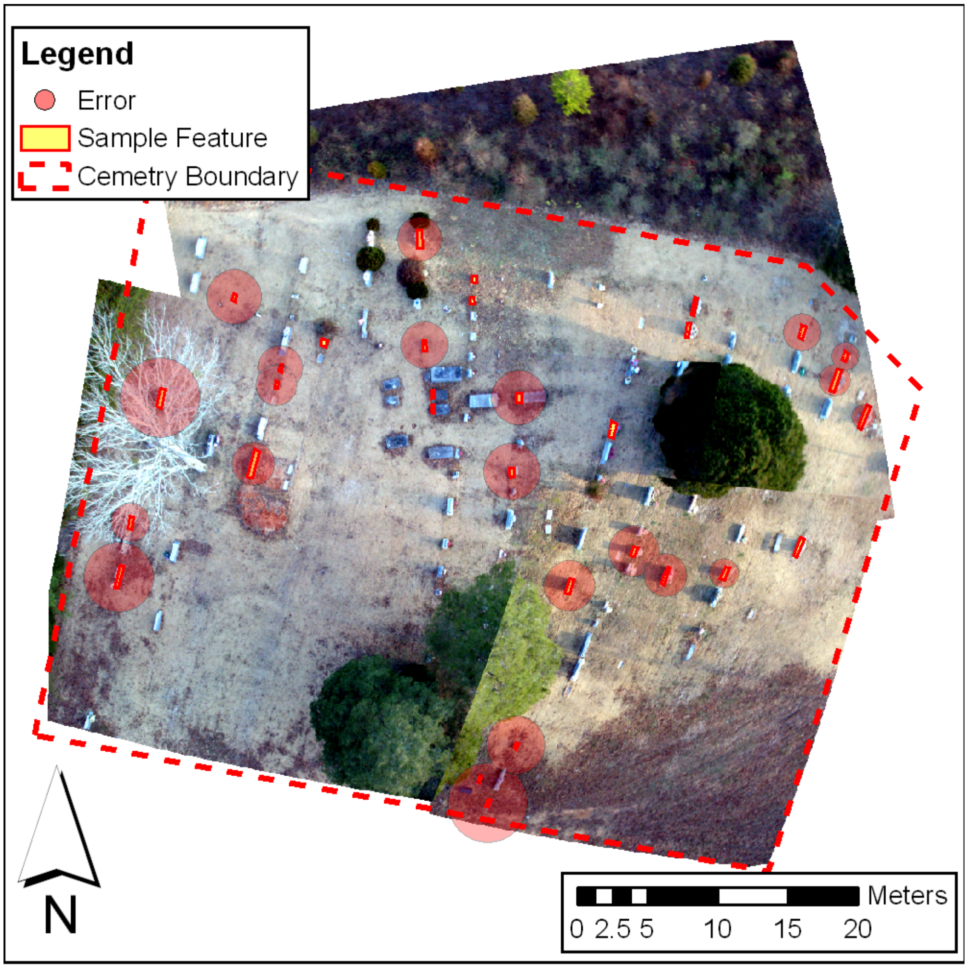

Figure 12: Slygo Cemetery showing error in digitized feature locations

square (RMS) of 1.779 meters. The digitized features exhibited an average calculated facing direction of 72 degrees (standard deviation of 9.5 degrees), with 0 being true North. The features exhibited a measured facing direction of 105 degrees (standard deviation of 7.0 degrees), compensating with a magnetic declination of 3.5 degrees West.

Sarah Chapel Cemetery

At the Sarah Chapel Cemetery, see Figure 13 (images are histogram-equalized, see Appendix B for samples of original imagery), 112 digitized features were selected for analysis representing 32.5% of the digitized features. Sarah Chapel Cemetery was the

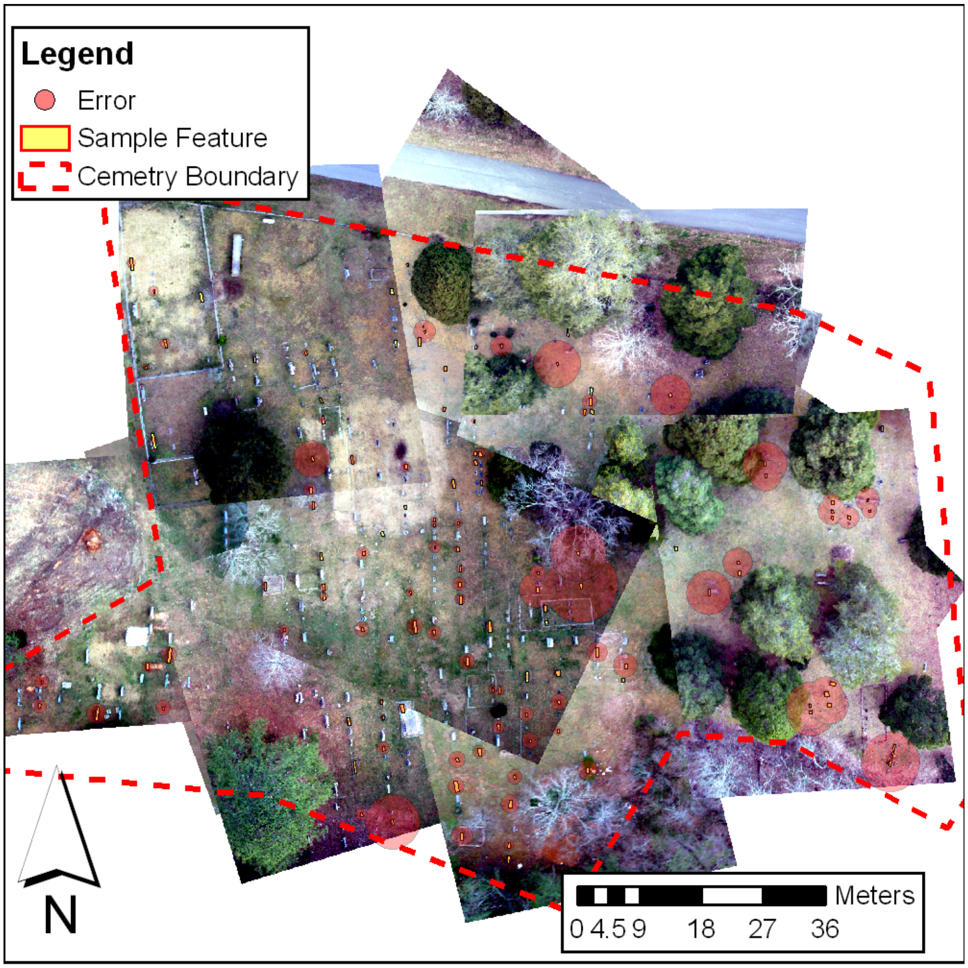

Figure 13: Sarah Chapel Cemetery showing error in digitized feature locations

largest in the study. The digitized features exhibited an average difference from the DGPS collected location of 1.191 meters resulting in a root mean square (RMS) of 1.567 meters. The digitized features exhibited an average calculated facing direction of 92 degrees (standard deviation of 6.6 degrees), with 0 being true North. The features exhibited a measured facing direction of 90 degrees (standard deviation of 4.8 degrees), compensating with a magnetic declination of 3.5 degrees West.

Combined Results

The combined digitized features (Figure 14 shows a scatter-plot of error in Longitude and Latitude) from all three cemeteries exhibited an average difference from the DGPS collected location of 2.023 meters resulting in a root mean square (RMS) of 2.059 meters. The digitized features exhibited an average calculated facing direction of 92 degrees (standard deviation of 13.1 degrees), with 0 being true North. The features exhibited a measured facing direction of 91 degrees (standard deviation of 8.4 degrees), compensating with a magnetic declination of 3.5 degrees West.

Spatial and Temporal Resolutions

The Slygo Cemetery was small enough to get complete coverage in three images, compared to seven images for Aetna Cemetery and fifteen images for Sarah Chapel Cemetery. The ease of identification of matching features in the USGS High Resolution images for both Slygo Cemetery and Sarah Chapel and the relatively clear horizon

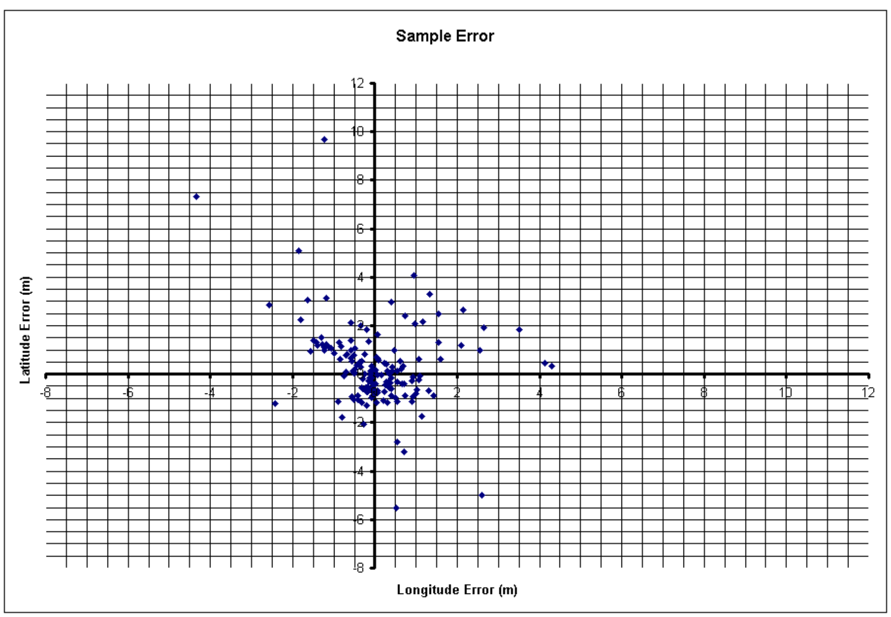

Figure 14: Error in Longitude and Latitude (in meters)

combined for much greater accuracy than the features in Aetna Cemetery. Features digitized through this technique had generally poor accuracy (greater than 2m) compared to the precision of the imagery (less than 2cm). Further, features captured through this method also exhibited poor orientation compared to orthorectified aerial photographs.

The method of geo-referencing the imagery did make a significant difference in the resulting image accuracy. The imagery for both Aetna Cemetery and Slygo Cemetery were initially combined into a single mosaic and then wholly geo-referenced to the USGS High Resolution Imagery (first geo-referencing method). However, each individual image for Sarah Chapel Cemetery was geo-referenced separately to the USGS High Resolution Imagery (second geo-referencing method). The process of creating a single mosaic from the images and then geo-referencing wholly to the USGS High Resolution Imagery resulted in a reduction in accuracy of nearly 100% in both location and orientation (see Table 1 and Table 2).

	First geo-referencing method	Second geo-referencing method
N	38	112
mean	2.350m	1.191m
SD	2.019	1.024
RMS	3.081m	1.567m

Table 1: Comparison of positional accuracy of the two geo-referencing methods

	First geo-referencing method		Second geo-referencing method	
	Calculated angle	Measured angle	Calculated angle	Measured angle
Mean	90.376°	94.921°	91.941°	90.152°
SD	23.670°	14.116°	6.644°	4.825°

Table 2: Comparison of directional accuracy of the two geo-referencing methods

Despite the poor accuracy results, the imagery was able to accurately portray several identifying features of the Upland South Folk Cemetery complex. The overall distribution of the graves and the general Eastern orientation are clear in the images. Further, the spatial resolution of the imagery makes identification of practices such as “making-do” decorations and scraping and mounding possible (see Figure 15). In these cemeteries, however, the graves with the best examples of “making-do” decorations were completely obscured by tree canopies. Finally, the flexibility in temporal resolution and low cost of the methodology make possible documentation of cultural events like cemetery cleanings.

Figure 16 shows the same extent of the Aetna Cemetery in the USGS High Resolution Imagery (USGS Imagery, April 2002), the imagery used for this analysis

Figure 15: Graves showing scraped earth (left) and "making-do" decorations (right)

(Original BAP Imagery, 27 February 2006) and an image acquired after a significant cleaning event occurred (After Cemetery Cleanup, 16 March 2006). In the imagery used for this analysis, the setting is easily identified as a cemetery but many headstones and other features are completely obscured. In the image acquired after the cleaning event it is very easy to identify the location as a cemetery and clearly identify many more ground features like headstones and other grave markers. The fact that the imagery used in the analysis has a cell-size of 1.5 centimeters and the image acquired after the cleanup has a cell-size of 11.4 centimeters demonstrates how temporal resolution can be more significant in identification of small features than spatial resolution.

Limitations

This methodology has several significant limitations. First, the acquired imagery was geo-referenced to the USGS High Resolution Imagery which has a coarser spatial resolution of 30 centimeters compared to the spatial resolution of 15 mm aerial photography acquired in this study. It would be impossible for the resulting imagery to

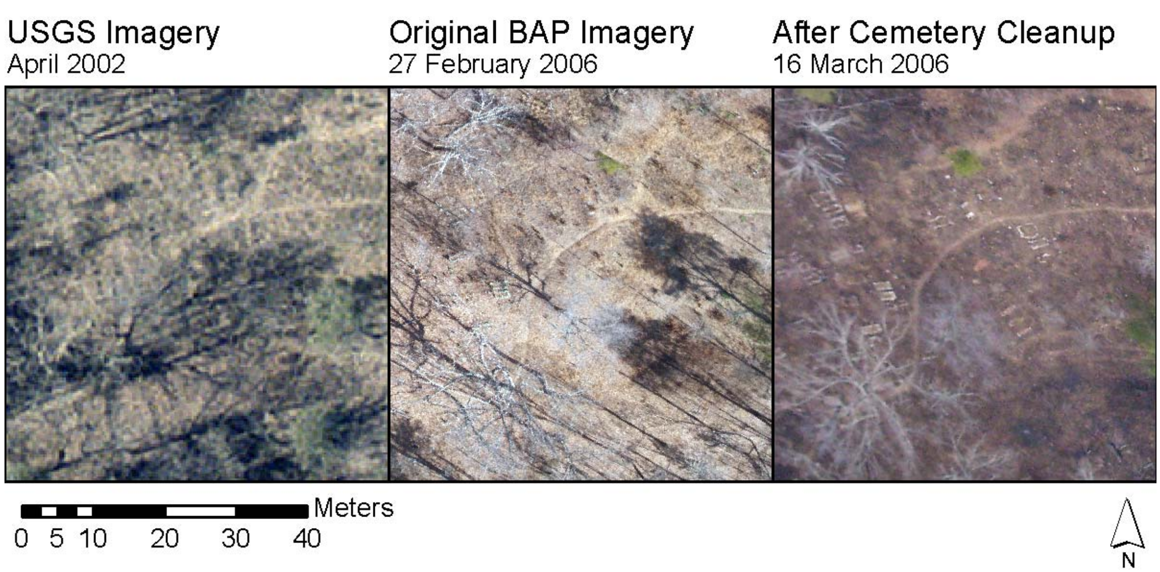

Figure 16: Aetna Cemetery - all three images are of the same spatial extent but at different times

have greater accuracy without using more accurate control points. In figure 16, it was clear that the imagery could provide clear identification of numerous features. The imagery could be geo-referenced to DGPS captured locations for these features. However, using DGPS collected ground control points for geometric rectification may not be practical due to the large amount of time and labor needed for collecting sufficient ground control points. Capturing a single DGPS ground control point accurate to 15mm could take several hours.

Second, like airplane-based aerial surveys, the low-cost technique is limited by the weather conditions in which it can operate. While cloud coverage is not as much of a concern, the balloon requires windless conditions to operate optimally and the kite requires a steady wind of at least 5 kilometers per hour. Fortunately, the combination of both kite and balloon allows for operation under most non-severe conditions including light rainfall and heavy cloud coverage. While both platforms provide good stability, a very fast shutter speed, at least 1/250th of a second, is necessary to capture clear images. A larger proportion of the images would be usable if the camera orientation could be maintained through accelerometers and servos. The images would maintain North-up and near vertical orientation resulting in easier geo-referencing and rectification.

Third, the low-cost technique does not work well in areas of heavy tree coverage as there is a tendency for the tether to become tangled in the branches. Further, there appeared to be a correlation between the density of the tree canopy and the accuracy of the features either due to poor image rectification or decreased satellite reception in the DGPS receiver.

Fourth, the technique is not well suited to surveys of large extents. Each image covers only several hundred square meters and must be geo-referenced individually. For example, the University of Tennessee at Chattanooga campus encompasses approximately 482000 square meters (UTC 2006). With a 60% overlap, almost 1000 separate images would need to be acquired and geo-referenced.

CONCLUSIONS

This study considered the spatial accuracy of aerial imagery collected using a low-cost, low-altitude technique. A helium-filled balloon or airfoil kite was used as a platform to place a consumer digital camera with a near-vertical orientation overhead of the subject 70m to 100m. The resulting imagery was georeferenced to freely available imagery provided by the USGS and features were extracted through manual digitization. The ground-locations of randomly sampled features were established using a differential GPS and errors measured. Also, the spatial orientation of the facing of each randomly sampled feature was calculated from the digitized features and compared to ground-truth. The spatial distribution and orientation of headstones are two features that contribute to the Upland South Folk Cemetery complex. Through this study, it was hoped that a baseline of accuracy could be established for this method.

It was found that the process of georeferencing the imagery to existing, lower-precision imagery, like the USGS imagery used in this study, dilutes the precision to the extent that precise spatial position of features cannot be assessed. A resulting accuracy of about 2 meters was calculated for the imagery exhibiting a 15 millimeter precision. Further, the East-West orientation of individual digitized features was found to be significantly different from ground-truth. Overall, the resulting imagery lacked robustness for photogrammetric purposes and feature extraction compared to orthographically corrected airplane and satellite collected aerial imagery.

However, the relative spatial position of features was represented well-enough to determine patterns in distribution. A chaotic distribution of graves is an established component of the Upland South Folk Cemetery complex. Further, the general East-West orientation of the graves was preserved in that the mean orientation calculated from the digitized features did not deviate significantly from the measured mean value. The low-cost technique was successful in documenting these traits of the Upland South Folk Cemetery complex.

The spatial resolution and flexibility in temporal resolution of the technique were found to be better than aerial imagery. The spatial resolution of 15mm in the imagery results in a rating on the NIIRS scale between levels 7 and 8 – sufficient to determine the species of tree based on the texture of the bark but not sufficient to identify individual cattails. Flexibility in the temporal resolution of the imagery far exceeds airplane or satellite methods as images could be captured on demand hourly, daily or weekly. The imagery of the Aetna Cemetery clearly shows that the surrounding landscape had changed significantly since the USGS Imagery was acquired, showing the benefit of being able to acquire on demand. And the final imagery of the Aetna Cemetery shows the benefits being able to return to the site after significant events to document change. In fact, Figure 16 demonstrates that flexibility in temporal resolution can be more important in feature identification than spatial resolution as features are more easily identified in the 11.4mm imagery acquired after the cemetery cleanup event than in the 1.5mm imagery acquired before.

The accuracy of the imagery could be improved by adapting more traditional techniques used in aerial photography. Establishing ground control points visible in imagery to greater accuracy than the precision of the imagery would provide better geo-referencing but would require access to expensive DGPS equipment. Further, a DGPS receiver may take several minutes to several hours to calculate a position with greater accuracy than the USGS High Resolution Imagery.

Ortho-rectifying the imagery to elevation models should improve the accuracy of the location and orientation of features. However, this would require access to costly software packages. Further, most digital elevation models (DEM) are only accurate to ten meters or greater. Ortho-rectifying 15 millimeter imagery to a ten meter (DEM) would likely not result in significantly better imagery.

Providing a 60% overlap of imagery through a controlled flight-plan would eliminate many of the edge-effects of consumer grade cameras but would require significantly more time for image acquisition. Finally, providing camera stabilization through accelerometers and servos would result in more acceptable images but would significantly increase the complexity of the system.

The process of geo-referencing imagery to imagery of lower accuracy might be extended further with possibly better results. The platform could be maneuvered to an altitude great enough to capture the entire extent in a single image. This single image could then be geo-referenced to lower accuracy, freely available imagery. Then, with the platform maneuvered lower, higher spatial resolution imagery could be captured and geo-referenced to the single image of the entire extent.

The technique presented here could have many applications where large-scale imagery is desired but expense and flexibility in temporal resolution are limiting factors. Archeological teams could acquire imagery of a site throughout the excavation process. Construction companies could acquire imagery of a building site throughout the construction process. Spatial properties of cultural events, like parades and sporting events, could be documented and analyzed. Automobile traffic patterns as well as pedestrian traffic patterns could be documented, especially around significant events. Changes in geomorphology could be documented during events like flash-floods and before and after forest fires. Patterns in group animal behavior could be easily studied due to the non-intrusiveness of the platform compared to airplanes and helicopters. Algae plumes due to increased water temperature releases at nuclear power plants could be documented.

APPENDIX A

Civil NIIRS Criteria

A more detailed listing of criteria used to determine the rating of imagery on the National Imagery Interpretability Rating Scale.

Level 0	Interpretability of the imagery is precluded by obscuration, degradation, or very poor resolution.
Level 1	Identify abandoned meander sections in major river flood plains. Identify long-lot land ownership patterns along major waterways. Detect a golf course.
Level 2	Detect windbreaks (i.e., rows of trees) between fields. Identify large buildings as multi-wing. Detect two-lane improved roads.
Level 3	Detect trail clearing/cutting in forested areas. Identify a road as divided or undivided. Detect towers associated with power lines.
Level 4	Detect active plowing of fields. Detect a security fence at an urban industrial facility. Distinguish between individual trees in an orchard.
Level 5	Identify prairie dog towns based on soil disruption pattern. Identify tree species on the basis of crown configuration. Identify ornamental tree nurseries.
Level 6	Detect a closed gate across a single lane road. Distinguish between sand and pebble/rock beaches. Count sheep or goats in a flock.
Level 7	Identify a manhole cover. Detect large raptor (e.g., eagle, osprey) nests. Identify individual asphalt shingles on a residential roof.
Level 8	Identify a cellular phone antenna on a passenger car. Identify individual cattails. Distinguish between tree species based on bark texture.
Level 9	Identify individual grain heads on small grain (e.g., wheat, oats, barley). Identify individual barbs on a barbed wire fence. Detect individual spikes in railroad ties.

APPENDIX B

Unacceptable image demonstrating poor verticality

Unacceptable image showing poor image extent

Unacceptable image showing poor image clarity

Acceptable image from Aetna Cemetery, non-georeferenced and uncorrected


Acceptable image from Slygo Cemetery, non-georeferenced and uncorrected

Acceptable from Sarah Chapel Cemetery, non-georeferenced and uncorrected

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