Narrative Final Project Report

National Center for Preservation Technology and Training Grants
Grant Agreement P16AP00377

Geographic Information System Processing of Remotely-sensed Data for Analyzing Land Cover Change in Cultural Landscapes

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September 12, 2017

Table of Contents

EXECUTIVE SUMMARY

Introduction

Cultural resource professionals working with landscapes encounter a range of challenges related to documentation of historic conditions and evolution resulting from the scale of landscapes, the dynamic nature of plant material, and the easily modified spatial configuration of landscapes. As cultural resource managers give ever-greater attention to resources at the landscape scale, continual development of methods for documentation is essential. The landscape research methods investigated in this project manipulate and evaluate remotely sensed data sources to provide information about change in rural cultural landscapes. The authors experimented with a variety of data sources and methods for spatial analysis and describe two promising methods here. One uses a method called pan-sharpening to compare historic aerial photographs with contemporary imagery in a georeferenced overlay to clarify changes in vegetation and other features between the two periods. The other method uses light detection and ranging (lidar) topographic data to aid in mapping terrain anomalies that indicate locations of historic roads and fences.

Site

The project site exemplified a range of typical conditions in rural landscapes in the Inner Bluegrass region. Auvergne is a large cattle farm that was historically the property of Brutus Clay and has remained in the Clay family since 1827. The farm’s gently sloping terrain is typical of the Inner Bluegrass Region.

Results

The pan-sharpened 1937 photograph overlaid on the 2016 aerial image clearly revealed non-extant roads, fence lines, tree canopies, and buildings. The overlay image has the value of showing these non-extant features alongside features extant in both periods and those that are more recent in origin.

The lidar-derived topographic map of Auvergne revealed rock fences and roads – extant and non-extant – as linear ridge and swale signatures interrupting the consistent flow of contour lines. Tree canopy cover did not cause any discernable reduction in the clarity of these features on the topographic map. Non-extant wire fence locations were apparent but less obvious, with discontinuous indications in the topography that correlated with existing tree locations to locate fence lines. Remnant foundations, other collapsed materials, and graded level areas created noticeable topographic signatures at former building sites.

Conclusion

Pan-sharpened overlays of historic and contemporary aerial images and lidar-derived topographic maps both offer useful sources of information for cultural landscape research and preservation planning. Continuing development of methods to use GIS and remotely-sensed data promise to expand the range of tools available for cultural landscape analysis.

INTRODUCTION

Cultural resource professionals working with landscapes encounter a range of challenges related to the documentation of historic conditions and their change over time. These challenges result from the scale of landscapes, the dynamic nature of plant material, and the easily modified spatial configuration of landscapes. The large scale of rural cultural landscapes amplifies all of these factors. In the landmark National Register Bulletin *Guidelines for Evaluating and Documenting Rural Historic Landscapes*, McClelland, Melnick, and colleagues identified physical components of rural landscapes. Several of these components either traverse, enclose, or occupy large spaces in the landscape and thus require a wider view of the landscape to document (McClelland et al. 1999, 3). Historic farms may contain building clusters which change slowly and whose evolution leaves clear evidence in the form of building fabric, but farms may also contain circulation networks, boundary demarcations, and vegetation, which change more rapidly and leave more subtle traces of their former condition. This is not to say that building documentation is simpler, but that the challenges of landscapes are specific to their nature. As cultural resource managers give ever-greater attention to resources at the landscape scale, continual development of methods for landscape documentation is essential. Because of the linear and areal scale of these components, methods for mapping and spatial analysis that can allow economy of field work are particularly valuable.

The landscape research methods described in this paper manipulate and analyze remotely sensed data sources to provide information about change in rural cultural landscapes. The authors have experimented with a variety of data sources and methods for spatial analysis; we describe two promising methods here. One merges historic aerial photographs with contemporary imagery in a georeferenced overlay to clarify changes in vegetation and other features between the two periods. The other method uses light detection and ranging (lidar) topographic data to aid in mapping terrain anomalies that may indicate locations of historic roads and fences. Both methods have limitations but can be helpful in interpreting landscape change related to the more easily changed and dynamic elements of rural landscapes.

Applications that might incorporate this work are Historic American Landscapes Survey (HALS) reports, National Register nominations, Cultural Landscape Reports, Historic landscape studies related to Section 106 and 110 review, and preliminary archeological surveys. The two analysis processes described could aid in understanding landscape evolution and integrity for these different types of research projects.

BACKGROUND

Previous work in cultural landscape documentation has established the importance of large-scale and distributed feature types in rural landscapes and the importance of being able to piece together information from distinct periods to establish a chronology of landscape change and to evaluate integrity. Many disciplines – those related to preservation and archeology, along with those concerned with landscape ecology – have developed novel approaches to using remotely sensed information that extend its informational capability.

Cultural Landscape Documentation

National Register Bulletin Number 30 focuses on the documentation and evaluation of 11 landscape characteristics in rural cultural landscapes. Of those 11 characteristics, four (patterns of spatial organization, circulation, boundaries, and vegetation) typically involve larger areas/spatial scales that make the use of remote sensing especially valuable (McClelland et al. 1999, 3). National Register nominations largely hinge on assessment of historical integrity, which in turn relies on a conceptual understating of change in significant landscape features and patterns. Analysis methods that can supply information for assessment of change over larger landscape scales may be useful in documentation and the evaluation of integrity.

Cultural Landscape Reports (CLR) also can deal with a wide variety of landscape scales. The US National Park Service identifies 13 categories of landscape characteristics appropriate to consider in CLRs and, like the categories in Bulletin 30, several of them concern larger-scale patterns. These specifically include spatial organization, land use, circulation, and vegetation (Page et al. 1998, 53).

Evaluation of landscapes at the slightly smaller scale of individual properties and especially in designed landscapes have relied on the concept of reconstructing plans for significant periods as a way of assessing change and integrity. In the article *Cultural Landscape Analysis: The Vanderbilt Estate at Hyde Park,* Patricia O'Donnell illustrated the process of analyzing a complex (many features and scales) cultural landscape on a property of about 700 acres and using the development of plans from different periods (O'Donnell 1992). This type of work was influential in the development of the methodology for Cultural Landscape Reports. It is unlikely that sufficient time would exist to develop full period plans in a district-scale rural landscape for most landscape researchers and managers, but understanding the nature of landscape change still requires analysis of the changing configuration of landscapes over time using methods suited to the scale of large landscapes.

Remote Sensing, Aerial Photography, and GIS

Remote sensing passively or actively gathers information without directly contacting an object, area, or event (Jensen 2007). Passive remote sensing collects information using existing sources of energy. Aerial photography, for example, is a method of collecting reflected electromagnetic energy sourced from the sun to create images. Active remote sensing directs an energy source at surfaces to create and collect information. Lidar is a method of active remote sensing that directs energy at the earth's surface, and objects on that surface, and then collects as data the time intervals traveled by that energy.

From the time of Nadar's aerial photograph of the village of Petit-Becetre, taken from a balloon in 1858, aerial imaging methods have developed in tandem with the advancement of flight (Gosling 1976, 13). In 1908 an airplane was first used as a platform for aerial photography. During World War I, aerial reconnaissance and photography capabilities expanded to address the need for observation and map making. After the war, aerial photographers created commercial companies for public and government contract services.

Cities began to commission aerial surveys for planning services in the 1920s, taking advantage of the ability to develop consistently scaled and descriptive aerial images. In the late 1930s, the United States Department of Agriculture (USDA) began using aerial photography to document much of the continental United States. Even as Landsat imagery developed beginning in the 1970s, aerial photographs flown under contract to the USDA continued as the highest resolution source of aerial information in the United States. The range of remote sensing information available at a high level of resolution increased when black and white imagery was augmented with multispectral imagery and lidar data in the 1990s (Jensen 2007).

Lidar data is also obtained through aerial reconnaissance. Lidar sensors are able to record multiple returns from the energy impulses they emit, including those for vegetation layers, buildings, and the ground surface. High-resolution lidar from statewide or other large-scale surveys may typically consist of a three-dimensional point cloud with 0.68 meter point spacing and vertical accuracy of 15 centimeters (Quantum 2016). Data at this level of resolution can be accurately converted into two-foot contour intervals.

The roots of Geographic Information Systems (GIS) are in large-scale landscape planning. Ian McHarg built upon the work of predecessors to develop a geographic overlay system for decision making in environmental planning, which he described in the seminal book *Design with Nature.* His analog overlays were able to combine natural and social factors in landscape analysis and to display information clearly (McHarg 1969). McHarg's work coincided with the environmental movement of the 1970s and was a clear breakthrough in the ability to make better land use and environmental design decisions. Because the overlays are data intensive and the process uses iterative revision of analyses, planners quickly began developing computer programs to manage and display data. GIS programs are the digital counterpart to McHarg's overlays, but have also expanded well beyond that original set of purposes (Lillesand et al. 2008). Environmental Systems Research Institute (ESRI), founded in 1969, is the dominant developer of GIS software (Longley et al. 2011). ESRI was able to commercialize GIS in the 1980s, but their software did not see widespread use until the late 1990s (Jensen 2007).

Early use of Remote Sensing in Archeological Predictive Modeling

Archaeological fieldwork is labor and cost intensive; to minimize effort, archaeologists have sought novel methods for using remote sensing and GIS to gather predictive data. Before the development of GIS, archeologists were experimenting with both high and low-resolution imagery to predict archeological site locations. Jay Custer and colleagues developed methods to use Landsat imagery in archaeological predictive models in the early 1980s. The Delaware Department of Transportation applied the method to highway planning studies, but the spatial resolution of Landsat data available at the time limited the ability to identify smaller scale sites and features (Custer et al. 1983).

Ebert and Gutierrez conducted a similar study in Shenandoah National Park in the late 1970s, but used USDA aerial photography to predict locations of prehistoric occupation sites (Ebert and Gutierrez 1979). The high-resolution aerial photographs allowed a great degree of detail but the study was before the advent of contemporary GIS technology, which could have made the assessment process more efficient.

Jay Johnson and colleagues, in 1988, created a predictive archaeological settlement model using the analytic capability of GIS to locate prehistoric settlements in north Mississippi. The model relied on infrared and multispectral imagery. The team found that their methods held promise but were not an efficient way to look for settlement patterns at that time because of the primitive state of GIS (Johnson et al. 1988).

Roderick Salisbury's 2012 study *Soilscapes and Settlements: Remote Mapping of Activity Areas in Unexcavated Prehistoric Farmsteads* was able to combine contemporary GIS software with a time-efficient soil core sampling process to map chemical residue in the soil in Hungary to locate prehistoric farmsteads. Salisbury's project connects GIS analysis to the location of smaller scale landscape features within a larger landscape area but without using remote sensing (Salisbury 2012).

Landscape Studies Using Remote Sensing

Margareta Ihse, in her 1995 article *Swedish Agricultural Landscapes – patterns and changes during the last 50 years, studied by aerial photos*, explains the use of historic and contemporary aerial photography to identify change in agricultural landscapes. Ihse compared black and white photography from two periods, but redrew the information into maps by hand, creating a time inefficiency and introducing room for cartographic error (Ihse 1995).

Bender and Boehmer's 2005 *Using GIS to analyze long-term cultural landscape change in Southern Germany* described techniques intended to analyze and quantify landscape change from 1850 to the present. The team used land register data, cadastral maps, and aerial photographs, demonstrating the effectiveness of combining different historical sources of spatial information in one mapping project in GIS (Bender et al. 2005).

Baily and Inkpen's 2012 article *Assessing historical saltmarsh change; an investigation into the reliability of historical saltmarsh mapping using contemporaneous aerial photography and cartographic data* describes a similar method for comparing historic hand drawn maps and historic aerial photographs with contemporary aerial photographs to understand spatial change in salt marsh ecosystems in the United Kingdom. The authors found limitations in the accuracy of the hand drawn maps in comparison to historic aerial images (Baily and Inkpen 2013). Photographs can be rectified; historic maps can only be referenced and, in addition, maps introduce greater possibility of cartographic error.

In *Studying Long-Term Vegetation Dynamics Using Digital Processing of Historical Aerial Photographs,* Kadmon and Harari-Kremer compared aerial photographs flown in 1960 and 1992 to analyze vegetation change in northern Israel. The authors found that aerial photography is an effective tool for analysis of changes in landscape-scale vegetation patterns and that historical aerial photographs are the only data source on vegetation change that "combines high spatial resolution, large spatial extent, and long-term coverage" (Kadmon and Harari-Kremer 1999).

Watkins and Griffiths' *Reconstruction and visualization of historic landscapes using GIS* illustrates a method in which the spatial-illustrative value of historic maps is extended by draping them on digital elevation models to visualize historic rural landscapes in England (Watkins and Griffiths 2000). Combining terrain models created with high resolution lidar data and historic aerial photographs could potentially extend this process to better understand non-extant features revealed by terrain.

The study *Integrated Remote Sensing and Excavation at Double Ditch State Historical Site in North Dakota* led by Kvamme and Ahler used several active and passive remote sensing techniques to explore and document a large Native American site in North Dakota from 2001 to 2004. The team obtained aerial color photography and thermography using a powered parachute and high-resolution topographic data using a ground-based total station, along with several other non-destructive survey techniques (Kvamme and Ahler 2007). The Double Ditch project illustrated the value of high-resolution digital terrain analysis combined with aerial imagery in locating ground features in a landscape. The amount of time spent collecting and processing topographic data would now be drastically shortened with the availability of lidar.

RESEARCH QUESTIONS

The research described in this paper was speculative and methods-oriented. The intent of the project was to explore and document GIS methods that could be incorporated into the work of cultural resource professionals for landscape research and evaluation. The specific questions in the project included the following inquiries related to pan-sharpened overlays and lidar-derived topographic information.

- Can pan-sharpened overlays of historic and contemporary aerial imagery be useful for documenting changes in patterns of tree canopy on historic properties?
- Are pan-sharpened overlays useful in revealing the locations of relic linear landscape features such as roads and boundary demarcations?
- Is lidar data a useful tool for revealing the locations of relic line or point terrain features in rural landscapes?
- Does tree canopy cover reduce the effectiveness of lidar in revealing ground features?

SITE

The site for this project was familiar to the research team from previous experience and it exemplifies a range of typical conditions in rural landscapes in the Inner Bluegrass region of Kentucky. Auvergne is a large cattle farm that was historically the property of Brutus Clay and has remained in the Clay family since 1827. The farm’s gently sloping terrain is typical of the Bluegrass landscape (Figure 1). Land cover is largely pasture with remnants of savanna tree cover (Figure 2) and some tree lines along fences and drainage ways. Fences on the property include traditional dry-laid rock fences (Figure 3), made of quarried limestone, and wire fences. Wood fences would have coexisted with rock fences before the advent of wire. Relocation of some wood and wire fence lines has left remnant fence lines (Figure 4). Multiple farm roads, some relocated from former routes, traverse the property. The farm includes an intact building cluster surrounding the Clay house. This cluster includes remnants of an orchard and terraced gardens and a family cemetery. There are two non-extant building clusters, one a group of slave houses and the other an industrial complex. Extant and non-extant outbuildings are distributed widely across the landscape.

METHODS

Data for the project included historical images scanned from film negatives, and contemporary digital data, which was publicly accessible for downloading. The historical aerial photographs for Auvergne were created by the United States Department of Agriculture in 1937, and were scanned at the National Archives. The 2016 aerial imagery was obtained through the USDA Geospatial Gateway. Lidar data was obtained through the Kentucky Geological Survey website.

Data Processing: Pan-Sharpening

To pan-sharpen the images, we first georeferenced the historic black and white photographs to the modern aerial images using ESRI's ArcMAP georeferencing tool. This situated the historic black and white image in geographic space. We then texturized the historic photograph to increase the "roughness" of the image so that ArcGIS could better distinguish the differences in the pixels using a process described by the United States Forest Service (United States Forest Service 2005). The texturizing routine searches for change on the image and produces visually pronounced edges, which are typically related to field vegetation, fences, and roads. This process employed the "Focal Statistics" tool in the Spatial Analyst toolbox, and required deriving, filtering, and smoothing the textured image. The "smoothed" image is rescaled to reduce file size (Figure 5). The "Create Pan-sharpened Raster Dataset" tool allows merging the texturized historic image and the modern color aerial image. The resulting image shows field boundaries, structures, and other significant features from the 1937 image as white shadows on the modern landscape (Figure 6). The white lines were termed "ghost marks" in reference to the term used by many preservationists and architectural historians. An additional pan-sharpened image produced using the un-texturized historic aerial created a merged image with more detail but less pronounced contrast (Figure 7).

Data Processing: Lidar

The first step in analyzing the lidar data was to add data files from the Kentucky Geological Survey into ArcMAP. We created contours in ArcMAP by navigating to the Spatial Analyst toolbox, using the Contour Tool, and setting the Contour interval at two feet. The contour file based on the lidar data is a highly detailed visualization of topography. The last lidar return (the return from the ground surface) formed the data set for the digital elevation model, allowing impenetrable features like rock fences, roads, houses/foundations to appear as part of the terrain, while eliminating the effect of trees in other data returns (Figure 8).

RESULTS

Results evident in the pan-sharpened image and the lidar-derived topographic map are described independently here, but may often be most useful when correlated with each other or overlaid into a composite image. As in other work with cultural resources, multiple information sources fill in gaps, corroborate each other, and build knowledge through visualization of spatial relationships.

Pan Sharpening

The pan-sharpened texturized and un-texturized versions of the historic 1937 photograph merged with the 2016 aerial image clearly revealed non-extant roads, fence lines, tree canopies, and buildings that were present in 1937 but non-extant in 2016. The pan-sharpened image has the value of showing these non-extant features alongside features extant in both periods and those that are more recent in origin. Particularly noticeable were the specific locations of multiple non-extant outbuildings, remnant fence lines, and the reduced number of large canopy trees in cattle pastures. Savanna pastures are considered a significant component of the Inner Bluegrass agricultural landscape and an example of vegetation related to land use. For those concerned with preservation of this vegetation pattern, the pan-sharpened imagery yields useful information about canopy distribution. The two pan-sharpened images in combination provided both conspicuousness (the texturized image) and detail (the untexturized image.) In this particular set of photographs the extreme vertical displacement in the 1937 photographs created more detailed views of trees, and the contrast between leaf-off in the 1937 photos and leaf-on in the 2016 photos made differences between tree locations in the two periods easily discerned in the un-texturized image. This would not be the case in all photograph combinations.

Lidar Data

Assessment of the results from the lidar-derived topographic map of the Auvergne property involved comparison of point, linear, and cluster patterns revealed on the map and the investigation of those locations in the field. This assessment played out as a back and forth interrogation of the plan data, the visual evidence in the landscape and the knowledge of the landowner. Rock fences and roads – extant and non-extant – appeared clearly on the lidar-produced topographic map as linear ridge and swale signatures interrupting the consistent flow of contour lines. Tree canopy cover did not appear to cause any discernable reduction in the clarity of these features on the topographic map. Non-extant wire fence locations were less obvious with discontinuous indications in the topography that, if correlated with existing tree locations, could be visually linked to locate the fence line. Finally, remnant foundations and other collapsed materials of non-extant outbuildings created noticeable topographic signatures as relatively small bumps in the landscape.

One stretch of substantially built and intact rock fence with a height of approximately 42 inches did not appear clearly in the topographic plan. This section of fence was immediately adjacent to a group of large round hay bales stored in a pasture. The lidar was likely “tricked” by the hay bales because of their density, and created a return value at the height of the bales. The resulting effect was to accentuate the high point in the field, obliterating the contour signature of the fence.

Pan-sharpened images show what was present at the times of the merged photographs, while lidar is less specifically tied to specific periods and much more to the level of impression a feature made in the landscape. Lidar imagery augments aerial photographs first by penetrating vegetative cover visible on aerial photographs to reveal non-extant features from past eras. Additionally, those non-extant features may have been demolished or become unused at a time pre-dating the earliest available aerial photographs and they may still appear in lidar-derived topographic images.

CONCLUSION

Pan-sharpened overlays of historic and contemporary aerial images and lidar-derived topographic maps both offer useful sources of information for cultural landscape research and preservation planning. Like all cultural resource research methods, they offer incomplete views into the history of a landscape: pan-sharpened images are limited to the period of the photographs and not every landscape activity is so deeply imprinted into the landscape that lidar data will make it apparent. These methods, however, can create valuable information for landscape research. Continuing development of methods to use GIS and remotely-sensed data promise to expand the range of tools available for cultural landscape analysis.

ACKNOWLEDGEMENT

This work was made possible by a grant from the National Center for Preservation Technology and Training.

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