White Paper Report

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White Paper

Title: Mapping archaeological landscapes through aerial thermographic imaging
ID: HD-51590-12
Director: Jesse Casana (University of Arkansas)
Co-Investigators: Andrew Clark (South Dakota State Historical Society), Kevin Fisher (University of British Colombia)
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a. **Project Activities**

This project, funded by a Digital Humanities Start-Up grant, was very successful in developing new methods for collection and processing of large-scale thermal imagery in archaeological contexts, as well as in disseminating these results to a large international audience. Since the 1970s, researchers have recognized the possibility that archaeological remains would be visible in a thermal image, because buried stone walls or other architectural features likely retain, reflect and transmit thermal infrared radiation at different rates than surrounding soil. A thermal image that is collected at a time in the diurnal cycle when these differences are most pronounced should enable these features to be recognized. Experimental data suggest that features buried up to a half meter below the ground surface produce a recognizable signal at the surface, yet to date there has been no cost effective way for archaeologists to collect thermal imagery at the right time of data and with sufficiently high spatial resolution.

This project was devoted to developing new methods for collecting and processing aerial thermal imagery of archaeological sites. Several recent technological advances make this project possible in a way that would not have been just a few years ago. In particular, the increasing sophistication of commercial UAVs, the rapidly evolving power of photogrammetric software that employs automated image-matching and "structure-from-motion" techniques, and the decreased size and improved reliability of thermal cameras all enable very high resolution aerial thermal images to be collected of archaeological sites during precise times of day or night.

Much of the first year of the project was spent perfecting the underlying technology we required. Throughout the project, the UAV proved to be a particularly challenging component, as most commercially available UAVs are poorly suited to the needs of precise surveying. We initially selected the Cinestar8, an eight-rotor "octocopter" that is designed for cinematography, meaning it can lift a variety of rather large cameras, and has the ability to fly pre-programmed, GPS guided flight paths. Despite being one of the most advanced UAVs available when we began the project, it was nonetheless prone to frequent failures, software glitches, and other problems, and thus required constant maintenance in the field and frequent repairs. However, the fact that the UAV is sold as a kit meant that it could be readily customized to suit our needs, and that when parts inevitably broke, they could be replaced or repaired. In the final year of the project, we began using a smaller and increasingly popular UAV, DJI's Phantom 2. This small UAV can be customized to fly pre-programmed flight paths using after-market software and telemetry devices, and proved more reliable than the Cinestar. While the Phantom 2 does not have the same capabilities in terms of camera stabilization and can lift a much smaller payload than the Cinestar, its low cost and reduced rate of malfunction have made it increasingly our UAV

of choice. Certainly, it seems likely that commercially available UAVs will continue to improve in reliability and ease of use, while coming down in cost.

In order to collect thermal imagery with the UAV, we purchased a FLIR Tau II thermal camera core. The uncooled FLIR Tau II is the highest resolution thermal camera available commercially (640 x 512 pixels), and is very small and lightweight, measuring just a few centimeters on a side. We built custom electronics necessary to run the camera in the field, including a battery and an SD card recording device, and mounted them inside an aluminum case. In the last year of the project, we acquired a lower resolution DRS thermal camera for comparative purposes. We also began using a small video recorder, and outfitted the thermal camera, battery and recording system in a more lightweight configuration. Both thermal cameras performed well in out tests, but the higher resolution FLIR offered better results.

To process images, we primarily employed a powerful photogrammetric software package, AgiSoft's Photoscan, which is now being increasingly widely used by archaeologists for 3D recording of excavations and artifacts. Processing thermal data using the software presents some additional challenges because it is recorded by a non-standard sensor on a video feed. We nonetheless succeeded in efficiently extracting still images from the feed and processing them to produce large-scale mosaics. We also experimented with several other software packages that are designed specifically to create mosaic images directly from video feeds, with some success depending on the particular project. In addition, we experimented with several new methods for processing thermal images to highlight archaeological features. These methods included performing various raster math operations such as a Principle Component Analysis (PCA) on multiple images from the same site, as well as combining thermal imagery with other near-infrared imagery, as well as with derived imagery including an NDVI.

Over the course of the project, we undertook surveys at many different archaeological sites, with a wide range of results. Surveys were conducted at Arzberger, South Dakota in March 2013, Cahokia, Illinois in April 2013, Blue J site in northwestern New Mexico in June 2013, Kalavasos *Ayois-Dimitrios,* Cyprus in November 2013, and the Collins Site in Arkansas in April 2014.

Our first survey at Arzberger, South Dakota was largely unsuccessful primarily because the UAV suffered a hardware failure while on site, eventually crashing and requiring substantial repairs. After making necessary repairs, we then attempted a survey at Cahokia, Illinois, where we had our first successful collection of large-scale thermal imagery. Unfortunately, on our third flight above the site, there was a short on one of the circuit boards that resulted in a debilitating crash. Imagery from the site, which was covered by rather dense grass at the time of the survey, did not reveal much of archaeological interest, but did enable us to develop our methods of both collection and processing.

In June 2013, we then undertook a survey at the Chaco-period site of Blue J in northwestern New Mexico. The imagery we collected at the site, from several different times of day and night, enabled us to map virtually all domestic structures at the site, as well as to trace the architectural layout of several compounds. We also identified the likely location of a feature that may be an as-yet unrecorded Great Kiva. The relatively sparse vegetation cover, shallow archaeological remains, and extreme diurnal temperature variations all combined to make the survey of Blue J our most successful project to date.

In November 2013, we undertook a week-long survey at the Late Bronze Age site of Kalavasos *Ayois-Dimitrios* in Cyprus. We planned this survey for a time of year when the fields would be completely clear of crops, as our previous experiments at Cahokia and Blue J both suggested that vegetation creates a strong thermal signature which can be difficult to see through. The results of thermography at Kalavasos however were somewhat disappointing, as few if any of the monumental building remains that are probably just below the modern ground surface are visible in the imagery. In all likelihood, the extreme aridity of the soils at the time of the survey reduced contrast in thermal properties between the buried architecture and the surrounding soils, and thus we plan to attempt another survey at Kalavasos when the ground is wetter.

In April 2014, we then undertook a series of surveys at a prehistoric ceremonial mound complex known as the Collins Site, located in Elkins, Arkansas. The proximity of the site to the University enabled us to visit it several times under a variety of different conditions, and to use it as a training opportunity for interested graduate students. Three of these students formed a team, "The Flying Razorbacks" to participate in a thermal imaging contest sponsored by thermal camera manufacturer, DRS. The insightful results from the Collins Site mounds, using the technology being developed as part of this project, won our team third place overall in stiff competition against teams from universities across the country.

In May 2014 we brought the thermal camera and drone to the Kurdistan Region of Iraq where project director Casana runs a regional survey project. We had intended to use the technology at several sites in the region, but unfortunately customs officials seized the luggage coming into the country and refused to allow it to leave. This again is one of many things we have learned in pioneering this new technology.

b. Accomplishments

In our view, this project has been a great success. We achieved all of the primary goals of our initial proposal, developing a powerful new approach to archaeological investigations that we anticipate will have wide ranging impacts. We were forced to shift the location of our original planned work in Dubai to New Mexico, but we were also able to undertake surveys at several other sites that we had not originally planned to investigate including Cahokia and Collins.

Results of our investigations have appeared in numerous publications, were presented at several international conferences, and received substantial media coverage (as outlined below). The most detailed discussion of our methodology was published in a paper in *Journal of Archaeological Science* in March 2014, and has since been downloaded over 5000 times, as well as being featured as the lead story on *Elsivier Connect*, the publisher's primary means for disseminating significant findings that appear in its journals. In addition, the project serves as the basis for one MA thesis project and a PhD dissertation.

c. Audiences

The primary intended audience for this project were archaeological researchers and remote sensing scientists. Based on the intense popularity of our published papers, we believe that the results of the project have reached a very large, international audience of scholars numbering in the thousands. In addition to scholarly interest in our published

papers, there proved to be significant interest among the public in our work, judging by the extensive popular media coverage that our work generated (summarized below). Media stories about the project appeared in many of the world's most popular publications and websites, and were probably seen by an audience numbering in the millions worldwide.

d. Evaluation

The project itself was not formally evaluated, although we have had several publications of project results subjected to rigorous peer review, resulting in publications in top journals.

Our own assessment is that the project was extremely successful. The results we achieved and the scholarly and public interest they generated far surpassed the modest size of the initial grant. The project has also generated a whole suite of new collaborations and other projects we are currently pursuing.

e. Continuation and Long-Term Impacts

We have already continued research on archaeological thermal imaging beyond the grant funded portion of the project. These investigations include several projects supported by the NSF-funded SPARC (SPatial Archaeometry Research Collaborations) program at the University of Arkansas' Center for Advanced Spatial Technologies (http://sparc.cast.uark.edu/). The aerial thermal imaging methods we pioneered in this project have now become part of the remote sensing tool kit used on new and ongoing projects with collaborating researchers in Jordan, India, Botswana, New Mexico, and elsewhere. Our methods were also employed by one of our project team members on a major project in North and South Dakota funded by the Army Corps of Engineers, in which ten sites were surveyed using the aerial methods we developed.

Moving forward, we anticipate many rich new arenas for investigation. One of our MA students is currently pursuing a thesis project based on experimental data. In order to better understand some of the results we saw in our field-based surveys, we created an experimental plot in which walls of various materials, ditches, pits and other faux archaeological features were buried at known depths. We are currently imaging this test plot periodically over a year in order to test the effectiveness of thermal imaging on different types of materials in different seasons. We are also experimenting with more sophisticated processing methods. For example, we are planning to purchase a device that will sample the data stream produced by the thermal camera at a much higher bit-rate, meaning that we may be able to discriminate more subtle thermal differences than in the standard 8-bit images we are currently collecting. Finally, the underlying drone technology and approaches to aerial surveying of archaeological sites has wide application, and we are now exploring ways to leverage our expertise in these areas towards other types of sensors, such as LiDAR imaging.

f.   Products

Published Papers:
Casana, Jesse (2014) New Approaches to Spatial Archaeometry: Applications from the Near East. *Near Eastern Archaeology* 77 (4).

Casana, Jesse; John Kantner, Adam Wiewel, and Jackson Cothren (2014) Archaeological aerial thermography: A case study from the Chaco-period Blue J community, New Mexico. *Journal of Archaeological Science* 45: 207-219.

Papers in Progress:
Casana, Jesse and Adam Wiewel. Archaeological Aerial Thermography in Theory and Practice. *Archaeological Prospection.*

Stephanie Sullivan, Adam Wiewel, Autumn Cool and Jesse Casana. UAV-based aerial thermography and archaeological geophysics at the Collins Mound Site, Arkansas. *Advances in Archaeological Practice.*

Conference Presentations:
Jesse Casana, Adam Wiewel and Autumn Cool. "Archaeological Aerial Thermography in Theory and Practice," *Society for American Archaeology Annual Meeting* San Francisco (scheduled April 2015)

Stephanie Sullivan, Adam Wiewel, Autumn Cool and Jesse Casana. "UAV-based aerial thermography and archaeological geophysics at the Collins Mound Site, Arkansas" Space2Place: 5th International Conference on Remote Sensing in Archaeology. Duke University (October 2014)

Adam Wiewel and Jesse Casana. "UAV-Based Archaeological Aerial Thermography," Poster Presentation (with Adam Wiewel) *Society for American Archaeology Annual Meeting* Austin (April 2014)

Adam Wiewel and Jesse Casana. "UAV-Based Archaeological Aerial Thermography," *Digital Domains: Remote Sensing of Human Landscapes* Dartmouth University, Hanover, NH (March 2014)

Selected Media Coverage:
Elsevier Connect, "Drones are the latest archaeological tool" (June 2, 2014) online

Wade, Lizzie, "Aerial Drones Reveal Hidden Archaeology" *Science* (May 12, 2014) online

Klein, Christopher, "Can Drones Revolutionize Archaeology?" *History Channel* (April 29, 2014) online

Johnson, Brad "Archaeology benefiting greatly from drones," *The Guardian: Liberty Voice* (April 24, 2014) online

Bryan, Susan Montoya, "Drones Unearth more details about Chaco Culture," *Associated Press* (April 22, 2014) online (reprinted in *New York Times, Boston Globe, Business Insider, Weather Underground,* and others)

Sollenberger, Roger, "Drones in Archaeology: UAV Reveals Ancient Invisible History," *3D Robotics* (April 18, 2014) online

CBS News, "Drone Images Reveal Ancient Village in New Mexico," (April 16, 2014) online

Grannon, Megan, "Drone Images Reveal Buried Ancient Village in New Mexico" *LiveScience* (April 8, 2014) online (reprinted in *Huffington Post, Yahoo News, CNN.com*)

De Pastino, Blake, "Hidden Architecture' of 1,000-Year-Old Village Discovered in New Mexico" *Western Digs Magazine* (March 31, 2014) online