Mediterranean Archaeology and Archaeometry, Vol. 14, No 4, pp. 101-108

PHOTOGRAMMETRY IN THE FIELD: DOCUMENTING, RECORDING, AND PRESENTING ARCHAEOLOGY

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Received: 03/12/2013
Accepted: 17/06/2014
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ABSTRACT

The development of three-dimensional documentation technologies such as LiDAR and Structure from Motion (essentially digital photogrammetry) has led to a recording revolution, as these methods are increasingly applied to field archaeology. 3D methods have the potential to become an integral part of the archaeological toolkit, as they have the capability to produce spatially-referenced outputs, such as orthophotos and digital elevation models (DEMs), with greater efficiency than traditional methods. The combination of Structure from Motion and low-altitude aerial photography can facilitate the production of these GIS outputs, which can then be used for digitization or as basemaps. These methods allow for accurate and precise recording with a relative minimum of field time. As the existing body of 3D data increases in size, museums have the unique opportunity to be able to take advantage of these datasets to update their exhibits and display archaeological context and the process of excavation through visualizations of 3D models. The spread of 3D documentation and recording in archaeology may provide a unique opportunity for collaboration between these two professions, and allow for archaeology to improve its public outreach. The methodology presented here is based on field research in Jordan

KEYWORDS: Cyber-archaeology, Photogrammetry, Low-altitude Aerial Photography, Jordan

1. INTRODUCTION

The development of new techniques of archaeological field recording has the potential to revolutionize the documentation, interpretation, and presentation of archaeological sites, and the archaeological process. Three dimensional recording techniques, especially Structure from Motion, allow for new methods of gathering data from archaeological sites, in ways that are more efficient, precise, and accurate than traditional methods. The data acquired using these approaches can also provide the basis for new ways of displaying archaeological context in a museum setting.

2. BACKGROUND

For archaeologists, context is the key to information about artifacts and sites. Recording provenience and context in the field is essential to preserving the information uncovered by excavation, given that field archaeology is an inherently destructive endeavor (Wheeler 1954). Excavators and surveyors remove artifacts from their contexts, remove, discard, and mix up the soil and stone that surround the artifact, and even annihilate potentially precious sources of data that are either too expensive, impractical, or, as of now, impossible to study. Once a site is excavated and its remains are moved to the laboratory, the potential research value of what is taken is reduced to the limitations set by the records and recovered artifacts of the excavator. Spatial relationships of artifacts and loci at the site become impossible to investigate beyond what is documented in the field. Mortimer Wheeler, an iconic advocate of detailed recording, expounded upon the need for recording of archaeological strata (an essential variable in context)—and criticized some of his contemporaries for their failure to do – as early as the 1950s (Wheeler 1954). Since these times, standards of archaeological recording have improved dramatically. The modern archaeologist justifies his destruction of cultural heritage through extensive documentation of both artifact and context. The tension created by the elimination of data at the hands of one who studies it is at least partially eased by the archaeologist's attempt to preserve the context of discovery in a number of different ways. By recording information that can be used to recreate the circumstances of the field, archaeologists facilitate the efforts of later scholars to reinterpret their data and also improve their own ability to provide more concrete evidence for their assertions.

Recent developments in technology have allowed for an improvement in field recording techniques to the point where it is now possible to digitally recreate the circumstances of excavation in the lab (Levy 2013). This is made possible by the availability of technologies such as LiDAR and Structure from Motion, which have moved the possibilities of recording and presenting archaeological context into the third dimension. The potential to digitally create photorealistic and spatially accurate representations of objects or areas of interest has opened up a new realm of documentation – that of 3D recording. Archaeological projects have made increasing efforts to capitalize on this development (Lambers et al 2007; Lerma et al 2010; Ortiz Sanz et al 2010; Al-kheder et al 2010; Olson et al 2013; Verhoeven et al 2012). Meanwhile, laser scanning and photogrammetry have been already widely applied to the documentation of ancient monuments for conservation purposes and in museums, mostly in digitizing artifacts, whether for the purposes of documentation or digital display (Wachowiak and Karas 2009; Bruno et al 2010; Yilmaz et al 2007; Pavlidis et al 2007). Attempts to use some of the increasingly available 3D datasets from archaeological projects for museum display of the contexts artifacts are recovered from are less common. Techniques of three-dimensional recording of archaeological sites allow for the creation of a fully-three-dimensional record of archaeological excavation with high temporal and spatial resolution (Olson et al 2013). The acquisition of this type of data also potentially allows for new approaches to presentation of archaeology to the public.

3. METHODS

The 2012 Edom Lowlands Regional Archaeology Project (ELRAP) provides a case study of one method of data collection well-suited to creating a photorealistic, three-dimensional record of an archaeological site. Members of the UC San Diego ELRAP team conducted intensive excavation at a number of sites in southern Jordan's Wadi Arabah, among which was Wadi Fidan 61, a Neolithic period site. The team used a 1-ply Kingfisher Aerostat K14U-SC balloon, with dimensions of ca. 3.6 m x 3.0 m, volume of ca. 21.0 m^3, and lift of ca. 13.6 kg when fully inflated. The balloon was tethered to a reel by 800-lb. strength Spectra fiber line and manipulated by a ground-based operator. In order to perform low-altitude aerial photography, the balloon was outfitted with a custom triangular frame capable of holding two high-resolution (15.1 megapixel) Canon EOS 50D Digital Single-Lens Reflex (DSLR) cameras equipped with 18mm lenses. These DSLRs were also applied independently of the balloon rig to record the site in a number of different ways and resolutions. Needing to document an excavated tomb of ca. 2x3 m and the entire site at which the tomb is located (ca. 6 ha.), ELRAP team members developed custom strategies designed to record every feature with overlapping high-resolution images.

Photographic data collection was oriented towards creating high-quality 3D models using Structure from Motion technology, a digital procedure that updates and uses traditional photogrammetric techniques to create a three-dimensional model from points of similarity between photographs of the same object taken from different angles. To that end, the team applied custom, individualized strategies to the tomb and to the site. To document the tomb, ELRAP personnel captured photographs of the subject from the ground, attempting to achieve 360 degrees of overlapping (by ca. 80%) photographic coverage in order to ensure that every aspect of both the tomb and the excavated square would be recorded by several photographs. The site itself, consisting of a 6 hectare prominence rising from the Wadi Fidan, required more expansive coverage, necessitating the use of the balloon photography system briefly described above. By maneuvering the balloon in transects over the mound, the ELRAP team acquired high-resolution and overlapping aerial imagery covering nearly the entire site. The transects were designed with an intent to collect photographs with an ideal overlap of 50% between adjacent images, both along and between transects.

The data needed for the recording of the tomb (ca. 70 photos) took only five minutes, in the field. Field recording of the entire site using the balloon (ca. 300 photographs) was collected in approximately 2 hours in the field, a rapid pace allowing for the creation of a 3D model of the site within a single day. The same system of recording was used on excavation units at other sites in the ELRAP campaign twice each day, with a needed downtime from excavation of only ca. 20 minutes in the morning prior to the start of the day's work.

With photographic data of areas of interest collected and appropriately sorted and stored within the ELRAP database, the team applied the commercially-available Agisoft Photoscan program (run on a desktop PC outfitted with an 8 core 3.07 GHz Intel Core i7 processor, 12 GB of RAM, a 1 TB HD, and an NVIDIA GeForce GTX 580 GPU) to the photographic dataset in order to create 3D models of recorded areas. From this three-dimensional dataset, the team also produced 2D orthophoto and DEM outputs. Agisoft Photoscan is a user-friendly software package providing a comprehensive Structure from Motion approach, with the ability to process unsorted photographs into a photorealistic, geometrically-accurate, and georeferenced 3D model. The process of generating 3D models through this program's workflow breaks down into three main steps. After uploading a set of photos to the program, the first processing stage is known within the program as "Align Photos." During this step, the unsorted dataset is developed into a point cloud representing the points of similarity between the different images (with the identification of points known generally as the stereo-matching problem). As part of this process, the location of where each photograph was taken is calculated using the angles of capture of each image and a process called photogrammetric bundle adjustment (Triggs et al 2010). This stage of model development is relatively computationally intensive, taking 1-3 hours to process on the ELRAP computer, depending on the number of images used to create the model. The output of this stage of processing consists of a low-density point cloud (usually of ca. 100-300,000 points), which can be edited, cropped, and cleaned up to both facilitate and improve the accuracy of the ensuing processing stages. The point cloud is used as the basis for the next step of processing, which is known as "Build Geometry." This phase produces a solid geometrical model based on the point cloud, with the possibility to set standards of model accuracy and resolution (in the form of the number of geometric faces of the model) determining the quality of the output of this stage. This model can also be trimmed and cropped according to areas of interest and/or quality. Building the geometry of the model is also fairly computationally intensive, taking 1-3 hours, the total of which also depends on the size of the input dataset. The final step of model processing is known as "Build Texture," which consists of overlaying the original images used to create the model back onto the geometric form created in the prior stages. The way in which the images are overlaid can be customized according to the desired function and appearance of the model (See Verhoeven 2011 for more information on Agisoft Photoscan workflow). This final stage of model processing is the quickest and least-intensive, taking only ca. 5-30 minutes. This workflow was applied to each of the areas of interest, with care taken to maximize the resolution and quality of the developing model at each step of processing. The tomb model took approximately 2.5 hours to develop, the excavation unit requiring ca. 4 hours, and the site model – with the largest input dataset – processing in ca. 7 hours.

The last aspect of the workflow taking place within Agisoft Photoscan consisted of georeferencing the models, using control points recorded in the field with a total station or GPS unit. The ELRAP team manually entered the coordinates of each point into the program for each area of interest, thereby georeferencing the models and preparing them for the exporting of data in GIS-compatible formats.

4. RESULTS

The workflow outlined above was primarily designed with the intention of producing spatially-referenced two-dimensional outputs with the highest degree of accuracy and precision possible. Developing a 3D model allows for the creation of orthophotographs, top-down images that are corrected for lens and elevation distortion (Lo 1974), and digital elevation models (DEMs). Orthophotos provide a more accurate basis for digitization of architectural features than do georeferenced photos (Verhoeven et al 2012) and are a critical part of the ELRAP campaign, which produces daily top plans of extant architecture. These plans are crucial for interpretation and publication of the site, and their accuracy – facilitated by their basis in orthophotos – is of the utmost importance. Digital elevation models also provide a useful basemap for contextualizing sites, and can be used to create contour lines within ArcGIS or other GIS software. Structure from Motion allows for the rapid (ca. 10 hours) production of high-resolution, precise (ca. 5-10 cm) DEMs that would otherwise take days or weeks of valuable field time to produce with traditional methods of EDM survey, requiring hundreds or thousands of points (cf. Louhaichi et al 2003). The documentation at WF61 produced a 2cm resolution orthophoto of the entire site (with submeter spatial accuracy across the mound) (Figure 1).

Figure 1 Orthophoto of WF61 with 2cm resolution. This image, corrected for lens and elevation distortion, was exported from a 3D model of the site, allowing for the creation of the orthophoto.

The team also manufactured a 4cm resolution DEM (Figure 2) suitable for the production of quality contours.

Figure 2 DEM of WF61 with 4cm resolution. This model was exported from a 3D model of the site, allowing for the creation of the DEM.

Finally, a high-resolution orthophoto of the tomb (with ca. 2 cm spatial accuracy) was created for the purposes of digitization of the rock features of the tomb with the highest degree of accuracy possible (Figure 3).

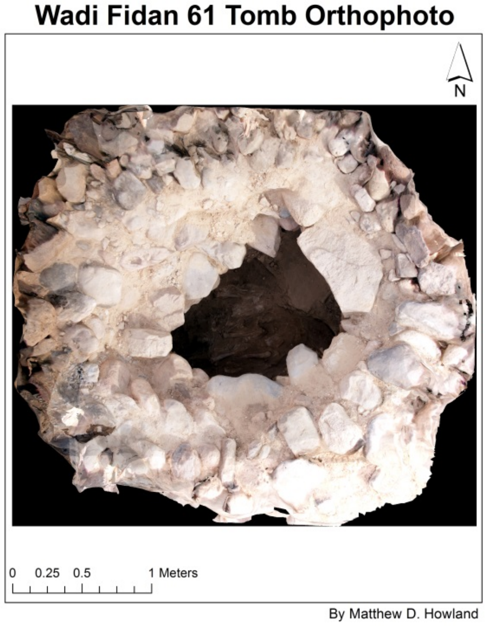

Figure 2 Orthophoto of tomb at WF61 with high resolution. This orthophoto was used as the basis for digitization of the rocks surrounding the tomb.

5. DISCUSSION

The models produced in the process of generating these 2D georeferenced outputs for the ELRAP GIS represent a spatially-comprehensive 3D record of the site. With models both extensive enough to contain data for the entire site and intensive enough to show specific archaeological contexts, the three-dimensional documentation of excavation and research at Wadi Fidan 61 is relatively complete. The speed of recording, discussed above, using the combined tactics of balloon photography and Structure from Motion have allowed the ELRAP team to create a record with high spatial and temporal resolution without sacrificing valuable time in the field. The temporal efficiency of this workflow was made evident to ELRAP team members by an internal comparison between the extent of data collection coverage attained by the previously outlined photographic/Structure from Motion workflow (6 ha.

sites recorded in ca. 2 hours of fieldwork) and that of ELRAP terrestrial laser scanning efforts, which required similar timeframes for recording only small subsections of sites, given the necessity for multiple overlapping laser scans. A comparison between the relative accuracy and precision of these Structure from Motion and terrestrial laser scanning is beyond the scope of this paper, although we suggest that Agisoft Photoscan-developed models and GIS products are well within the limits of acceptable spatial error for archaeological purposes.

This case study shows that even relatively technologically-intensive methods of 3D recording have the potential become an integral part of archaeological field projects such as ELRAP, given the efficiency of photogrammetric field recording at multiple scales. With Structure from Motion-based approaches, archaeologists can acquire three-dimensional datasets with high temporal and spatial resolution and accuracy with minimal to no disruption to other avenues of field investigation.

Equally as important to the archaeologist is that the combination of low-altitude aerial photography and Structure from Motion allows for the creation of GIS-based data that are unique in their combination of extent and resolution, as compared to the products of other methods. Sitewide orthophotographs of ca. 2 cm resolution are both substantially more detailed than satellite imagery and also free of the lens and elevation distortion inherent to traditional vertical photography. Meanwhile, site DEMs of ca. 5 cm resolution provide a high-precision basis for the creation of site contours or elevation-based spatial analyses. Compared to satellite-acquired elevation data – often available at resolutions no better than 30 meters, larger than many small archaeological sites – a resolution allowing researchers to pick out even small features of sites on a DEM is extremely valuable.

ELRAP's development of a 3D recording system to produce GIS content has also resulted in the creation of a great deal of aesthetically-pleasing and accurate 3D data showing archaeological context. We believe that these datasets – already produced for reasons of documentation and preservation – can be used in a museum with a relative minimum of effort and the reward of being able to display archaeological context as it was seen by the excavators during the process of investigating the site. 3D models created primarily for purposes of archaeological conservation and documentation can have a secondary use in presentation of archaeology, in digital museums or in traditional museums with television or computer displays (Bruno et al 2010; Carrozzino and Bergamasco 2010). The possibility of acquiring these high-quality and aesthetically-pleasing datasets has the potential to be a boon for museums, which now have the possibility of displaying these models in a number of different ways. The usefulness of this type of context-focused display was demonstrated by a cyberarchaeology exhibit titled "EX3: Exodus, Cyber-Archaeology and the Future" developed and presented by the University of California, San Diego's Qualcomm Institute (Salamon et al in press) (Figure 5).

Figure 3 An undergraduate docent presenting the animated 3D model of WF61 to an interested visitor, pointing out the tomb in the context of the larger site.

Given that context is an essential variable in archaeology, it seems also important to present this data in a museum setting. We propose that three-dimensional data is an ideal and cost-efficient solution to the problem of how to display

6. CONCLUSION

The photogrammetric method of Structure from Motion is a viable tool for archaeological documentation and field recording. Structure from Motion-based approaches are practical and useful on archaeological projects given the efficiency of field collection and the precision and accuracy of the datasets produced using these techniques. We suggest that photogrammetric methods in combination with both ground-based and low-altitude aerial photography represents an effective workflow for 3D documentation and collection of spatial data at scales ranging from small excavation units to entire sites.

Additionally, the increasing availability of 3D data at high spatial and temporal resolution provides museums with the opportunity to present the process of excavation and archaeological context to their publics, expanding the possibilities of public outreach for archaeology.

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