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Towards a three-dimensional cost-effective registration of the archaeological heritage

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A B S T R A C T

Archaeological practice within the European context of heritage management is facing huge challenges in ways of recording and reproduction of ex-situ preserved sites. As a consequence of the Valletta-treaty, numbers of archived images and drawings of excavated structures as prime sources of past human activity, are exponentially growing. Contrarily to portable remains however, their future study and revision is biased by the two-dimensional character of the recorded data, rendering difficult their future reconstruction for new study or public dissemination. A more realistic three-dimensional (3D) way of recording and archiving should be pursued. In this paper the possibilities for 3D registration of archaeological features are examined in a computer vision-based approach using the PhotoScan software package (Agisoft LCC). It proved to be a scientific and cost-effective improvement compared to traditional documentation methods. Advantages can be found in the high accuracy and straightforwardness of the methodology. The extraction of an orthophoto or a Digital Terrain Model from the 3D model makes it feasible to integrate detailed and accurate information into the digital archaeological excavation plan. The visual character of 3D surface modeling offers enhanced output-possibilities allowing a better documentation of in-situ structures for future research and a higher public participation and awareness for the archaeological heritage.

1. Introduction

1.1. Context and aims

Archaeological remains constitute a considerable part of the cultural heritage. Investigating the past by means of excavations can be considered in many cases as a process of guided destruction of the excavated heritage itself, especially when no stone structures are involved or when no preservative measures are taken. This creates a fundamental epistemological paradox: the production of scientific historical knowledge by means of excavations directly leads to the very destruction of its basic *in-situ* dataset, rendering reproduction of the data and a future revised scientific and public interpretation potentially problematic.

Portable material culture finds, although extracted from their in-situ positions and preserved in heritage collections and depots, are most often the only remaining original data-source allowing future new studies and interpretations. However, the contexts from which they were divorced during excavation are mostly not preserved. These principal witnesses of past human activity are only preserved *ex-situ* by means of contemporary-produced evidence such as drawings, photographs and – in a very few cases – films which generates a loss of information and renders them less suitable for later study and revisions. Consequently, the present and future scientific and public community are basically left with a two-dimensional interpretation of a 3D structural dataset from heritage remains recorded in the field.

This problem has never been more apparent than it is today. Since the ratification or application of the guiding principles of the Valletta Treaty,[1] in many European countries, archaeological research has undergone fundamental changes (Kristiansen, 2009).

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[1] Convention on the Protection of the Archaeological heritage of Europe, also known as Malta Convention: http://conventions.coe.int/Treaty/en/Treaties/Html/143.htm

One of the consequences is an exponentially growing set of two-dimensional data, produced by a continuously increasing number of archaeological researches on terrains potentially threatened by infrastructural works. For the Flemish archaeology for instance, this is well illustrated by the number of excavation permits issued, rising with 453% between 2004 and 2009 (De Clercq et al., 2012). Another fundamental change can be observed in practices of evaluation and excavation. These must be adapted to several evolving scientific, economic and social parameters such as large scale excavations, assessment of quality and preservation, restraints in time and money, technological evolution and the need to increase public awareness. As a consequence the processes of registration of the archaeological heritage have become increasingly digitized, mostly in order to speed up the work-flow and output. However, the basic documentation from the excavated contexts, albeit digitized, still provides present and future communities with a large dataset biased by interpretation (drawing) and a two-dimensional view.

Archaeological investigations require detailed, high resolution registration and documentation techniques, in order to maximize the opportunities for future reproduction of the structural dataset, especially when it comes down to remains from non-preserved or non-stone build sites such as soil-features and structures in organic material. In the framework of contemporary archaeological heritage management, these methods should be fast and accurate, easily accessible and manageable for contemporary and future communities and preferably proceeding to a more than two-dimensional way of data-storage and reproduction of the structural components from the archaeological heritage. Multi-dimensional recording and reproduction of excavated structures could potentially bridge the gap between *in* and *ex-situ* preservation. It could enhance the quality of the archived heritage for future perception and study by offering a better visualization and allowing a personal participation of the present and future data-viewers in the manipulation of the images of the excavated structures.

This paper aims therefore at investigating the possibilities of a low-cost computer vision-based software package, Agisoft PhotoScan (AgiSoft LLC, 2011b), for the 3D documentation of archaeological research using ordinary overlapping images. Based on case-studies developed in the framework of Flemish archaeological heritage management as well as in scientific research, 3D surface modeling is investigated as a method for (i) the registration of archaeological surfaces and contexts during excavations, (ii) the visualization of excavation data during the post-excavation process and (iii) the visualization of the unmovable archaeological heritage for a professional and a wider audience.

1.2. A review of 3D techniques applied in archaeological field recording

In the last decade, 3D applications have increasingly found their way into archaeological heritage research. Several studies focused on the registration and preservation of rock art, with examples on the British Isles (Chandler et al., 2007; Simpson et al., 2004), the Iberian Peninsula (Lerma et al., 2010; Sanz et al., 2010), Australia (Chandler et al., 2005, 2007) and in the Altai Mountains, Russia (Plets et al., 2012a, 2012b) or the registration and preservation of ancient temples and monuments (e.g. Al-kheder et al., 2009; Barazzetti et al., 2011; Grün et al., 2004; Karauğuz et al., 2009; Rajani et al., 2009) and even dinosaur footprints (Remondino et al., 2010). Other studies implemented 3D in the analysis of archaeological artifacts, including lithics (e.g. Clarkson and Hiscock, 2011; Lin et al., 2010), pottery (e.g. Karasik and Smilansky, 2008; Koutsoudis et al., 2009, 2010; Koutsoudis and Chamzas, 2011; Tsiafakis et al., 2004; Zapassky et al., 2006) and faunal remains (e.g. Niven et al., 2009). Furthermore, 3D technologies are frequently used in the reconstruction (e.g. Fatuzzo et al., 2011; Rua and Alvito, 2011) and the presentation (e.g. Bruno et al., 2010; Chow and Chan, 2009; Plets et al., 2012b; Tsiafakis et al., 2004) of the archaeological heritage. Although the application of 3D technology in archaeological surveys and excavations remains rather limited, these techniques are becoming more and more prevalent in archaeological fieldwork. Several researchers have combined GPS or Total Station field recordings with 3D GIS to obtain 3D excavation plans (e.g. Barceló et al., 2003; Barceló and Vicente, 2004; Katsianis et al., 2008; Losier et al., 2007), while other researchers have investigated laser scanning for the recording of archaeological excavations (e.g. Doneus and Neubauer, 2005; McPherron et al., 2009). Tokmakidis and Skarlatos (2002) have used close ranged photogrammetry to produce an orthophoto and Digital Terrain Model (DTM) of an archaeological excavation. Finally, Pollefeys et al. (2000), (2003); Doneus et al. (2011), Verhoeven (2011) and Verhoeven et al. (2012), (in press) have applied computer vision techniques for the 3D registration of archaeological sites and excavations and/or archaeological landscapes.

Recent technical advances in 3D recording illustrated the potential for 3D registration in archaeological and cultural heritage studies (Pavlidis et al., 2007). These techniques, as described in detail by Remondino and El-Hakim (2006), are based on (i) image-based modeling, including photogrammetry (e.g. Guidi et al., 2004; Hendrickx et al., 2011; Koutsoudis et al., 2007), (ii) range-based modeling (e.g. Entwistle et al., 2009; Fowles et al., 2003; Lerones et al., 2010; Lin et al., 2010; Stojakovic and Tepavcevic, 2011) or (iii) a combination of image-based and range-based modeling (e.g. Al-kheder et al., 2009; Lambers et al., 2007; Lerma et al., 2010; Yastikli, 2007). However, both methods require a certain degree of expertise and are not straightforward implementable during archaeological fieldwork. Furthermore, aiming at both a scientific and cost-effective improvement of the archaeological documentation methods, these techniques are often time consuming and can be rather expensive. From the cost-effective point of view, the recent developments in computer vision, aiming at developing mathematical techniques for recovering the 3D shape and appearance of objects in imagery (Szeliski, 2011: 3), are promising. The implementation of various computer vision techniques such as structure from motion (SfM) and dense stereo-reconstruction algorithms in low-cost or open source computer vision based software packages (e.g. Autodesk 123D Catch (Autodesk Inc., 2012), Automatic Reconstruction Conduit (ARC 3D) (VISICS, 2011), Bundler (Snavely, 2010), PhotoModeler Scanner (Eos Systems Inc., 2012), PhotoScan (AgiSoft LLC, 2011b), Photosynth (Microsoft Corporation, 2011) or VisualSFM (Wu, 2012)), makes the generation of 3D point clouds and representations easy accessible, even for users without an intimate technical background.

2. Method

For the 3D registration of the archaeological heritage, the low-cost software package PhotoScan (professional edition), released mid-2010 by the Russian manufacturer AgiSoft LCC, was applied (AgiSoft LLC, 2011b). It allows the extraction of 3D data from ordinary 2D images using SfM and dense stereo-matching algorithms. The workflow presented is inherent to the characteristics of PhotoScan and consists of two general steps, data collection and data processing.

2.1. Data collection

The data acquisition is the only phase of the process taking place in the field. It comprises two steps, (i) the recording of ground