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Multi-image photogrammetry as a practical tool for cultural heritage survey and community engagement

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ABSTRACT

Multi-image photogrammetry is rapidly emerging as an important archaeological tool due in large part to the increasing level of automation in off the shelf software. The technique can offer significant reductions in the cost of archaeological survey and in the enhancement of survey results and is of particular value therefore to archaeologists working in contract-led context, which in many areas accounts for the majority of archaeological work (up to 80% in Scotland for example). Recent advances in multi-image photogrammetric software have resulted in highly automated workflows and significantly reduced the burden of technical knowledge required to produce survey results of an acceptable standard. Although the majority of multi-image photogrammetry surveys are still undertaken in an academic context the technique is increasingly being used by a far wider proportion of heritage professionals, many of whom are not first and foremost specialists in photogrammetry. The adoption of such highly automated workflows presents certain risks with regard to accuracy and reliability of results as noted by Remondino et al. (2012, 52). However the enormous potential of the technique for rapid and accurate survey and for reduced costs cannot be ignored and the challenge we face is to ensure that the highly automated workflows adopted by archaeologists in contract-led contexts are robust and reliable and underpinned by guidance and knowledge exchange. This paper is not intended as a comprehensive technical review of the technical aspects of the technique or of its development but instead focusses on highlighting its potential as a practical everyday tool for archaeological practitioners to apply in two of the main types of contract-led archaeological work, rapid survey and community engagement. A non-technical overview of the technique is given followed by case studies illustrating how the technique has been applied successfully in a non-academic contract-led and community engagement context. These surveys have been undertaken with very limited budgets for both survey and post-processing of data and typically with very limited time frames. In each case study, use of multi-image photogrammetry has allowed for better, faster and more cost-effective results than would otherwise have been possible. Case studies include a survey of an Iron Age fort, a rapid survey of exposed segments of an intertidal wreck, both commissioned for heritage management purposes and a community survey of a 17th century gravestone undertaken by children under the age of 16. Finally the obstacles to wider adoption in the contract-led sector are discussed and it is argued that a concerted approach is required to create and disseminate simple and reliable workflows.

1. Introduction

Multi-image photogrammetry or Structure from Motion is a relatively new technique for accurate digital capture of 3-dimensional objects and surfaces. The technique is practical and versatile and is increasingly being adopted for cultural heritage to replace or enhance more established survey techniques such as manual survey and laser scanning. In multi-image photogrammetry, some of the most technically challenging and time-consuming elements of traditional stereo and convergent photogrammetry have now been automated and it is now possible to combine large groups of images rather than pairs, making this a far more cost-effective, user-friendly and powerful approach. As a result there is an increasing number of published examples of archaeological surveys based wholly or partly on recording of 3-dimensional features using multi-image photogrammetry. The vast majority of these have been undertaken in academic or research contexts despite the fact that in many areas the bulk of

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archaeological survey and excavation, is undertaken by archaeologists in commercial or non-profit heritage organisations funded through contracted heritage projects, much of which can be characterised as pre-development mitigation survey and excavation. The slower adoption of the technique in this sector is due to the amount of time and technical expertise required to achieve accurate results, archaeologists working in commercial contexts having relatively little time to devote to research and development. Working under contractual obligations to produce results to a predefined standard can also discourage innovative or experimental methodologies which carry a higher risk of failure. As with the early days of laser scanning there is a need for collaboration and skill sharing across the entire heritage sector in order to realise the full potential of multi-image photogrammetry. Of particular interest, given the simplicity of the photogrammetric data capture, is the potential for use of multi-image photogrammetry as a tool for community outreach and engagement projects, an increasingly important part of the contract-led heritage sector.

As recently as 2003 an assessment of the value of multi-image photogrammetry for recording of carved stones in Scotland found the technique to be unsuitable for detailed recording of archaeological features, due mainly to the low level of detail in the models that could be generated within a reasonable amount of time (Jeffrey, 2003, 112). However due to subsequent improvements in software, the technique has undergone a rapid evolution, making it much more useful and accessible than ever before. As a result of these developments it can now be said with confidence that under certain conditions, multi-image photogrammetry offers archaeologists a viable alternative in terms of technical complexity, accuracy, cost and flexibility to established techniques such as manual survey and laser scanning. The wider adoption of the technique is being driven by an on-going convergence of related technologies, including advances in digital photography, in the development of reliable Small Unmanned Aircraft (SUA) such as quadcopters and hexacopters, in more efficient and powerful software and by increasing computing power both on desktops and in the cloud. A number of surveys undertaken by the author in the UK in 2012 using this technique are presented in order to illustrate the value of multi-image photogrammetry as a practical and cost-effective method for accurate survey and as a tool for community engagement with heritage.

2. Defining photogrammetry

As stated above the contract-led heritage sector has been conservative in its use of multi-image photogrammetry and given that one of the aims of this paper is to encourage the adoption of the technique by archaeologists with limited or no experience of the technique, it is appropriate to give a brief overview of the technique and its application in heritage. For a more comprehensive and technical discussion see Szeliski (2011).

In simple terms, photogrammetry is the process of making measurements of features through analysis of overlapping photographs, and is fundamentally based on trigonometry. As early as the 1850s a French Army surveyor, Aimé Laussedat, realised that where the optical characteristics of a camera are known, multiple images taken with that camera from slightly different angles could be compared to obtain accurate measurements of the relative dimensions of that subject (Laussedat, 1854, 1859). Laussedat successfully applied the technique to ground-level topographical survey. However, the equipment available meant that great technical skill and extensive manual calculation were required. Adoption of photogrammetric techniques was gradual and limited and theodolites have remained the main tool for ground-based survey to the present day. Since Laussedat's time the most successful application of the technique has been for large scale aerial survey of topography by cartographers such as the Ordnance Survey of Great Britain. This approach relies on overlapping vertical aerial photographs analysed using various techniques such as stereo plotters. Because of the scale of the area covered this was one of the few applications of photogrammetry where the amount of time required for the technique was outweighed by the benefits derived from it. In the last decades of the 20th century a significant effort was made to automate as much as possible of the workflow in order to reduce the burden of analysis. However it was not until the advent of digital photogrammetry in the early 1990's, where film was replaced by scanned digital surrogates, optical trains replaced by computers and left/right eye-pieces with 3D monitors, that automation in photogrammetry really took off allowing 3D data to be automatically generated using pixel correlation algorithms. Despite this the technique remained a highly specialised and expensive technique, both in terms of time and hardware.

3. Archaeological applications of stereo photogrammetry

One of the main applications of photogrammetry for a specifically archaeological purpose has historically been analysis of stereo aerial photography for accurate aerial mapping of archaeological features such as crop marks. Despite the need for extensive manual input, a number of attempts have also been made by archaeologists to apply stereo photogrammetry to terrestrial survey. One of the most notable recent heritage photogrammetric surveys was a pioneering survey at Stonehenge, resulting in the creation of 350 digital models of the megaliths (Bryan and Clowes, 1997). However, as Jeffrey (2003) points out, due extensive manual editing required the surveyors did not attempt to model fine surface detail such as faint carvings on the stone but to aim for a point density of two centimetres in order to capture an accurate geometric model of the stones. Even so the processing ran for over three years. Another more recent example of photogrammetry based on stereo pairs was the highly successful Northumberland and Durham Rock Art Project (NADRAP), an English Heritage-funded project led by Northumberland and Durham County Councils (Bryan and Chandler, 2008). A total of around 1500 rock art sites were recorded using stereo photogrammetry with a high degree of success, producing dense and accurate 3D models of the features. The project relied heavily on volunteers, both for data capture and processing. However, there were a number of limiting factors encountered. Although the workflow adopted was relatively simple, it relied on proprietary software and was limited to stereo-pairs captured with pre-calibrated cameras. The cameras were calibrated for a specified distance from the subject, thus limiting the size of area that could be captured (Bryan and Chandler, 2007, 213). Capture of larger rock art panels required multiple stereo-pair models to be combined. However this proved to be too time-consuming and the majority of sites were recorded using stereo photogrammetry only. Despite the success of these projects, it is clear that stereo photogrammetry has been restricted to a very small and specialised proportion of the archaeological community.

4. Defining multi-image photogrammetry

The term 'Multi-image Photogrammetry' (sometimes used interchangeably with 'Structure from Motion') is used in this paper to describe to a more recently developed approach to photogrammetry, where stereo pairs are no longer the focus. Instead much larger datasets of overlapping digital images of a feature taken from different positions can be loaded in a single batch into software capable of automatic camera calibration, feature matching and reconstruction of complex dense 3-Dimensional models, with