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Evaluating the 3D documentation of an early Christian upright stone with carvings from Scotland with multiples images

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ABSTRACT

The documentation of cultural heritage assets requires precise and consistent approaches to preserve, analyse and monitor their integrity to future generations. The present paper deals with the 3D documentation of a unique early Christian carved stone discovered from Scotland that had been restored in the early 20th BC after accidental fragmentation. Different recording approaches are investigated; one range-based, acquired with a triangulation laser scanner and two image-based 3D reconstruction approaches, following computer vision and photogrammetric workflow with differing numbers of images. An off-the-shelf zoom digital camera was used to acquire the data, followed by 'structure from motion' and dense multi-view image matching to create dense 3D point clouds. The differences in the derived 3D models are presented and meaningful recommendations can be extrapolated for likewise surveys.

1. Introduction

The conservation and restoration of a unique artefact requires systematic and exhaustive recording before intervention. Conservation centres are used to applying reliable recording and documentation techniques for analysing not only the shape but the constituent materials, chemical composition, style, without forgetting the historical significance of the asset over time, its religious implications, etc.

The 3D documentation of objects, monuments and sites, as well as the 3D reconstruction of small artefacts can be undertaken with a wide range of digitisation and surveying techniques. Pavlidis et al. (2007) point out that the plethora of existing 3D digitisation techniques is due to three main factors that affect the suitability and applicability of the existing systems: first, complexity in size and shape; second, morphological level of detail; and third, diversity of materials. Three additional factors might also be added: available economical resources, processing time to develop the output and last but not least required expertise. Blais (2004) presents an exhaustive review of 3D laser imaging digitising techniques with emphases on available commercial systems. Remondino and El-Hakim (2006) review the full pipeline for 3D modelling from terrestrial images and range data, considering the variety of approaches and steps involved in the overall processing such as calibration, orientation, visualisation and 3D reconstruction.

Nowadays the boost of fully automatic solutions based either on Structure from motion (SfM) standalone or on photogrammetric SfM plus dense multi-view 3D reconstruction has allowed a democratisation of image-based solutions basically for surveys far beyond what many professionals expected a few years ago. There is a priori no restriction in the imaging sensor, the pictures can be taken unordered and from arbitrary viewpoints. SfM can be applied to large, uncontrolled collections of conventional imagery either on single standard computers or on imagery downloaded from the Internet (Agarwal et al., 2010). Similarly, images can be uploaded to web-based reconstruction services for processing on servers and get back automatic 3D reconstructions (Vergauwen and Van Gool, 2006). In any case, aspects such as data privacy and copyright should not be neglected prior to uploading the data, but that is another issue out of the scope of this paper.

Web-based 3D reconstruction services, low-cost and open-source image-based software are even known by non-experts. However, significant metric differences can be achieved making

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use of them for the same purpose. A review of different recent literature is worth considering, especially when compared with range-based solutions. Remondino et al. (2012) point out both the potentialities and the limitations of automatic SfM especially when tackling large complex datasets, and alerts about the lack of reliability and repeatability. The way the interior orientation parameters of the camera is determined within the block spatial orientation is probably the main error source to be considered. Barazzetti et al. (2010) and Lerma et al. (2014) introduce an automated image-based methodologies making use of markerless images and demonstrate the reliability, precision and robustness of photogrammetric SfM procedures on free-form objects and rock art shelters, respectively.

In the last years the democratisation of image-based processing in archaeology is being demonstrated across the scientific community in different areas such as modelling and mapping of underwater sites (Skarlatos et al., 2012), aerial reconstruction (Eisenbeiss et al., 2005; Verhoeven, 2011), rock art (Plets et al., 2012; Lerma et al., 2013), on site excavations (Doneus et al., 2011; Ducke et al., 2011; De Reu et al., 2014), and 3D modelling of archaeological artefacts (Barazzetti et al., 2010, Kersten and Lindstaedt, 2012), without forgetting aerial reconnaissance for archaeology (Bewley, 2003) and geomorphological structures (Westoby et al., 2012) where low-cost and efficient image-based photogrammetric approaches are also being more considered and demanded.

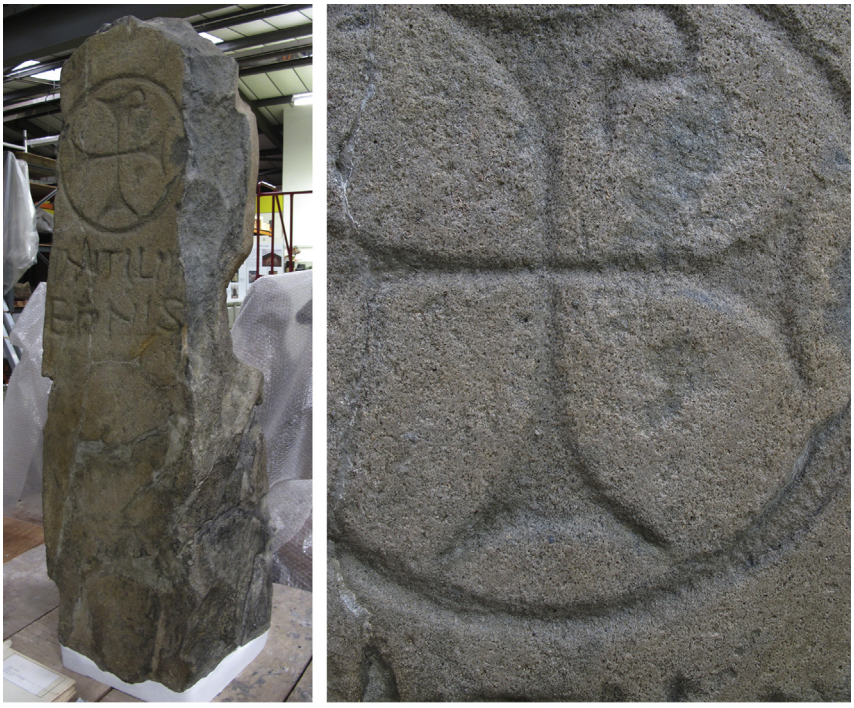
Multi-view dense image-based reconstruction is just one of the approaches that should be considered for 3D recording of archaeological sites. Many contributions suggest the integration of image-based solution and range-based solutions especially when complex, overall satisfactory surveys are expected. This latter statement is not only valid in archaeology (Guidi et al., 2008; Lambers et al., 2007; Lerma et al., 2010; Domingo et al., 2013) but also in related areas such as palaeontology (Petti et al., 2008; Remondino et al., 2010) and architectural documentation of cultural heritage sites with multispectral sensors (Lerma et al., 2012).

This paper reports on the multi-view image-based dense 3D reconstruction of an apparently simple shaped carved stone made of greywacke (Fig. 1). Its dark-coloured, speckled, granite-like morphology makes the approach far from ideal from a photogrammetric point of view for intensity-based matching. But the advanced performance of new dense image matching approaches existing nowadays deserve this research to show alternative approaches to expensive solutions based on high-end laser scanners; existing low-cost laser scanners solutions so far are not ideally suited to able to reconstruct the carved geometry. The image-based counterpart approach is challenging due to its simplicity, efficiency and low-cost. However, when only one of the existing approaches has to be selected, and the deliverables have to be ideally provided on time and accomplishing existing standards, the need to research prior to producing 3D reconstructions is mandatory and has to be neatly confirmed before mobilising both human and economic resources.

In the following, Section 2 introduces the case study carried out on a repaired carved stone. Section 3 will deal with the image-based conducted procedures and solutions following different orientation and calibration stages plus multi-image matching to achieve dense colourful point clouds; the range-based processing and output ground truth 3D model are also included herein. Section 4 compares the yielded 3D models with the different approaches. Section 5 discusses the results achieved and brings out possible variants. Finally Section 6 draws some conclusions.

2. Kirkmadrine 3: the 'Lost Stone of Kirkmadrine'

The target of our 3D documentation was an early Christian carved stone from south west Scotland known as 'Kirkmadrine 3'. The monument measures 970 mm in height by 270 mm in width, by 250 mm in depth. It is carved from greywacke, a dense, impure sandstone that contains feldspar and lithic fragments, as well as quartz, and weighs 177 kg. The stone bears carved figures and a



(a) (b)

Fig. 1. 'Lost Stone of Kirkmadrine' inside Historic Scotland South Gyle: a) frontal-left view; b) frontal close-up view.