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Technical Note

Developing the use of Structure-from-Motion in mass grave documentation

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ABSTRACT

Methods for mass-grave documentation have changed markedly since the first forensic investigations nearly 70 years ago. Recently, however, there has been little advancement in developing new and better methodology, especially when compared to other forensic disciplines and even within traditional archaeology. This paper proposes a new approach, using 3D modelling for the documentation and eventual analysis of mass-graves. Structure-from-Motion (SfM), which creates digital 3D models from a set of still photographs, was tested on a small, simulated mass grave. The results of this test suggest that the method offers resolution previously unavailable to mass-grave investigators, and facilitates stronger analytical potential than the more traditional methods. Further tests are needed to validate these methods, but these initial findings are promising and their application could enhance our knowledge of mass grave dynamics.

1. Introduction

The scientific excavation of mass-graves, which draws on techniques from both forensic anthropology and traditional field archaeology, has become an essential component of forensic work [1–3]. In the past twenty years, the number of mass-grave excavations has exceeded several dozen; this number is unlikely to decrease in the forthcoming years, as conflict and war have become a part of life for many parts of the world. While early methods for mass grave recovery and analysis resemble exhumations rather than excavations, current methodological approaches are based on archaeological principles and techniques [4,5]. The crucial component shared by all modern methodological approaches is the recording of 3D coordinates; this aides in establishing provenance of artefacts and can help to build a relative site chronology. Utilising these techniques, the events leading up to the grave creation can be reconstructed and potentially linked to the person(s) involved. However, no standard protocols yet exist for the proper documentation of mass-grave sites, with even the Minnesota Protocol only recommending the use of standard archaeological techniques without further explanation [6].

Currently, the most often employed method for recording and mapping archaeological sites is the total station; however, concerns have been raised as to the perils of using failure-prone electronics, and as such, more traditional methods – like a level and staff – still feature in the archaeologist's tool kit [5]. It has been suggested that the most effective way to document a body (*in situ*) is to combine point measurements of the major joints of the body (along with the centre of the cranium) and create a 'stick figure' using GIS or CAD software [7]. Other approaches suggest the recording of body outlines instead, although this is somewhat more time consuming [8]. In addition to mapping, comprehensive photography of the site is essential to provide adequate documentation; the method proposed in this paper combines mapping and photography, which may save valuable time on site [4,5,8,9].

However, there appears a reluctance within the forensic archaeological community to adopt new methodological approaches, since most national courts have regulations in place which demand them to be scientifically tested and verifiable (for example the Daubert criteria in the U.S.) Nevertheless, the development of new methods in related fields cannot be ignored, especially when considering digital methods, which provide new opportunities for analysis and more thorough documentation of mass-grave sites.

Structure-from-Motion, or SfM, facilitates the creation of a 3D model from a set of 2D images; this technique has been utilised

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within the field of computer vision since the 1980s, but technological advancements in recent decades has brought this technique to the attention of other disciplines [10,11]. As this method has only been adapted recently for use in archaeological investigations, there are only few current studies employing it [12–18]. Initially, it served as a means of visualisation [12,18], but recently researchers have discovered its potential for recording [13,16,17]. Some studies use it as a supplementary method, while others rely entirely on the models for the site record [14,15]. The benefits of SfM have so far not been recognised anywhere in the forensic disciplines, with very few exceptions [19], although other 3D modelling techniques have been applied to forensic investigations [20,21]. In regards to its applications on the analysis of burials, there is very little available literature, and the two examples that exist – Forte [15] and Ducke et al. [12] – only examine archaeological sites.

The present study presents the first application of SfM in mass-grave analysis, and will evaluate its benefit over more traditional and established methods. For practical and ethical reasons, the information gained here is from an experimental study involving the simulation of a mass-grave.

2. Materials and methods

2.1. SfM

Structure-from-Motion itself refers to the process of transforming 2D images into 3D models. In order to accomplish this, the following steps (detailed below) must be completed, using appropriate software packages. For this current experiment, Agisoft's PhotoScan (Professional edition, version 1.0) was employed for the transformation process while CloudCompare and MeshLab were chosen for analysis.

2.1.1. Acquisition of images

At the base of the 3D modelling process lies the image acquisition. As the name implies, the important aspect is to move around the scene, taking photographs. Hereby, it is important to consider that there should be some overlap between successive images as each point must be visible on a minimum of 2 (3 for most other software packages) images [11,22,23]. This involves taking images at different angles and elevations. Any kind of digital camera can be used for this purpose, but the higher the original resolution, the higher the model quality. The camera used in this experiment was a Canon EOS 1000D and the data were processed using a Dell Precision T3600 with an Intel Xeon CPU E5-1650 0 3.20 GHz processor, 64GB RAM and Windows 7 Professional operating system.

2.1.2. Image alignment and sparse point cloud

The images taken of the scene are uploaded to the programme, which extracts the EXIF files from each image to gain information about the camera parameters such as camera model and make, focal length, ISO value, aperture, and shutter speed. The programme detects feature points, which are then tracked through the entire image set. These unique points, represented in two or more images, are used to reconstruct the scene geometry. All these points together constitute the sparse point cloud (Fig. 1). By using the information provided in the EXIF files, the programme knows the camera position from which each picture was taken.

2.1.3. Dense cloud construction, mesh creation and texture mapping

The next step consists of adding further points from the now known camera positions to create a dense point cloud (Fig. 2) which can be geo-referenced or scaled for accurate positioning and measurements. This point cloud can also be transformed into a closed mesh with surface texture for a more realistic visualisation, but it is the dense point cloud which is best suited to most analytical tasks. PhotoScan offers various quality settings for the reconstruction [22]. For the present experiment, high quality was chosen as the best compromise between model resolution and time demands. Analysis of the point clouds was performed in CloudCompare and MeshLab, two open source programmes.

2.2. Mass grave simulation

For the present study, a small mass grave was simulated using six anatomically correct plastic teaching skeletons, some of which were (partly) clothed. This protocol was employed as to remove the ethical constraints and not to interfere with an actual investigation.

Each skeleton was placed on top of each other in an irregular pit measuring approximately 2.35 × 2.15 m with a maximum depth of 0.7 m and were subsequently covered with soil. Six ground control points (GCPs) were placed around the grave and measured using a total station to georeference the point cloud. Although only three GCPs are required to georeference a point cloud, additional ones were introduced as a back-up in case of incomplete photographic coverage of the scene [24]. The distances between the individual

Fig. 1. Sparse point cloud. Note the loose dispersal of points which represent the key points matched throughout the image sequence.