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# Landscape applications of photogrammetry using unmanned aerial vehicles

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ABSTRACT

Photogrammetry is quickly becoming an important, cost effective technique for recording cultural heritage. Beyond the micro-scale of site evaluation, however, there are also effective landscape applications, with drone-based image collection allowing for large-scale survey. This combination of highly portable technology, which is not fully automated, can be used to create accurate and dense three-dimensional models at a fraction of the cost of LiDAR, and often at a much high spatial resolution. Yet, despite this, few studies have assessed the viability of this technique in regard to landscape studies. Those that have, such as Muñoz-Nieto et al. (2014), highlight the effectiveness of this technique and its ease of use. This paper assesses the viability of this technology for mapping large archaeological sites such as hillforts, providing a case study for its application to landscape archaeology.

## 1. Introduction

Photogrammetry is quickly becoming an important, cost effective technique for recording cultural heritage, with particularly impressive and innovative applications in excavation and artefact recording (De Reu et al., 2014; Dellepiane et al., 2013; Roosevelt et al., 2015; Lerma and Muir, 2014). Beyond the micro-scale of site evaluation, however, there are also effective landscape applications, with drone-based image collection allowing for large-scale survey. This combination of technology can be used to capture overlapping geo-referenced vertical and oblique photographs in order to create accurate and dense three-dimensional models at a fraction of the cost of LiDAR, and often at a much high spatial resolution. Furthermore, the hardware is highly portable, allowing the user to access a wider range of sites. The surveys have become fully automated and modern structure from motion software allows the user to create ortho-rectified aerial photographs and DSM's (Digital Surface Model) at the click of a button. Yet, despite this, few studies have assessed the viability of this technique in regard to landscape studies. Those that have, such as Muñoz-Nieto et al. (2014), highlight the effectiveness of this technique and its ease of use. This paper assesses the viability of this technology for mapping large archaeological sites such as hillforts, providing a case study for its application to landscape archaeology.

## 2. Drone survey and photogrammetry

Topographical surveys can contribute greatly to the identification of previously unseen surface features and can be used to produce three dimensional computer models of the surveyed area, which can be manipulated in a number of ways. The digital environment can be viewed from any perspective, free of vegetation or features that may obscure view. The height and direction of the sun can be manipulated to create shading and shadow effects, making interpretation easier. Micro-topographic surface features of buried or destroyed archaeological deposits occasionally exist, and can be identified with the exaggeration of the vertical axis by a set multiple (Newman, 1997, 11).

Until recently, the acquisition of topographical data was undertaken with a total station or D-GPS (Differential-Global Positioning Systems). Barratt et al. (2000, 141) have speculated that a single total station team would capture about 1000 points in a day, whereas one person using a D-GPS systems can record up to 2000 points every hour. More recently, LiDAR (Light Detection and Ranging) surveys have been used for archaeological purposes to collect large amounts of elevation data. This technique allows millions of points to be acquired in a matter of hours at an accuracy of + or −7 cm vertically, and + or −15 cm horizontally, usually with a resolution of 1–16 data points per metre squared. The common weakness in these techniques is that data collection and processing can be time consuming and costly.

Terrestrial photogrammetry has been used by archaeologists since the early eighties (Fussell, 1982) but the prohibitive expense of hardware and processing equipment meant that it was not a viable technique for most projects. With the advent of low-cost digital cameras and increased computer processing power in the late 2000s, however, this technique became a more viable option for artefact analysis and small-scale site evaluation. However, even until recently, photogrammetric surveys of monuments were undertaken using cumbersome methods such attaching cameras to poles or kites and relying on an extensive system of ground control points for software programmes to knit the

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photographs together (see McCarthy, 2014).

In the past few years, the rapid development of drones and structure from motion software, as well as the substantial decrease in their cost, has made them a viable option for archaeologists. While they have quickly become the go-to platform for taking site and excavation photographs, the ability of this technology to further enhance archaeological investigations has not yet been fully realised. Even low-cost drones aimed at casual, non-professional users can now be integrated with free mapping and flight planning software for automated flight and data capture to create highly detailed three dimensional models.

There are a number of problems with this approach, most notably the inability of the technique to penetrate vegetation and tree canopy, and the absolute accuracy of the collected data. The former is also a problem for LiDAR (though usually not promoted as such), with data collected in environments with dense conifer forestry often being unusable (for example, see O'Brien and O'Driscoll, 2017, 214–215). Absolute accuracy depends on the type and accuracy of the GPS integrated with the drone. With non-professional consumer drones this can vary considerably and can sometimes be in the range of + or −50 m or more. If accessing the erosion rate of a coastal monument, for example, where multiple surveys of the same environment are needed, this is inadequate and a much higher absolute accuracy is needed. There are a number of different options to correct this, such as setting up control points with a DGPS or using smart ground control points like AeroPoints, buying a RTK-GPS enabled drone, or georeferencing the collected data in GIS. However, if accessing an individual site in a one off survey, the relative accuracy of the data is more important. This depends on the height of the drone during survey and quality of the camera used, but is usually between 1 and 2 cm, which is more than accurate to produce a highly detailed and accurate model.

## 3. Practical applications of drone survey

For this study, a DJI Mavic Pro was used. This drone weights 0.734 kg including the in-built camera, battery and gimbal and can be folded into a 0.083 m (height) by 0.083 m (width) by 0.19 m (length) package, making this a highly portable unit. Using the freely downloadable Drone Deploy app on a mobile phone or tablet, the software connects to the Mavic Pro via a USB cable linked to the controller. Once the app automatically connects to the drone, the user then creates a project by zooming into the area of interest on a satellite map and creating a polygon that outlines the extent of the survey area. The user then assigns the height of the drone, which determines the resolution of the model and number of data points per metre squared. This allows the software to automatically generate a flight path, with the number of traverses increasing as the user decreases the height of the drone. The direction of these traverses can also be adjusted if necessary. The percentage of overlap is automatically set to 65% sidelap and 75% frontlap, though for more accurate readings the user should increase both to at least 80%. Once these settings have been input, the user simply uploads the flight plan to the drone via the upload button. Once this is completed, the user selects ‘begin collection’ and the drone will automatically take off, rise to the desired height, and move to the first traverse where it will automatically begin taking images (Fig. 1). The user can view where the drone is on their phone/tablet and also view what is visible from the camera. A survey can be planned in a matter of minutes in the field, allowing for archaeologists to collect survey data on the fly (pun intended!).

Like many forms of modern digital archaeology, photogrammetry is easily implemented. It is therefore easy to view this technology in terms of its inputs and outputs, without any knowledge of its internal workings. The algorithms and processes used by photogrammetry programmes are complex and are continually developing. It is not the concern of this paper to summarise the evolution of this technique in an archaeological context (see Remondino, 2014 for a comprehensive outline). Instead, the author proposes to quickly outline the basic methodologies used by photogrammetry programmes as well as how to use this software in a practical setting.

The collected images are imprinted with XYZ coordinates, allowing the photogrammetry software to locate where the photographs were taken in three-dimensional space, although this is not essential for the software to produce good quality outputs (Many non-commercial drones cannot geo-tag photographs and can still produce excellent quality DSM's). The software is able to create a three-dimensional model due to the multiple overlapping images at slightly differing positions, giving each photograph a unique angle of the select area/object while also providing it with keypoints (reference points) visible to multiple photographs. As such, it is important that multiple photographs overlap (hence the increase in the percentage of overlap applied above). In instances where there is sufficient overlap, the number of keypoints per pixel can be in excess of 10,000. This is more than sufficient to derive an accurate model.

For software programmes such as Pix4D, the creation of a DSM and orthomosaic is as simple as dragging the photographs into the folder (Fig. 1). Once these have been uploaded to the cloud, the programme automatically begins to process the data, giving outputs such as a DSM, orthomosaic, LAS file, Mesh OBJ file, etc. Depending on the variables outlined above, a survey can have a resolution in excess of hundreds, and sometimes thousands of points per square metre. This programme will also automatically create a three dimensional model that you can view and manipulate immediately after completion of the processing. Similar to the way setting-up and undertaking image capture with a drone has become a straightforward and easy process, the practical use of the photogrammetry software is also uncomplicated. While these outputs can immediately be manipulate in GIS without any processing from the user, programmes such as Pix4D does allow users to further enhance or clean-up data, but in many instances this is just for aesthetic reasons. The remainder of this paper will outline a number of different case studies to highlight the applicability of this new survey technique to landscape studies.

## 4. Case study: Cahercommaun, Co. Clare, Ireland

Cahercommaun fort is position at the southwestern edge of Tullycommon townland in Co. Clare, Ireland (Fig. 2). The site is *c.* 145 m above Ordnance Datum and overlooks a deep north–east/south–west ravine, approximately 30 m in height. The fort itself is approximately 0.68 ha in total area and comprises three widely spaced enclosing elements that abut the edge of the ravine to the north. These defend the eastern, southern and western approaches to the fort, while the north is protected by steep natural cliff face. The monument was partially excavated by Hugh O'Neill Hencken (1938) in 1934, who argues that the site was an important centre of a regional Early Medieval chiefdom known as *Tulach Commain*.

Cahercommaun is more broadly situated within the extensive karst landscape of the Burren. This environment was formed in the last glacial maximum, when ice sheets eroded the overlying soil and exposed the limestone surface. The lack of soil cover is less suitable for intensive farming which has led to the survival of much of the ancient landscape, including significant Early medieval remains (Hull and Comber, 2008).

Survey of the site was funded by a Royal Irish Academy grant which aimed to record in detail the Western Stone Forts on the tentative list of UNESCO World Heritage sites in Ireland. In total, 166 geo-tagged aerial images were captured, resulting in the generation of a DSM and orthomosaic 11.69 ha in size (Figs. 3–4). This took approximately 17 min to collect in-field. The DSM consists of 13,519,874 three-dimensional data points with an average density of 186.84 points per square metre. This data was then processed in GIS to produce hillshade (Fig. 5) and slope (Fig. 6) models which were analysed to create a plan (Fig. 7) of the visible archaeological features.

Cahercommaun is a particularly good case study, as there have been a number of surveys undertaken to record the layout of the fort. Despite