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A hybrid measurement approach for archaeological site modelling and monitoring: the case study of Mas D'Is, Penàguila

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ABSTRACT

There are several methodologies for obtaining and processing geospatial data with the aim of generating 3D models that represent reality. Thus, it is necessary to analyse the performance and capabilities of each methodology and its integration into archaeological heritage documentation. This paper analyses and compares the generation of 3D archaeological site models through the integration of aerial photogrammetry from an unmanned aerial vehicle, terrestrial photogrammetry and laser scanning. This process is carried out for two different excavation campaigns to monitor the sites based on dimensional analysis. Finally, a hybrid 3D model is generated by merging the three methodologies into a true orthophoto of the archaeological site for each campaign. One of the most relevant aspects of the model is the integration of multiple geo-technologies, which requires establishing a rigorous methodology for geo-referencing different data and equipment that is supported by the use of a dual geodesic coordinate system. The results obtained confirm that the geo-technologies proposed for integration are perfectly complementary, providing high quality and thorough models of archaeological sites.

1. Introduction

Knowledge of the topographic features of an archaeological site is essential for its full documentation. Methodologies such as terrestrial laser scanning (TLS) and terrestrial and aerial photogrammetry, the latter from unmanned aerial vehicles (UAVs), have been used to document archaeological sites, each showing great potential separately. Terrestrial photogrammetry offers a low-cost, highly flexible alternative by allowing automated methods, and it opens procedures to all users for performing dimensional analyses and even reconstructing simplified models from images taken with any type of camera (Tokmakidis and Skarlatos, 2002). In addition, the recent emergence of UAV technology has allowed these principles to be extrapolated to aerial photogrammetric imagery with spatial and temporal resolution impossible to achieve with standard satellite procedures (Gomez-Lahoz and Gonzalez-Aguilera, 2009). At an archaeological site, because it is a great advantage to have vertical and oblique bird's eye view images without any obstacles and from a unique perspective, UAV photogrammetry has emerged as a technology of great interest to the scientific archaeological community. However, one of the biggest drawbacks of both terrestrial and UAV photogrammetry lies in the difficulty of modelling and treating complex non-parametric geometries. Lately, laser scanning technology is being applied to the recording and 3D modelling of highly complex archaeological sites, for example, archaeological sites and/or underground caves where the complexity of the shapes and object sizes necessitates non-destructive techniques for documentation and reconstruction (González-Aguilera et al., 2011a,b). However, one of the major drawbacks in its lone application resides in the lack of semantic information in the resulting point clouds, which is vital in the process of archaeological interpretation.

Therefore, various authors have chosen to integrate different geo-technologies in order to make use of hybrid synergy and obtain more complete and competitive products. Eisenbeiss et al. (2007),

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Lambers et al. (2007) and Remondino et al. (2009) use aerial photogrammetry taken by UAV, terrestrial photogrammetry and TLS to obtain digital terrain models (DTMs) of archaeological settlements. They combine information from different sensors and methodologies to obtain a DTM that overcomes the deficiencies of the individual methodologies.

In an attempt to merge satellite data, Patias et al. (2009) use a UAV-helicopter, TLS and QuickBird satellite images to carry out the documentation of archaeological sites. In this case, the satellite images provide added value because they allow geolocation and a general representation of the whole environment.

Although all of the cited works have integrated geotechnologies, none of them have developed a thorough georeferencing methodology capable of guaranteeing high precision and enabling automation in the registration process of all the data and sensors. This aspect is crucial in archaeological campaigns where numerous sensors are used and the data obtained correspond to different methods. A proper georeferencing system would allow adaptive hybridization of the models so that redundant information is removed in common areas and extra information is provided in shadow areas. Furthermore, the registration of images from UAV and terrestrial photogrammetry incorporates breaklines through stereoscopic restitution processes, providing higher quality and authenticity to the final model, two key aspects in the generation of a true-orthophoto.

This paper describes how three capture techniques: aerial photogrammetry from UAVs, laser scanning and terrestrial photogrammetry, can be integrated to generate hybrid archaeological products: a three-dimensional model and a true orthophoto, allowing archaeological site monitoring to quantify the degree of progress at a site. The development of a rigorous geo-referencing method will be of great utility for future archaeological works, making it possible to obtain better results while establishing a basis for automated sensor registration.

The modelling methodology used here allows the generation of a three-dimensional hybrid model with its corresponding true orthophoto. To demonstrate the added value of hybridization methods in 3D modelling, a series of comparisons (quantitative and qualitative) are made in order to evaluate and quantify the advantages and disadvantages of each methodology separately and together. Finally, the variable of time is incorporated to monitor the degree of evolution of the site. More specifically, we propose to perform a dimensional analysis to assess the excavation volume and identify areas most affected in two different campaigns.

2. Materials

2.1. Site description

Placed in the municipality of Penàguila (Alicante, Spain), the archaeological site of Mas D'Is is set in the location known as “Les Puntes”, close to the Penàguila River. The site proves to be in flat terrain in an agricultural area. This is why the terracing under the crop fields is hidden. This site holds great interest for the archaeological scientific community, offering a new image of the Neolithic communities in the Mediterranean area of the Iberian Peninsula. In contrast to the traditional view, which considered some continuity between habitat sites of Mesolithic and Neolithic groups with a preferential use of caves, recent data suggests the development of sedentary villages in the locational strategies of the early farming groups (Bernabeu Aubán et al., 2003) (see Fig. 1).

Several geometrical shapes and various irregular reliefs can be found in the settlement of Mas D'Is. The former are related to human presence, whereas the latter correspond to the morphology of the terrain. These characteristics provide the site great complexity, so it is important for them to be recorded and reconstructed by hybrid approaches and models. On the other hand, factors such as vegetation and the depth of excavations create added drawbacks in terms of shadows and matching errors, seriously affecting the final product if they are not carefully filtered.

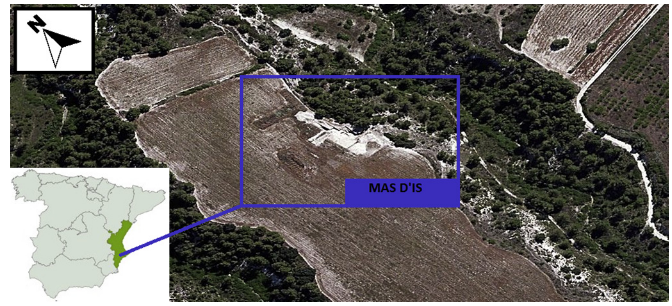

Fig. 1. Aerial image of the archaeological settlement.

2.2. Instruments for reference system definition

The instruments used for establishing a reference frame (Fig. 2) include a total station, Topcon Imaging Station, a high-accuracy GPS type RTK GNSS Leica System 1200 and several artificial targets for geo-referencing the dataset acquired from each sensor. A complete description of each instrument is detailed below.

2.2.1. Total station

To obtain the coordinates of the points that enclose the common framework of the work equipment is used that ensures precise topographic observations (Fig. 2). Total Station Imaging Station 2 allows the measurement of points without a prism reflector from a distance of 250 m to 2000 m. Moreover, with the use of a prism the range can be extended up to 3000 m. Prism measurements can be performed by a single operator using the robotic tracking receiver RC-3. The range precision for that instrument is ±2 mm + 2 ppm for distances with prism measurements and ±3 mm for reflectorless measurements. It also has dual axis compensator ±6 ' accuracy. The minimum angular reading is 1 mgon and since the maximum working distance is approximately 40 m, all this translates into accuracy in determining the position of better than 0.01 m.

2.2.2. High accuracy GPS

The linkage of this work to a cartographic reference system is performed by GPS sensors (Fig. 2). Leica System 1200 receptors works with the L1 and L2 frequencies emitted by the constellation satellites GPS and GLONASS. This allows measurement in real time kinematic (RTK) mode while static observations are recorded in the base receiver. In the subsequent post-processing step, the coordinates of the measured points are obtained in a global system with centimetre accuracy. To minimise the possibility of recording false coordinates, this equipment updates its position with a frequency of 20 Hz (0.05 s). Absolute positioning, when points were surveyed in static mode, provided accuracy of 5 mm + 0.5 ppm in horizontal and 10 mm + 0.5 ppm in vertical, and 10 mm + 1 ppm in horizontal and 20 mm + 1 ppm in vertical when points were surveyed in cinematic mode.

2.2.3. Targets for geo-referencing the obtained models

The need to integrate all the data captured by each of the sensors under the same coordinate reference system requires that targets be of different types depending on their use. Stakes with a nail in the centre were used for installing the base of the GPS,