Mapping and Interpreting Vanished Archaeological Features Using Historical Aerial Photogrammes and Digital Photogrammetry

Cerrillo-Cuenca, E.[1], Sanjosé, J. J.[2]
[1] Instituto de Arqueología – Mérida, CSIC, Spain
[2] University of Extremadura, Spain
ecerrillo@iam.csic.es, jjblasco@unex.es

With the arrival of spatial technologies, digital photogrammetric restitution has facilitated the integration of historical flights into GIS, making it possible to analyse historical flights as if it were current data. In this paper we discuss how we have incorporated this technique in a survey project, using photogrammes taken by the USAF in 1956. We have created ortho-images and digital elevation models from a region that was completely flooded in the 1960's.

Keywords: Photogrammetry, historical flights, megalithic sites.

1. Introduction

During the last decade, the integration of aerial photographs into GIS platforms has become one of the most successful tools in landscape analysis. The availability of ortho-images has increased exponentially, and these images have become a valuable tool for archaeological surveying purposes. Unfortunately, most of these "ready-to-go" ortho-images have been taken in recent times. Therefore, they don't provide enough historical perspective to understand how diverse landscape elements have changed, or how they have influenced the recognition of archaeological sites.

By increasing the capability to incorporate diverse sources of information, GIS platforms have shifted towards a more open concept. With the advent of geographical information technologies, digital photogrammetry has facilitated the integration of aerial photographs into GIS projects with less effort and more accuracy. Within the archaeological discipline, aerial photogrammetry is often presented as a way to recognise and map geographical features (CORNS and SHAW, 2008). Close-range procedures to obtain metric properties and digital models from archaeological sites have also been designed (GÓMEZ-LAHOZ and GONZÁLEZ-AGUILERA, 2009). In this paper, we present a different application. We focus on extracting cartographical information from photogrammes taken more than fifty years ago of non-preserved (or badly conserved) sites and their environments.

2. Objectives and methods

2.1. A case study: Alconétar's megalithic necropolis

This paper discusses the incorporation of photogrammetric techniques into a project aiming to analyse the prehistoric landscape of Alconétar, which is located in west-central Spain at one of the fords of the Tagus River drainage (Figure 1). Alconétar is part of one of the most transformed landscapes on the Iberian Peninsula, because the building of several dams in this region, as well as in Portugal, flooded large areas of land. The area where we are currently working was flooded in 1969. This flood led to the development of a minimal policy of heritage documentation and rescue. Fortunately, there was enough historical information (photos, manuscripts, drawing sketches, etc.) gathered prior to 1960 that provides rich information about a series of prehistoric dolmens and their location within the currently flooded area (Figure 2). The main goals of this ongoing project are the documentation and understanding of specific landscape aspects of these funerary structures.

The first task for this project was to create a common map where information from historical research and fieldwork could be recorded. Unfortunately, historical topographic maps are not of high enough resolution to be used for this purpose. To guarantee the success of this project, it was necessary to develop our own cartography by applying photogrammetric procedures to US Air Force flight data obtained in Spain during the 1940s and 1950s.

The topographical setting is hopefully revealed by the combination of two cartographic products: a DEM (Digital Elevation Model) and an ortho-image of the area. This allows us to do the following: 1) recreate the topography of the flooded area, 2) map archaeological features that have disappeared, 3) analyse the location of the barrows in the landscape, and 4) plan a survey of regularly non-flooded areas.

Figure 1: *The location of Alconétar's ford in the Iberian Peninsula. The blue line marks the limits of the Extremadura region.*

Figure 2: *A small megalithic chamber, with schist slabs, that emerged as the water level subsided (November, 2007).*

2.2. Historic photogrammetric flights

In archaeology, the use of data from historical flights has been extraordinary common in landscape projects. It is well known, however, that there are several issues that must be taken into consideration when using this flight data. The main issues are as follows: 1) flight data often have a highly variable scale, 2) some portions of the photogrammes do not have adequate resolution due to over-exposure or to certain film conservation issues, and 3) some basic parameters of the flight (i.e., focal length or height of flight) are completely unknown.

The first programmed flight over Spain took place during 1945, and was the result of an agreement between the American and the Spanish Air Forces. This flight cannot easily be used for photogrammetric purposes because we know very little information about the conditions in which the photogrammes were taken. The photogrammetric scale is approximately 1:44000 and the height of flight was estimated to be between 5700 and 8800 meters.

During the 1950s, Franco´s and Eisenhower´s governments established diplomatic relationships. This allowed another flight to be carried out in 1956. The flight was conducted by the 6th Aerial Survey Team in Europe, with a base near Madrid, and covered all the country. The data from this flight was used for this project.

The photogrammes are 22,5x22,5 cm, and they have been scanned using a photogrammetric scanner with a resolution of 21 microns in TIFF format (each file is around 140 Mb). The photogrammes were taken at a height of approximately 4900 meters, and the focal length of the camera was 153.78 mm. Thanks to this information, we can determine that the photogrammetric scale is approximately 1:32000. Given this information, we can obtain a digital map with a scale equivalent of 1:10000 (ZHIZHOU, 1990) and an ortho-image with a resolution of nearly 0.8 meter/pixel.

The restitution was carried out using a common procedure. This procedure requires the following: 1) solving interior orientation of each photogramme, 2) solving exterior orientation, 3) triangulation of positions and generation of topographic models and 4) the production of an ortho-image.

2.3. Solving interior orientation: some issues

Unfortunately, we have not found calibration parameters for the cameras used during the 1956 flight. Consequently, it is not possible to obtain information about the position of the fiduciary marks, that had to be measured using a conventional procedure (KARARA 1980). The angular rotation of the lenses is also an unknown parameter, though it is a very important parameter that must be known to perform an accurate interior orientation. It should be noted that both parameters were necessary until the advent of analytical restitutors in the 1960s, which is why these parameters were not expressed on the photogrammes. Regardless of this issue, the results are still acceptable, as will be demonstrated below.

2.4. Obtaining Ground Control Points (GCPs)

When trying to solve the exterior orientation, the identification of GCPs is not simple on transformed territory. GCPs are necessary to make an efficient restitution of photogrammes. They can consist of old buildings or other kinds of constructions, or landscape references that can be accurately geo-referenced and recognised on the photogrammes. In recent times, it has become increasingly difficult to perform this task as several recognisable features are underwater and thus are no longer accessible, or they are ruined or demolished.

We waited until the water level receded before identifying as many GCPs as possible. These points were geo-referenced using a DGPS. In order to do this, we used benchmarks to reference all of our coordinates within the Spanish geodetic network (European Datum 1950, UTM 29 North). It is important to point out that not all the GCPs were used to solve the exterior orientation. Since the calibration parameters were unknown, we used some of the points as "check points" to validate the restitution results, and especially for quantifying errors in the DEM.

2.5. Photogrammetric restitution of the flooded terrain

In order to obtain a "draft" DEM of the area (Model A), we selected 8 photogrammes that covered the entire area surrounding the necropolis. The photogrammes were processed using the Leica Photogrammetry Suite software from the ERDAS suite. This analysis provided both a DEM (Figure 3) and an ortho-image. In the area where the most notorious tombs are concentrated, we used a digital restitutor and *ad hoc* software to obtain more detailed resolution and a more precise model (Model B). Both models are explained in the next section.

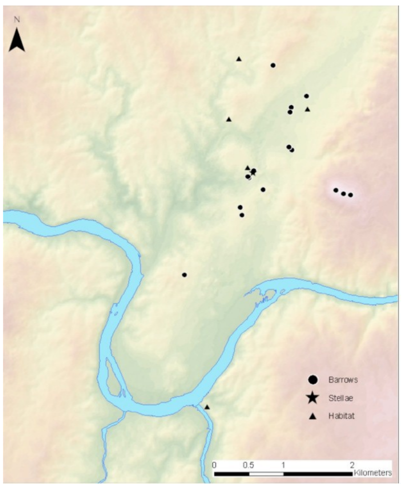

Figure 3: *The DEM of the study area (Model A), showing the sites mapped during the project: the main river and its secondary streams (digitalised over model) and archaeological sites (acquired by DGPS or digitalised over photogrammes).*

3. Results

The main goal of this work was to produce a detailed DEM of the study area that would represent the topographical setting before the flooding of 1970. Thus, we have produced a DEM whose values represent the topography of 1956 and are optimal to analyse the landscape during the Copper Age. Using parameters from the draft DEM, we estimated the root mean square error as a way to check the accuracy of the DEM from Model A. The RMS error is approximately 1.3 m. Given this, we can interpolate our data to within a 5 m/pixel resolution using the original Linear Rubber Sheeting algorithm from the ERDAS suite.

For Model B, contours were automatically produced using software and then manually edited by a specialised operator. A 2.5-metre interval between contours was found and the contours were later interpolated using splines. In order to produce a DEM with the best possible accuracy and the greatest resolution, we performed a cross-validation calculation to estimate the RMS error for different resolution and tension parameters. The final product was a 2-m/pixel model, taking into account the fact that this resolution offers the least error.

For both Models A and B, we took advantage of the possibility for further editing. We removed any anthropic topography modifications that were produced in recent times, such as the trenches of paved roads, railways paths, etc. This was done prior to the interpolation of the model.

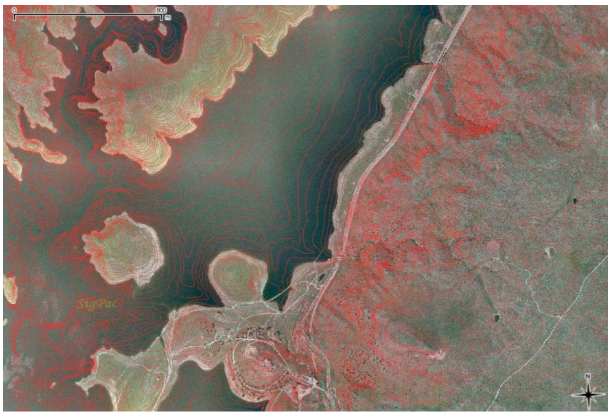

Figure 4: *Contour lines obtained using the digital restitutor (Model B) are shown in red. The interval between contours is 2.5. Contours overlay an ortho-image with 0.5-m/pixel resolution, showing the high accuracy that is found by restitution of currently non-flooded areas.*

Nearly half of the twenty documented sites are located underwater or have disappeared. Because of this, it was necessary to develop work protocols to add information from various sites to our geographical database. Our strategy consisted of the following: 1) recording the position of new sites with the help of DGPS, 2) checking whether the barrows described in historical sources could be recognised on the aerial photograph, and 3) incorporating these disappeared sites in our map with confidence in the reliability of their coordinates. This procedure allowed us to have a clear image of a complex prehistoric landscape, composed of elements such as funerary structures and habitats, as well as one engraved stelae.

3.1. Analysis of landscape by GIS tools

The DEMs obtained in this study were used to analyse the spatial distribution of barrows in the Alconétar area. Some scholars (GALÁN and MARTIN, 1991-1992) previously suggested that the main barrows were established in places near the river and its ford. However, neither the topography of the original area, nor the exact coordinates were known. Our aim is to check the validity of this hypothesis, given our accurate DEM of the terrain features, and the fact that we know more than 20 archaeological site positions. Finally, the analysis of viewsheds and least cost paths using non-parametrical tests has shown a clear correspondence between natural passes and the viewshed of barrows during the Copper Age.

Figure 5: *Digital photogrammetry makes it feasible to integrate different sources of information in the same GIS project. This figure shows an ortho-image generated from the 1956 photogrammes (in B&W), and, superimposed on it, a corrected and geo-referenced aerial image (colour). This last image shows the partially emerged bigger barrows.*

4. Ongoing works

For archaeological preservation, the Alconétar region must be considered as extremely fragile archaeological evidence, and documentation methodology must be adapted to reality. Our GIS projects will include a set of aerial photographs taken during the summer of, 2009, when the largest area of the necropolis was visible due to exceptionally dry weather conditions. These photographs have been corrected and geo-referenced using CGPs (Figure 4), following appropriate methods (DONEUS, 2001). In this case, the photographs have been corrected by using previous DEMs with a 0.10 m/pixel resolution. By combining both sources, we can produce highly detailed maps of the structures, and identify other characteristics that were unclear after the 1956 flight (Figure 5). Moreover, for some specific cases, we scanned several monuments using a Laser Scanner, demonstrating the utility of this technique for measuring the damage that the reservoir causes to various sites.

Conclusions

The restitution of historical photogrammes is a valuable tool for interpreting altered landscapes that provides a way to increase possible analysis options. By applying photogrammetrical procedures, we obtained an adequate basis to incorporate information from fieldwork and from historical sources of the same environment. The integration of DEMs and ortho-photos into GIS provides a new way to collect thematic features from past landscapes, making it feasible to treat sites that have disappeared as actual archaeological information. In this way, we can ensure that a future landscape analysis will be undertaken, considering the original characteristics of the study area.

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