Introduction

Aerial photography has proven to be very useful for archaeologists as it helps to identify features in the terrain that are not visible when standing on the ground\(^1\). As the use of aerial photography was introduced quite early with the invention of airplanes, we have at our disposal some precious material on the appearance of the terrain since the beginning of the 20th century\(^2\). These historical aerial photographs reveal features that may have been lost with the transformation of the landscape.

In this article we present three case studies in which historical aerial photographs are central elements in the research process and we demonstrate how the investigation benefits from a stereo visualisation of these images. They include aerial photographs from both WWI and WWII as well as photographs from the post war era, showing the situation on the ground as it once was, but which is now transformed or not even accessible due to human constructions.

Stereo as a Valuable Research Tool in Aerial Archaeology

\(^2\) HANSON, OLTEAN 2013
The idea of the stereoscope is very simple, based on the ability of human eyes to perceive the sensation of depth or 3D by letting each eye see different photographs of the same scene from a different angle or position\(^3\). This is achieved in aerial photography by taking a series of images while flying so that there is a substantial overlap between two consecutive photographs, as they are taken from two different positions.

One tool implemented to visualise images in stereo was the stereoscope, a pair of glasses, used by the photographic interpreters at RAF, that made it possible to look at such a pair of photographs in the same time. Modern techniques require active displays that can interchangeably or even simultaneously show these images, which can be seen wearing special glasses that show for each eye its respective image\(^4\). Alternatively, anaglyph images do not require such displays and can be printed on paper and visualised only requiring a pair of cheap and simple glasses, using red and cyan filters for each eye respectively.

We have developed our own automatic stereo pair extractor\(^5\) that finds the overlapping area (using computer vision methods), which then is extracted from each image and used as a stereo pair (Fig. 1).

The main reason why stereo images are important is that they give a much better understanding of what is actually seen on the ground than single photographs ever can. The important factor is the depth cue\(^6\) that helps understanding the content and adds the ability to distinguish between different objects such as bushes and trees, stones and pillars, hills and valleys etc. Hence, stereo helps in estimating the displacement of each object from the ground as well as the relative height of all objects forming a site\(^7\). Moreover, stereo helps in understanding the distribution of features on the ground, as well as the morphology of the site and of the surrounding landscape.

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\(^3\) Wheatstone 1838
\(^4\) Hast 2010
\(^5\) Hast, Marchetti 2014
\(^6\) Hast 2010
\(^7\) Casana, Cothren 2008
Case study: Battery Aachen

The first case study is about the use of English aerial photographs of the Belgian coast taken during the Great War (Fig. 2a). It resulted from a project aimed at 3D reconstruction of the German coastal battery Aachen in 1915 and 1917\(^8\) that was built in Raversyde near Ostend by the German troops that invaded Belgium in the summer of 1914. As the territory was part of a royal domain, it was not dismantled after the war and during World War II it was re-occupied by the German army, restored and integrated in the Atlantic Wall defensive system. The site is today an open-air museum where the remains of WWII bunkers can be visited\(^9\).

The goal of the project was to visualise in a realistic way the appearance of the site during WWI. There is little archaeological information about the buildings during WWI, but enough photographic material taken by German soldiers to document their military activity. In this phase, aerial images taken by the British military airplanes were very important to localise each terrestrial photograph. The correct 3D reconstruction of the coastal landscape was a crucial aspect of the project, as all the system of bunkers, trenches, observation posts and gun emplacements were integrated and camouflaged in the dunes. As the nature of the coastal territory is extremely variable, the dunes today are very different from what they were during WWI and therefore are very complex to reconstruct in 3D. Starting from a 3D mesh of the current terrain, dunes were modified to look like the ones in the historical images (Fig. 2c,d).

When the available aerial photographs of the site were analysed, it was discovered that there was a substantial but unintended overlap between a couple of images, which allows to create a stereo-pair. This makes it probably one of the oldest aerial stereo pairs in the world, taken in the first days of August 1916 (Fig. 2b). Because of depth cue, it became possible to compare the stereo image with the reconstructed 3D model. Each feature was clearly identifiable in the stereo image and this allowed us to verify the correctness of the

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\(^8\) NOLLET ET AL. 2015

\(^9\) RAVERSYDE ARCHAEOLOGICAL SITE: http://www.raversyde.be/en
3D reconstruction.

The 3D reconstruction will be used for the renovated exhibition in the onsite museum, that is planned to open in 2017. We hope that this stereo pair will be on display for the museum visitors, besides an interactive 3D visualisation.

Case study: Operation Crossbow and the GeoMemories project

In the second case study we refer to operation Crossbow\textsuperscript{10} where the RAF meticulously photographed Europe during WWII\textsuperscript{11} to obtain stereo images, which helped their photographic interpreters at Medmenham in Buckinghamshire in their search for military objects. Thanks to the use of stereoscopes, it was possible to view a single three-dimensional image (stereogram) that consists of stereoscopic pairs of images.

The Aero Fototeca Nazionale\textsuperscript{12} archive contains several million aerial photographs that can be utilised by aerial archeologists in a similar way. In 2010 AFN started the GeoMemories project\textsuperscript{13}, with the aim of publishing its contents on the web.

GeoMemories is a web platform that allows users to navigate among historical maps, based on aerial photographs that have been georeferenced and classified according with their date of creation, making it a valuable research tool (Fig. 3).

Our effort to create a stereo-pair from some set of these images gives us the possibility, for the first time after WWII, to visualise them in the way they were originally meant for. The incredible amount of details and landscape features that emerge from the stereo visualisations is a resource for future projects that will investigate the Italian landscape.

We show here examples from the cities of Genoa and Pisa where we visualise in stereo two monuments that do not longer exist. Firstly Castello Raggio (Fig. 4) in Genoa that was demolished to build the Cristoforo Colombo airport, and the Ponte in Mezzo in Pisa.

\textsuperscript{10} \textsc{Kelly 2011 A}
\textsuperscript{11} \textsc{Kelly 2011 B}
\textsuperscript{12} Aero Fototeca Nazionale (AFN) is an Italian Ministry of Cultural Heritage’s archive which contains aerial photographs of the whole italian landscape spanning the 20th century.
\textsuperscript{13} \textsc{GeoMemories Project: http://www.geomemories.org/}
Case Study: The Salas Reservoir

The third case study is about the Salas reservoir that in 1972 submerged a megalithic necropolis with 44 known tumulus, which now only can be studied thanks to photographs made in the mid fifties by the US air force.

It is well known that some of the tumuli placed in the southern part of the necropolis were destroyed by the construction process. Due to the fact that intensive prospecting work was carried out after flooding, there is a possibility that some not yet known structures exist or some tumuli have disappeared due to the deflation processes.

Although Galicia allows full open access to recent LIDAR data, which do not provide any information about the destroyed tumuli prior to the reservoir and it is not bathymetric heightened, it is necessary to use historical photographs in order to reconstruct and detect the lost sites, using photogrammetric techniques. The images that we used came from the American flight B series from 1956 as we were unable to use the images from the American flight A of 1945 because of resolution biases.

Using a total of three photographs from 1956, a 3D reconstruction was carried out through the photogrammetric technique structure from motion, which allowed us to reconstruct the elevations of the landscape. As the resolution was not enough to detect the sites, we used digital stereoscopy. Thanks to photo interpretation, we found some instances which could be considered as not previously registered tumuli (Fig. 6). In the future this technique will allow us to conduct a new study of the necropolis.

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14 Muínos, Galicia, North-western Iberian Peninsula, Spain
15 EGUILETA FRANCO 2003
16 EGUILETA FRANCO 2003
17 EGUILETA FRANCO 2003
18 MATAMOROS CORDER ET AL. 2013
19 WESTOBY ET AL. 2012
Archaeological Value and requirements

The historical development and changes in our world can be examined thanks to the rich source of aerial photographs at hand\textsuperscript{20}. As an example, some photographs reveal ancient man made constructions in places where no excavation can take place, such as in the case of the Salas Reservoir\textsuperscript{21} or lost because of the urban expansion like in Genoa or because of war like in Pisa\textsuperscript{22}. In the case of Battery Aachen\textsuperscript{23} it was possible to clearly identify features in the stereo images also present in terrestrial photographs, which allowed to verify the correctness of the final 3D reconstruction.

Nevertheless, there are still challenges to be faced in order to make good stereo visualisations. Besides the required overlap, there are other criteria that must be fulfilled in order to obtain a good stereo image. First of all the perceived depth cue will depend on the quality and the resolution of the original photographs. Unfortunately, some important historical photographs are of rather low quality (such as the case of the Salas Reservoir), which makes it difficult to distinguish important objects from the background.

Another important thing is to find images taken on the same altitude, with similar light conditions, in the same year and preferably even in the same season. In some cases it is still possible to create a stereo pair even if these conditions are not met. However, the final quality will be inferior. For instance in the case of the Battery Aachen stereo image (Fig. 2a) taken in different days of August 1916, the lighting conditions and the resolution were quite different. Nevertheless, it is possible to create a stereo image since the brain can cope with variations of light intensity rather well, even if the overall impression benefits from normalising the light intensity and we have therefore developed an

\textsuperscript{20} KIRK 2005; DUNNAGE 2002

\textsuperscript{21} ESTEVEZ 2015

\textsuperscript{22} ABRATE 2013

\textsuperscript{23} NOLLET ET AL. 2015
algorithm for this purpose\textsuperscript{24}. The second problem can be handled by rescaling one of the images so that they will have the same relative size, even if that means that they will not have the same degree of details. Nevertheless, the brain copes well with this discrepancy as well, as long as the difference is not too large.

Conclusion

We demonstrated using three case studies that stereo images are an important tool in archaeological research since they improve the understanding of aerial photographs. The perception of depth adds information that are not perceived in a single image. Moreover, historical aerial photographs contain important information on the landscape and human constructions that are lost today. Visualising them in stereo makes it possible to study them more accurately. For these reasons stereo images constitute a valuable support for future researches and for the preparation of new archaeological campaigns.

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\textsuperscript{24}HAST, MARCHETTI 2014 b

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