Stereo Visualisation of Historical Aerial Photos - a Valuable Digital Heritage Research Tool

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***Abstract*—We demonstrate with several examples how historical aerial photos can benefit from being viewed in stereo and how this can be useful as tool in digital heritage research. The main reason why stereo images are important is that they give a much better understanding of what is actually in the scene than single photos can. The important factor is the depth cue that helps understanding the content and adds the ability to distinguish between objects such as houses and trees and the ground as well as estimating heights of objects. There are however still challenges but also possibilities that will be discussed.**

I. Introduction

We demonstrate with several examples how stereo visualisation of historical aerial photos can be a valuable tool in the field of digital heritage and aerial archeology as well as what advantages and challenges that comes with such an approach. Historical aerial photos offer a way to go back in time exploring things as they were, while in the same time allowing to compare to modern photos how things appear on the ground today. Stereo photos allow to perceive depth information and this increases the understanding of the scene in a profound way as the environment and buildings appear to be 3D. It is much harder, and often impossible, to estimate heights of objects, such as trees, bushes and houses from single photos. Therefore, the depth cue [1] is very important for distinguishing between objects of different height and background. By viewing these photos in stereo, a better understanding of the content can be obtained and we demonstrate with several examples how this is beneficial for getting insight on what is actually seen, especially examples with a digital heritage value.

A. Historical Aerial Photography

Historical photographs [2] offer an unique way to go back in time, exploring the world as it were, while in the same time comparing to the actual situation using modern photos. Many pioneers in photography [3], [4], [5] have taken many thousands of photos of virtually everything that constitutes an important virtual archive for digital heritage research.

Since the birth of modern aviation, aerial photography have been a rich source for understanding the historical development and changes in our world [6], [7]. Particularly, these photos have also been used with success for aerial archeology [8], [9]. As an example, some images reveal crop marks etc revealing ancient man made constructions in places where no excavation can take place because of the urban expansion [10], so that the photos are the only practical way to study the past.

B. The Importance of Stereo

In the so called *Operation Crossbow* [11] the Royal Air Force tracked down, identified and destroyed many of the infamous V-weapons. The secret weapon used by the RAF at Medmenham in Buckinghamshire was a stereoscope, which allowed the photographic interpreters to study the landscape in 3D. This device made it possible to view a stereoscopic pair of images, containing left-eye and right-eye views of the same scene, as a single three-dimensional image or stereogram. These photos were available thanks to meticulously photographing the landscape of occupied Europe. The whole operation became one of the most significant successes of the RAF that most likely shortened the war. Many of these photos taken over Italy are now maintained by the AeroFototeca Nazionale (AFN) [12] of the Italian Ministry of Cultural Heritage in Rome. This extensive archive consists of several millions of aerial photos, some of which are being used in this paper to illustrate the advantage of stereo visualisation.

The idea of the stereoscope is very simple and most of us are familiar with the recent 3D animated movies even if many 3D films were produced already in the fifties and in fact even a long time before that [13]. Wheatstone [14] realised that we can perceive the sensation of depth or 3D by letting each eye see different photos of the same scene from a different angle or position. Therefore, the photographic interpreters at RAF used a pair of glasses that made it possible to look at such a pair of photos in the same time, without having to cross their eyes, which would lead to noticeable stress for the eyes and fatigue. Today modern glasses are used for this purpose and there are different techniques to achieve this, such as active shutter and polarisation [1]. However, they all require an active display that can interchangeably show these images. In this paper we will therefore only show so called anaglyph images that do not require such displays and can be visualised on paper. This simple technique only require a pair of cheap and simple glasses, which has one red filter for one of the eyes and a cyan (blue and green) filter for the other eye.

II. From Photo Positive to Anaglyph 3D

Even though the approach used by the photographic interpreters at Medmenham worked very well, it is much more feasible to use a pair of modern stereo glasses. One of the main challenges is that a stereo pair needs to be extracted, which can be done almost automatically and we will shortly relate the approach [15] used in this article. The photos used herein from the AFN archive are all positives that needs to be digitised, which in itself is a huge challenge to overcome as there are millions of photos in the archive. The resulting images, as they appear in figure 1, are typically of size $6k \times 6k$ pixels, which gives a high quality digital material to work with. Before starting the process, borders must be removed manually since these contain information about the flight etc, as can be seen in the figure and then the overlapping area is found by using standard computer vision techniques.

First key points are extracted from both images in a similar manner as done for SURF [16]. Next, tentative correspondences are found [17] and finally false positives are removed using a version of RANSAC (RANdom Sample Consensus) [18], [19]. The overlapping part can now be extracted using the information obtained from the correspondences. Furthermore, the transformation between the images is obtained from RANSAC so that a the stereo pair can be constructed. However, before putting together the stereo pair, each image needs to be corrected to eliminate any differences in illumination [20]. The transformed and corrected stereo pair is shown in figure 2 and it can be noted that the illumination is both more even but also similar as a simple tone mapping technique is being used.

The final anaglyph image is shown in figure 3 and the size for this particular image is 2215×4279 with one of the images in the stereo pair stored in the red channel and the other in both the green and blue channels, which gives the cyan colour often used by anaglyph glasses.

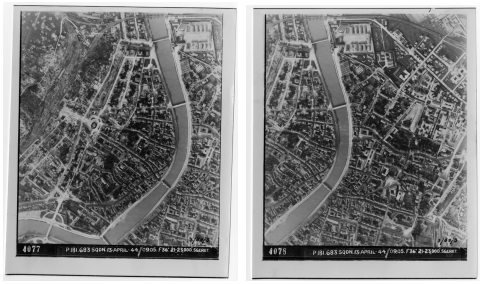

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Fig. 1. A pair of RAF photos from a flight over Pisa 13:th of April 1944. The digitised photos contain information about the flight in the bottom. The damage from the heavy bombardment is visible in the upper left. One can also note the uneven illumination that makes the photo a bit darker in the centre than the more brighter edges.

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Fig. 2. The semi-automatically extracted stereo pair from the overlapping areas of the original photos. They are both transformed in such a way that they have the same coverage and the illumination is corrected to give an optimal stereo experience.

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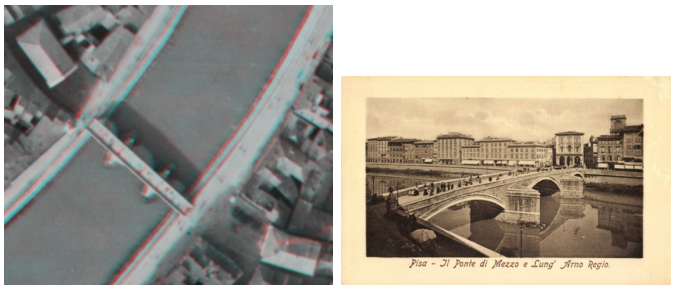
Fig. 3. The final anaglyph image that was obtained from the stereo pair. One can note some spots that only appear in one of the photos and also that people moved along the streets, which both disrupt the stereo notion (ghosting).

III. Examples of Cultural Heritage Value

Digital stereograms are a valuable resource for cultural heritage research and some examples will be given here. They are especially valuable in cases where the actual artefact or building do not exist anymore and the photos are the only available source. For an example, in figure 4 the famous bridge

Ponte di Mezzo in Pisa in Italy is shown as an anaglyph image to the left. The bridge was destroyed during the second world war and this is probably the first 3D visualisation of that bridge [15]. An old photo of the bridge taken from an old postcard is shown to the right. Unfortunately, there were many people in movement when the aerial photos were taken, which affects the stereo notion negatively. This effect is known as ghosting and will be discussed later.



Left:©MiBAC-ICCD, Aerofototeca Nazionale, fondo RAF, right: Photographer unknown - extracted from old vintage postcard.

Fig. 4. Left: A close up from the previous stereo pair showing the "Ponte di Mezzo". Unfortunately the 3D notion is affected negatively by ghosting. Right: The same bridge before it was destroyed in WWII.

This particular anaglyph was extracted from the anaglyph shown in figure 3. There are many more things to discover in this latter photo. For instance one can note that many houses were damaged by the bombardment and the roof for quite a few of them collapsed.

Another striking comparison can be made by comparing the situation of August 1943 with the one for February 1944 as they appear in figure 5. One can see how the wall has been damaged. A larger overview is given in the anaglyph in figure 6, which is the same as the right image in figure 5. The heavy bombardment came really close to the *Piazza dei Miracoli*, (which means the *square of of miracles*) and is one of the most famous tourist attractions in the world with its leaning tower seen in the left. In both of the images in figure 5, only the shadow reveals its height, while in figure 6 the height is clearly visible when using the anaglyph glasses.

IV. Discussion

The main advantage with stereo visualisation is that it gives a much better understanding of the photos. One example is shown in figure 7, where looking at one of the photos to the left does not reveal the height of trees, bushes or houses. Looking at the anaglyph in 3D (right image), on the other hand, reveals such details very clearly. Especially the brighter parts in the middle that looks like something that was bombed to a heap of rubble when looking at the single images, now clearly reveal that there are both tall trees and ground structures in that part of the image. Obviously, the varying heights is a very important cue for understanding the content of an image [1]. The vertical road in the bottom is *Corso Italia*, which lead to the *Ponte di Mezzo*. The height of objects in the photos is clearly visible in stereo, while it is much harder, often quite impossible, to estimate heights from single photos.

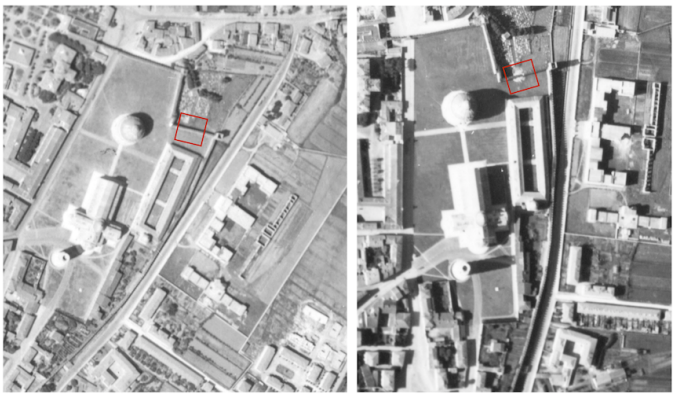


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Fig. 5. The *Piazza dei Miracoli* in Pisa. The left image shows how it looked in august 1943. The red rectangle shows the city wall in both pictures. The right image from February 1944 shows how the wall was damaged.

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Fig. 6. An anaglyph of the *Piazza dei Miracoli* in Pisa from February 1944, showing clear traces of the bombardment.

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Fig. 7. By looking at any of the photos in the stereo pair to the left it is hard to tell whether there are trees or bushes etc in the picture. The anaglyph stereo image, on the other hand reveals such details clearly.

The *Operation Crossbow* would surely not have been such a huge success if the stereoscope would not have been used. For an example, it would have been very hard, if not impossible, for the photographic interpreters at RAF to locate the mobile V-2 mobile ramps without the use of stereo. Similarly, stereo literally offers an extra dimension to digital heritage researchers, which should not be underestimated.

The obtained stereo pairs or stereograms can be stored and viewed in many ways. However, it is usually feasible to

store them digitally as a pair, which allows for using both active shutter techniques or polarised filter glasses as well as putting them together as anaglyph stereograms. There are such archives available online, but usually with very few stereo photos, since the process of creating stereograms still requires quite a lot of manual work and therefore the cost is high.

The process proposed in [15] is quite simple and is therefore also to a large extent automatic. Hence, it will help in producing a stereoscopic archive. Nevertheless, there are still a number of problems that need to be considered. First of all, many images need to be manually cropped, removing borders etc that might interfere with the matching process. The illumination correction is depending on several parameters which are set by the user and that will affect the final appearance. The image transformation involved, will produce an image pair that will, in most cases, not be rectangular and therefore also needs to be cropped.

There also exist other methods for finding the overlap of image pairs, such as phase correlation [21]. Nevertheless, having key points allows for computing the transformation between the images, which is necessary for rectification process. Moreover, the images are rather large, often about 20MB and it is therefore not feasible to use this technique since it is FFT based.

One challenge that still remains is to remove artefacts that disturb the stereo feeling of the images, such as scratches and spots that only appear in one of the images. Another problem is moving objects on the ground such as people, bicycles and cars. This is especially disturbing in the example of the *Ponte di Mezzo* in Pisa. This phenomena is know as *ghosting* and there are methods to cope with this [22]. However, it must be made sure manually that no important details are removed in the process.

V. Conclusions

The main reason why stereo images are important is that they give a much better understanding of what is actually in the scene since the perceived depth information adds clues that are not available in a single photo. Stereo really adds a new dimension to 2D photos, both literally, but also in terms of understanding and the ability to distinguish between objects and the ground. One advantage with historical aerial photos is that they are important time documents of both buildings and environments that do not exist anymore. Being able to view them in stereo helps in understanding and viewing them as they once were.

Obviously, the possibilities with stereo visualisation are important but there are also challenges, such as producing stereo photos automatically from image pairs. There exist semi-automatic procedures that makes the tedious procedure more easy to handle. Another challenge is to remove the disturbing ghosting artefacts without compromising the scientifically interesting content. Therefore, we propose these challenges to be solved in future research.

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