Comparative study of stereoscopic techniques applied to a virtual globe

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Abstract

For years, stereoscopy has been related to photogrammetry in topography. However, these methods are not efficient for virtual globes because the effect is only visible from one view point and this restricts interactivity. By using synthetic image techniques in order to generate stereo paired images, we can produce visible effects from any view point. In this paper, we present a comparative study of stereoscopic techniques in virtual globes supported by a test carried out among 51 participants. Three devices were used: anaglyphs, an autostereoscopic screen, and a quadbuffer system. The aim was to determine which one of the three devices causes a deeper feeling of immersion and which one can be more efficient in a virtual globe. Results show considerable differences between the quadbuffer system and the other devices. The mentioned system causes in the user a stronger feeling of depth and immersion in the virtual globe.

1 Introduction

Stereoscopic visualization of aerial photographs and satellite images has been a common practice in the last 30 years. Until today, photogrammetric techniques have been used to create stereoscopic effects in 2D geographic information systems. Photogrammetric aerial cameras, which take aerial photographs of previously planned areas, are usually employed for this purpose. If we use this technique in a virtual globe we encounter a main problem: the effect is only visible from one view point, namely, the one where the picture was taken from, and this restricts interaction and the stereoscopic

effect itself. Moreover, we will only be able to obtain stereoscopy in those areas where a photogrammetric flight has been carried out, and we must take into account the costs these flights involve.

The launching of Geographic Information Systems (GIS) which include interactive 3D view, enables the testing of new, inexpensive techniques in which the stereo effect is generated by synthesizing the digital image. Instead of using photogrammetry, we use the geometric information available to achieve a 3D effect. This fact favours interactivity with users and enables the exploration of certain points of view, which are impossible to reach by means of aerial photography. It also permits us to add elements that do not appear in the orthophotography, what in turn permits the planning of engineering or architecture projects.

To support our research, a test among 51 participants has been carried out within the framework of a GIS congress. With the data collected in a questionnaire after the test, we present a statistical analysis aiming to examine impressions experienced by the participants in the test. Subsequently, we present different stereoscopical techniques used in cartography. Then, we introduce gvSIG 3D as a framework for statistical study and present the state of the art in stereoscopic visualization for virtual globes. Further on, we describe in detail the tests carried out and their results. Finally, conclusions are drawn and possible approaches for our future work are explained.

2 Previous Work

Stereoscopical techniques have been used in topography to calculate terrain elevations by using two aerial photographs taken from different perspectives and which share a common area called covering. By means of photogrammetry, we are able to obtain from these two images the dimension and position of objects in space. In order to achieve stereoscopical vision, the covering must comprise at least 60% of the data contained in its longitudinal axis and 20% in its transverse axis, for this reason, an adequate programming of flights is essential.

In order to create a stereo image pair, a device called stereo restorer is used, which enables the photogrammetric restoring (Hobbie, 2010); These devices used to be analogical and helped to avoid calculations thanks to precision optics and mechanics. Later, analytical restorers introduced significant improvements, such as more precision in results, correction of mistakes enabled by the camera's optics, or the possibility to work with any kind of photograph or not photographic image.

Currently, restorers are digital devices and include multiple advantages compared to their prede-

cessors, such as image storage capacity, automation in most procedures, calculation speed, etc..

Photogrammetric techniques in the field of geographical information are used in the elaboration of cartography, but not in stereoscopic vision itself. However, due to the current increasing and improvement of topographic data and major advances in the field of computer graphics in general - and particularly in stereoscopy- the approach has changed and these techniques are now aiming more and more at stereoscopic visualization itself.

The aim is to improve the quality of the three-dimensional immersion feeling which can help the user to better observe and classify the data at hand and to include a new perspective in the analysis. Every stereoscopic system is based on the following principle: to show each of the observers's eye a different image (Wheatstone, 1838). If these two images haven been adequately taken or generated, our brain compares them and perceives the scene in depth (3D). This effect is not perfect due to the fact that our brain employs different mechanisms for the perception of depth, such as visual focusing, which still cannot be reproduced by means of stereoscopic systems.

In most systems, the viewer is to wear an eye-device so that each eye perceives a different image. The various models of 3D glasses, virtual reality helmets, mirror systems or polarizing filters are developed according to this principle. On the other hand, autostereoscopy does not require the viewer to wear eyeglasses, but it uses special displays to send images to each eye in different angles, so that each eye perceives just one image. The most common techniques to achieve stereoscopy are described below.

2.1 Anaglyphs

Anaglyph visualization is one of the most used techniques to create stereo illusion. It can be used with regular monitors in combination with special eyeglasses. The required eyeglasses are affordable and available to everybody. They use colour filters to separate both images (Figura 1).When looking through a red filter, green and blue colours are perceived as black. If we use a green, blue or cyan filter, red colour seems black.

In the rendering phase, a colour mask is applied to each of the views (red and green). Once the images have been mixed and thanks to the effect of both filters, each eye views the corresponding image of the stereo pair. The problem posed by this technique is that data's real colours suffer distorsion, which can have an effect on the viewer's illusion of depth. However, due to the inexpensive

3

price of the system and its good results, this is one of the most used techniques.

2.2   QuadBuffer System

The Quadbuffer System is one of the most expensive of the four alternatives described in this section. The eyeglasses are to be synchronized with the visualization device and for this reason, they require additional hardware. Nevertheless, it provides a priori better visual results.

The system consists of three basic elements:

- Shutterglasses: are liquid crystal glasses which can completely darken in order to prevent light getting through. The glasses quickly alternate the opening and closing of the LCD in front of each eye. This fact, together with the alternating projection of images to each of the eyes, permits each eye to view a different image. Thus, 3D illusion is achieved.

- 120 Hz Monitor: A monitor capable of refreshing the display at double the usual speed (60-75 Hz) is required to enable the interchange of images for each eye to create the stereoscopic effect. A device synchronising the image projection and the shutter glasses is also required.

- Quadbuffer graphics card: Due to the fact that a double number of frames are to be generated, we will need a professional graphics card, capable of bearing such a heavy load without the graphics performance being affected. These cards are used with virtual reality helmets.

    It is possible to set up the shutter glasses system in a way that the stereoscopic effect appears either in front of the screen or behind it (i.e. the viewer has to focus through the screen on a point behind its surface).

2.3   Autostereoscopic display

Stereoscopic displays are intended to show each of the images (two, in the simplest example but they can amount up to twelve) in a different angle. If we assume that each eye is placed in one of those angles, each eye will perceive a different image. There are two different ways of achieving this effect by using a LCD monitor or a regular plasma monitor, with the only requirement of its pixels having a rectangular geometry:

- Parallax Barrier: A grid is placed a few millimetres away from the pixels, which enables the visualization of some of them from a certain angle.

- Lenticular lens:uses a plate with small undulations which perform as tiny lenses by sending light of the pixels in different directions.

Originally, these screens worked with only two views, by sending the left eye image to the left and the right eye image to the right. This system enabled to perceive volume when each eye was located at a side of the central point of the screen, but the effect was not to be perceived from any other perspective. Currently, mostly all autostereoscopic systems are multi-view systems: They work with several visible images (usually from five to nine) in different angles. This fact allows us to perceive the effect from different positions. Figure 3 shows the generation of the 8 views required for an autostereoscopic lenticular monitor.

In order to generate 3D effect, the image displayed in the screen must follow a particular inter-twining, which varies according the developer. This intertwining must permit the lenticular filter or the parallaz barrier to send each image in a different direction (see Figure 4). Nowadays, lenticular monitors of 8 or 9 views are the most widespread, however, if the monitors' resolution increases, the number of views will also increase to improve the quality of the 3D effect.

Finally, Figure 5 shows an image that reproduces a similar effect to the one felt when seen in an autostereoscopic screen.

2.4   Dual Projection with polarizing filters

In most cases, anaglyphs do not allow the correct representation of colour. Therefore, polarized lenses are used, which require higher investment because they need specialized viewer devices. This technique is based on the polarization of light. If we project polarized light in a certain direction and view it with a polarized filter, by placing the filter with an inclination of 90 degrees towards the original light, the light will be blocked. Therefore, it is possible to project two images -the polarized one in a direction and the other, with an inclination of 90 degrees- and to use two polarized filters so that each eye perceives a different image. Filters are inexpensive. The most common practice is to use them with projection systems, but there are also television sets including them. Besides, they usually require two projectors or only one which has been specifically modified; as well as a screen

that does not depolarize light. We have to bear in mind that dark polarized filters darken the imagen and therefore very bright projectors are needed.

3   Stereoscopic visualization in gvSIG 3D

Nowadays, gvSIG 3D offers multiple stereo modes, including autostereoscopy. The effect can be combined with a full screen mode and with an animation module to do presentations. It also comprises the advantage of being open sourced and multiplatform. For these reasons, we have used gvSIG 3D to carry out this study.

Research on this extension (Ten *et al.*, 2008; Torres *et al.*, 2008) has been done, previous to the incorporation of stereoscopic visualization modes. It is based on osgVirtualPlanets (osgVP) (AI2, 2009), a group of libraries that use OpenSceneGraph (Osfield and Burns, 1999) c as rendering engine, and with accessible API for C++ and Java. This framework is capable of handling with multiple sources of raster and elevation data. It is also capable of using a wide range of vectorial symbology (Torres *et al.*, 2009) and to accept several formats of 3D models such as Collada or 3DStudio. Other lines of work on osgVP have been vectorial multiresolution (Gaitán *et al.*, 2009) and web visualization (Salom *et al.*, 2010).

In the gvSIG 3D stereoscopic module, techniques used are based on the calculation of the stereo pair by means of threedimensional geometry, which is already available. The procedure varies according the type of device we wish to use. But, in any case, it involves three different phases: generation of the amount of required views, separate rendering of each view and mixing of views.

The process is the following: In the generation phase, the matrix of each view is calculated taking into account several parameters such as the fusion distance, the distance between the eyes, and the distance between the viewer and the screen. Subsequently, this data is sent to the graphics card, which renders each view into a buffer. Then, the generated views are mixed according to the device we wish to use.

4 Virtual globes with stereoscopic support

There are existing precedents of the integration of stereo vision in both GIS 2D/3D and virtual globes (Boulos and Robinson, 2009). Most of them perform in 2D and by obtaining static anaglyph images. However, the ones of our interest are those capable of obtaining stereoscopy on flight, namely, dynamically and with interactive capacity.

The Company ESRI has recently included stereo hardware in its extension for ArcGis, Analyst3D (Esri, 2008) which includes visualization modes suitable for different stereo types (Esri, 2010), being among them the anaglyph and quadbuffer systems.

On the other hand, the Stereo GE Browser is available for Google Earth application (Suto, 2009) which is a stereoscopic browser based in the free plugin Google Earth Browser. It is defined by using three different Google Earth instances, namely, one with stereo view and two other matching each of the viewer's eyes.

Another existing option for Google Earth is the use of TriDef (TriDef, 2010) viewer. It belongs to a set of tools used to view other companie's applications in stereo. This viewer includes visualization by means of anaglyphs, autostereoscopy and quadbuffer system.

Though in a lesser extent, there are also existing precedents in open source GIS applications. Some virtual globes have been integrated in GIS applications (Walker and Kalberer, 2010), but very few of them present stereoscopic possibilities. There is a free plugin intended for anaglyph visualization for Nasa World Wind (NASA, 2004). There is also a stereoscopic version in development which supports multitouch navigation (Schöning and Daiber, 2010).

gvSIG 3D Extension is the open source application offering more stereoscopic hardware (see Table 1), and it includes multiple stereo visualization modes and the possibility of full screen. It is also worth mentioning that the application is a multiplatform one, which runs on operating systems Linux, Windows and MacOSX.

5 Tests carried out

In order to evaluate user experiences, a test has been carried out within the framework of a GIS Congress (6th Conference on gvGIS). 51 volunteers have participated in the test, 39 men and 12

women, between the ages of 24 to 64. 52% of the participants wore contact lenses or prescription glasses and one of the participants was unable of perceiveing the stereoscopic illusion because of his suffering from strabismus. 37 out of 51 volunteers had watched at least once a 3D film in the cinema.

For the development of the test, three equipments were set up, each one provided with a different stereoscopic display (see Figure 6). In the case of the Quadbuffer system the focal point was set up behind the screen. In our experience, and after a minimal test, putting the focal point behind the screen tends to work better for all viewing angles.

In first term the users tested the anaglyph screen, then the quadbuffer system and at the end the autostereoscopic display. For a more rigorous evaluation in terms of presence a one-way ANOVA method should be used as described in (Howell, 2002). Unfortunately, it was not possible to carry out the tests dividing the users in two groups or mantaining the ilumination conditions because the tests were done in the scope of a congress, not in a laboratory.

5.1   Framework

In the first part part of the test, threedimensional flights over two different areas (an urban and a mountainous area) were shown in each of the displays (Figure 7). Subsequently, a questionnaire consisting of 5 questions was given out; in most of the questions each participant was asked to evaluate his/her impressions with a number scale ranging from 1 to 5.

The questionnaire consisted of the following questions:

Q1. *Evaluate from 1 to 5the feeling of depth/relief you are experiencing (where 1 represents no feeling of depth and 5, deep feeling of depth).*

Q2. *valuate from 1 to 5 the feeling of inmersion provided by each type of technology (where 1 represents no feeling of inmersion at all and 5, full inmersion).*

Q3. *Did you feel dizzy/uneasy? Evaluate the experience from 1 to 5 (where 1 represents no feeling of dizziness at all and 5, deep feeling of dizziness).*

Q4. *If you have ever watched a 3D film in the cinema, evaluate the experience by comparing with the technologies you have just seen (where 1 means better experience and 5, worse experience).*

Q5. *What kind of technology do you think is more useful in a GIS environment? Classsify them from the most to the least useful (from 1 to 3).*

8

5.2 Results

This section analyses the results obtained in the test. For this purpose, the average and the standard deviation of each of the answers to the questions in the questionnaire have been calculated. Results are presented in Table 2.

As you can observe from the answers given to Q1, quadbuffer technology produces more depth and relief illusion in most of the participants, with an average mark of 4.78 points. Autostereoscopic technology is the one producing the least depth and relief effect, with an average mark of 2.94 points. Moreover, shutterglasses contribute to creating a deeper feeling of inmersion if compared to the rest of the devices.

Regards dizziness or uneasy feeling caused by the use of any of the devices (Q3), 32% of the participants did not experience such feelings with any of the devices. Within the group of volunteers who did experience this kind of feeling, anaglyph technology received the worst evaluation, with an average mark of 1.94 points of a maximum of 5. On the other hand, the quadbuffer system received the best evaluation, 74% of the participants had no dizziness feeling caused by this device.

Out of the 51 participants in the test, 37 had watched a 3D film in the cinema (Q4) and, within this group, the great majority (75.4%) described as a better experience the one felt with the quadbuffer system. The experiences produced by autostereoscopy and anaglyphs were similar to the ones felt in the cinema.

46% of the participants stated that the quadbuffer system could be the most efficient one in a GIS environment (Q5), followed by autostereo technology with 37% and lastly, anaglyphs with 17%.

Many users noticed that the anaglyph system distorts colours in the orthophoto, by which, the inmersion illusion is reduced. They were also surprised by the quality of the inmersion effect in this device, which was expected to be worse because it is an old system.

From the comments written on the back of the questionnaire, we can affirm that the autostereoscopic screen impressed the most the participants, who added that it had future potential because it did not require wearing eyeglasses. However, many of them, agreed that these devices still have to undergo improvements in order to put the stereo feeling on the same level than the quadbuffer system.

9

6 Conclusions and future work

This paper has aimed at describing the state of the art of stereoscopical techniques in virtual globes. First, we have rejected photogrammetry due to its low interaction level with the user and its high costs. Since the effect is only visible from the view point where the photograph was taken, this technique is not practical within a virtual globe, where the user has the possibility to explore the scene from any position.

Currently, there are existing methods which enable the attainment of stereoscopy by means of three-dimensional geometry. It also eliminates the expensive process of planning fotogrammetric flights and makes possible the inclusion of elements which are not present in the orthophoto. Some of these methods have been included in gvSIG 3D, which is presented as the most complete open source alternative among stereoscopic modes.

With the aim of listing advantages and disadvantages of each device, we have carried out a test searching for subjective evaluation of users by means of a questionnaire. From the results obtained, we can deduce that the quadbuffer system is the stereoscopical technology which currently provides the best results within a virtual globe. Participants experienced a deeper feeling of depth, relief and inmersion in the scene. It was regarded from the ones who had previously been in a 3D cinema, as a better experience. It also obtained the best results among those participants who had felt dizzy or uneasy. Quite the opposite happened with anaglyphs technology, which caused more problems.

On the other hand, autostereoscopic technology impressed users the most due to the fact that it is not required to wear glasses to feel the effect. However, the great majority agreed that these devices need to undergo improvements in order to reach the level of the quadbuffer system. The illusion of depth and inmersion is much lower but the margin of improvement is big. With the increase of the number of views supported by stereoscopical screens, the users might possibly improve their assesment.

A more rigorous approach is possible applying one-way ANOVA method and mantaining the same conditions of ilumination for all users.

Possible further research work could be the comparison of the results obtained in a new study including dual projection systems and polarizing filters. These were not included in the test in order to simplify the setting up and because a special room would have been required.

7 Aknowledgments

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List of Tables

List of Figures

GIS 3D Features	ArcScene (ESRI)	Nasa World Wind	StereoGE Browser	TriDef GE	gvSIG 3D
License	privative	LGPL	freeware	privative	GNU/GPL
Platform	Windows	Windows, MacOSX, Linux	Windows	Windows	Windows, MacOSX, Linux
Anaglyphic stereo	Yes	Yes	Yes	Yes	Yes
QuadBuffer stereo	Yes	No	No	Yes	Yes
Autostereoscopy	No	No	No	Yes	Yes
Dual Projection	Yes	No	No	Yes	Yes
Full Screen	Yes	Yes	No	Yes	Yes

Table 1: Comparative table of virtual globes supporting stereoscopy

Question Technology	Q1	Q2	Q3	Q4
Anaglyph	3.82± 0.71	3.38±0.85	1.94±1.85	2.83±1.16
Autostereo	2.94±0.84	2.84±0,93	1.84±1.18	2.24±1.09
Shutterglasses	4.78±0.50	4.56±0.67	1.50±0.97	4.13±1.08

Table 2: Means and Standard Deviations of Questionnaire Scores.
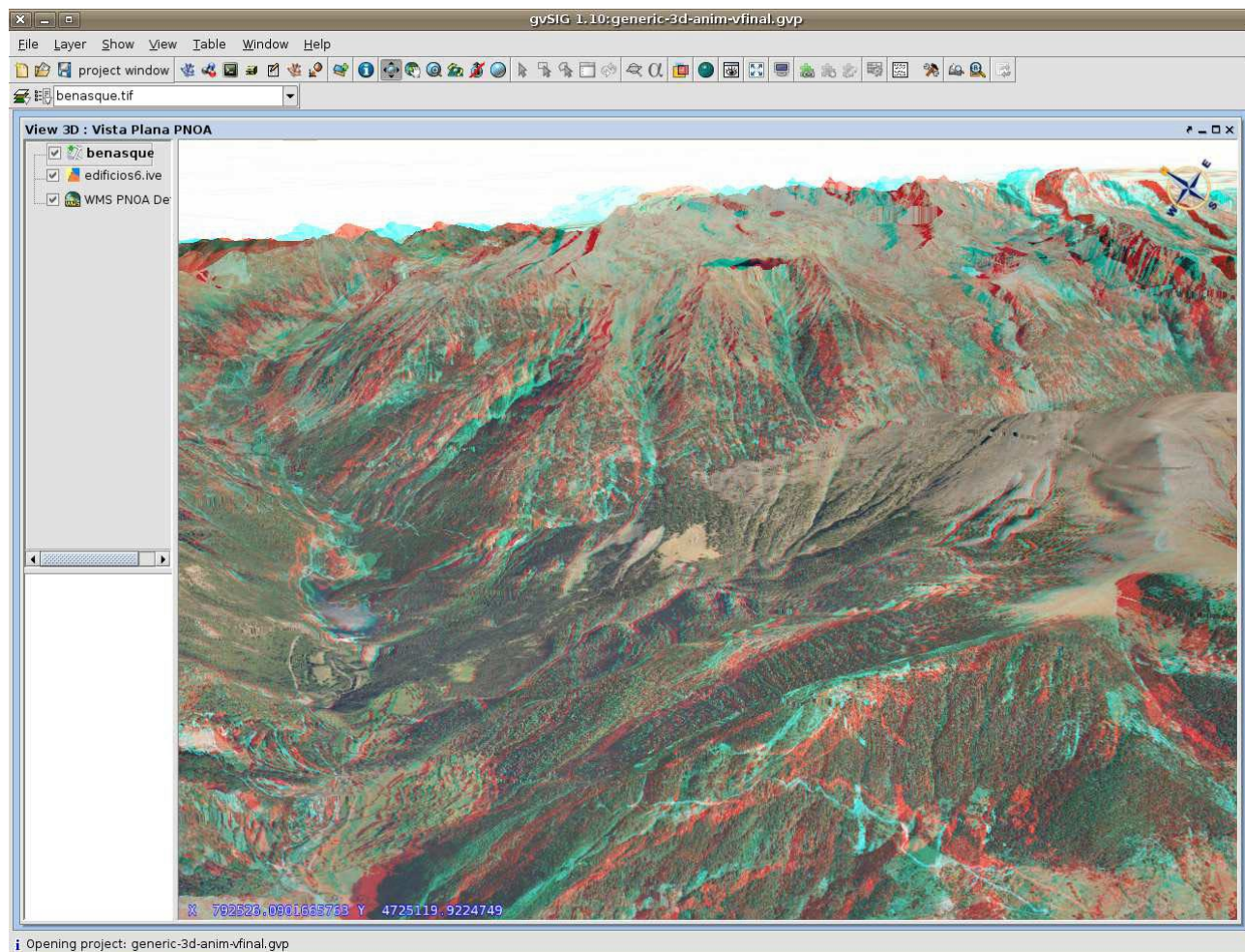
Figure 1: Anaglyph image of the valley Benasque, with gvSIG 3D and using data from a WMS service and an elevation layer.

Figure 2: 120 Hz Samsung monitor and shutter glasses NVidia 3D Vision used in the test. The object of pyramidal form is in charge of the wireless synchronisation of the parts of the system (image obtained from http://3dvision-blog.com).
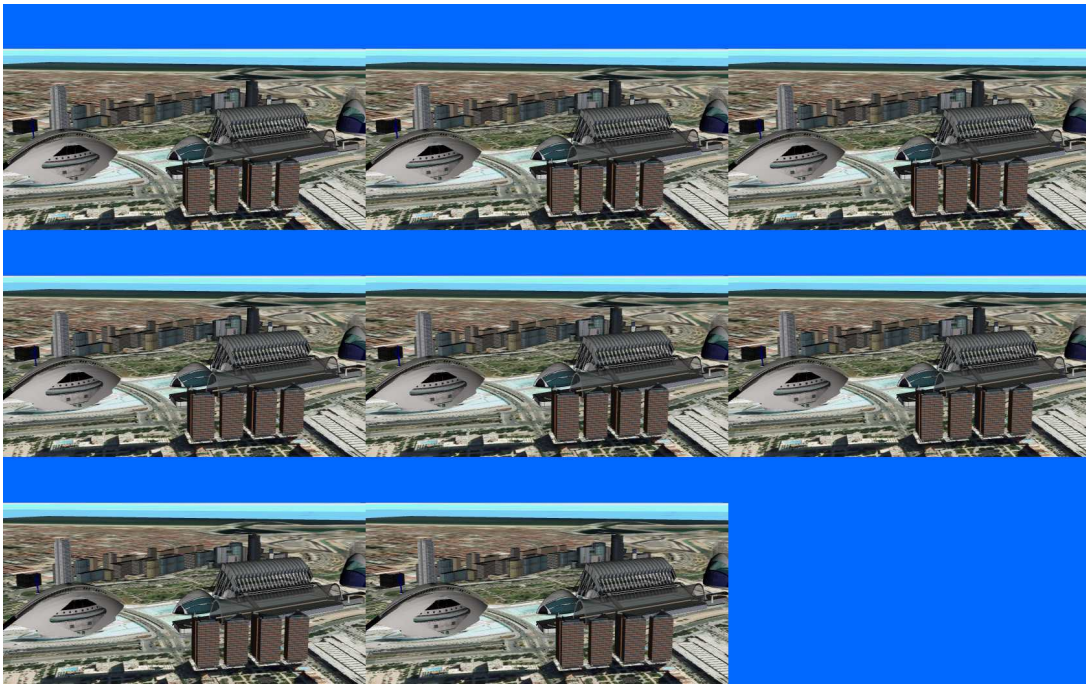
Figure 3: Mosaic with 8 generated views from an area of the city of Valencia. Each of them has a small separation in order to achieve 3D effect.
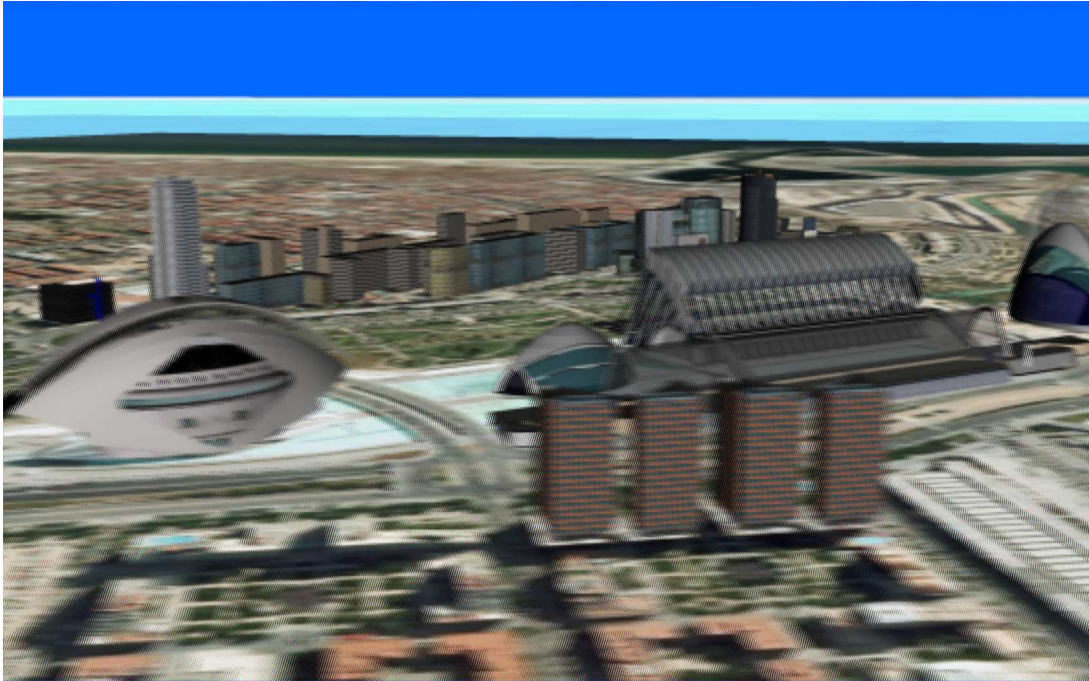
Figure 4: Final image of the mentioned area of the city of Valencia after intertwining the 8 views.
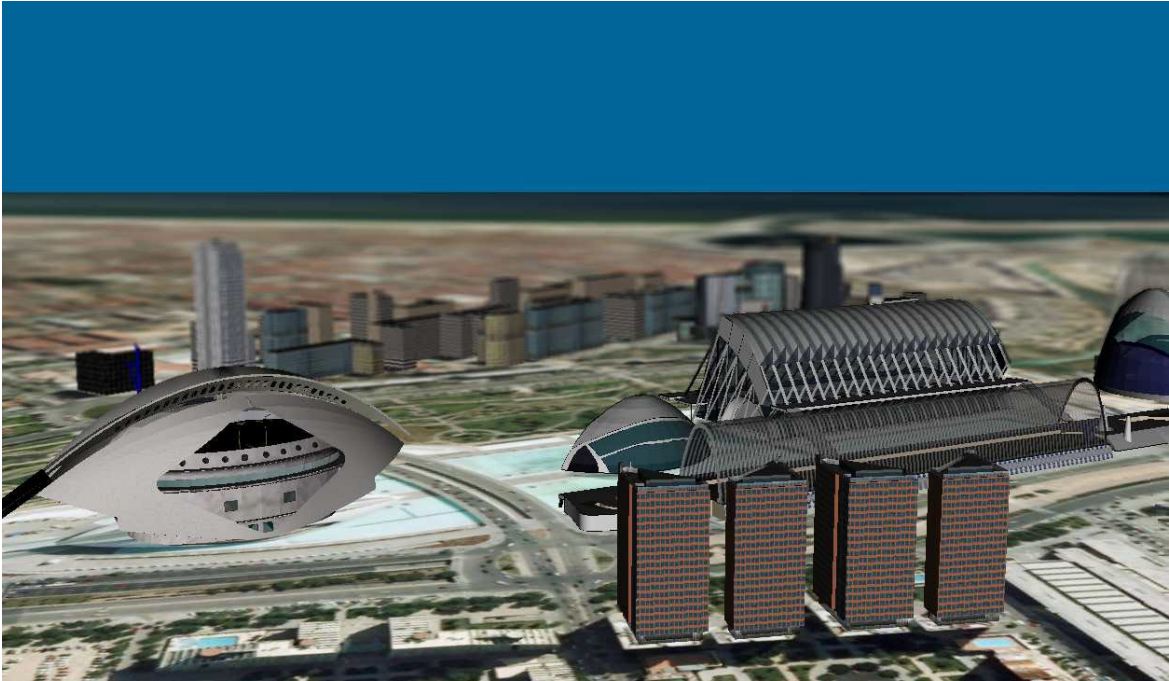
Figure 5: Image emulating the autostereoscopic effect of an area of the city of Valencia.

Figure 6: Equipments used for the test, all of them runing on full screen option in order to enhance the illusion of depth. From left to right: quadbuffer system, anaglyphs and autostereoscopic screen with lenticular filter.

Figure 7: Some participants during the test. The anaglyph system can be observed by more than on person at a time (participants with white eyeglasses), the same occurs with the autostereoscopic screen. In the case of quadbuffer system, only one pair of shutterglasses was available (participant with black eyeglasses). Image from http://picasaweb.google.com/gvsigproject.