VAST 2010

The 11th International Symposium on Virtual Reality, Archaeology, and Cultural Heritage

The 8th EUROGRAPHICS Workshop on Graphics and Cultural Heritage

– Short and Project Papers –

Paris, France
September 21 – 24, 2010

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The 11th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2010) *Short and Project Papers*
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3D Pipeline from Data Acquisition to Data Visualization of the Hellenistic - Roman Theatre of Paphos

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Abstract

In this paper is described the fusion of two different technologies for the three dimensional acquisition of the Hellenistic-Roman Theatre of Paphos located at the island of Cyprus. A laser scanner and an innovative device for the aerial photogrammetry have been used for this purpose. Despite the size of the archaeological site and the complexity of the survey; it has been possible in a short time to acquire the whole theatre using photogrammetric and laser scanning techniques. The final result is the complete 3D model of the theatre at present, which was used for 3D stereoscopic vision simulation.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation—Digitizing and scanning; Computer GraphicsI.3.6Methodology and Techniques - Grafics data structures and data types Computer GraphicsI.3.1Hardware architecture - Three-dimensional displays

1. Introduction

The development of the technologies applied to cultural heritage helps to create qualitative 3D models of complex shaped artefacts. Terrestrial laser scanning and photogrammetry are used for many years for recording, preserving and studying of cultural heritage. Recently, these technologies are integrated into the 3D pipeline to create high-resolution geometric models.

Aerial photogrammetry produces high-resolution images that allows to generate qualitative range maps of the surveyed areas, while terrestrial laser scanning allows to obtain a dense point-cloud to create detailed 3D models [Pel05, BGT*03]. The fusion of these two technologies allows to balance the weak points of both and the harmonization of the data. Nevertheless, a common ground coordinate system is used that plays a significant role on the data alignment and data transfer. This system enables an accurate fusion of the two acquisitions.

Finally, the post-processed model was used to realize a stereoscopic 3D visualization. The archaeological data in a three-dimensional immersive virtual environment helps archaeologist to easily visualize the theatre from several points of view.

2. Case Study

The site of the ancient theatre of Nea Paphos, constructed around 300 BC, is located in the modern town of Kato Paphos. It was built on the southern slope of a hill, which is in the very north-east of the ancient walled city. It measured m 90195 from side to side and had a seating capacity for over 8000 spectators. Five major phases of remodelling and renovation can be identified at least during the theatre's history representing the changing nature of performance from Greek and Roman audiences, and responses to earthquake damage. [BGR04]. Realizing the importance of the ancient site, we have elaborated acquisition, post-processing and visualization that are fast and qualitative, in contrast with other known techniques applied to cultural heritage.

3. Data Acquisition

In April 2009, the digital acquisition campaign of the theatre was carried out, involving the University of Sydney, the Cyprus Institute-STARC, CNR-ITABC and UNIOR-CISA. Aerial photogrammetry and laser scanning was used for surveying the whole area of the theatre. In total, we spent 4 days on site fieldwork. The aim of this project was to create a realistic 3D model reassembling the theatreâĂŹs original appearance for spatial analysis and documentation [GDA*10].

3.1. Aerial Photogrammetry and Terrestrial Laser Scanning (TLS): overview

An innovative device for aerial photogrammetry was used that was developed by CNR of Rome (ITABC) and the Menci Software of Arezzo. The device was tested for the first time on the Palace Tomb, Petra, Jordan [GLA*09,AFDG08]. The device was composed by two aluminium bars, 2 meters long, and three cameras, Nikon D80 (10 mpx) with 24 mm fixed frame [GAV*10] (Figure 1).

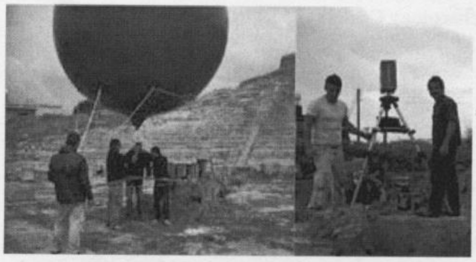

Figure 1: *Fly-Scan system, during the assembling and Laser scanner ZF Imager 5003.*

TLS Zoller & Frohlich 3D Imager 5003, is used for the 3D acquisition, that has been developed for applications on short and medium range. The distance measurement system is based on the phase measurement principle. This device also guarantees an elevated acquisition resolution with a speed of 500.000 points per second [FM04].

4. Registration of the range maps

Registration is a crucial step in integrating data from different methodologies. A bad registration may give misrepresented information. Therefore, for this reason before the acquisition of the 3D data, the morphology of the theatre was defined by brainstorming the position of each target and by placing them at the appropriate location. The location of the targets was determined by the area framed by cameras from the height of about forty meters.

In order to register the point-clouds from aerial photogrammetry and laser scanning, 387 ground control points were distributed over the theatre and the coordinates of each target point are acquired using a Trimble 5600 total station.

A large area of the theatre was recorded using aerial photogrammetry. In total, 175 triplets of photo were taken in two days. Parts of these were acquired with a rotation of 45° of the cameras, while the others with a birds eye view. The flight altitude was about 40 m above ground, according to the optimal accuracy of the survey.

Laser scanner fieldwork was carried out in only two days, following a well-consolidated pipeline [Sco05]. The position of the targets were ingested into the area, according to the planning survey [DIS08]. A total of 25 scans were taken during the two days; 15 scans were taken for left emphparodos and 10 scans for *summa cavea*. They were acquired with a medium resolution range of 220 sec. Furthermore, a handheld camera was used to take photos for texture mapping the point clouds taken out from laser scanning.

4.1. Range maps post-preocessing

In order to obtain a complete model of the theatre the data from aerial photogrammetry and laser scanning were blended.

The outcome of the photogrammetric survey with Fly-Scan system (realized by Menci Software, Arezzo) is a set of three images captured simultaneously from three cameras. Thirty triplets are used to cover the area of the theatre. The images were processed with two software: Z-Scan and Z-Map. The first processing step is to extract from each triplet a single point-cloud that contains spatial and colour information; the point-cloud is referenced in the same coordinate system obtained according to the total station survey. The final outcome is a textured colour per vertex model.

During the acquisition with the Fly-Scan device some issues came out: such as the wind sensitivity of the balloon and the data loss in areas with high contrast shadows or high exposition to the sun. On the other hand it was possible to guarantee a high accuracy of the geometric data by manipulating the resolution during the data acquisition and the post processing.

After the acquisition by the laser scanner, all the scans were processed with the JRC 3D Reconstructor software [SV07]. The merging process outputed an error of only 6 mm. Images were mounted on the several scans, creating coloured point-clouds. A number of sections were created, exported to CAD and placed on existing plans. The point-clouds were processed by referencing all the data captured from each methodology to a single object coordinate system in order to create the realistic 3D model of the theatre. The residual error of the registration process was better than 6 mm in XYZ coordinates, that depicts an acceptable result (Figure 2).

When the model is accurately blended and optimized the decision to visualize data is been made. The post-production of the model includes the stereoscopic visualisation that allows to do visibility studies, verifying them inside the 3D environment and using them as a tool to understand the spectators or actors visual perspective.

Furthermore, the application should offer more than a simple three-dimensional rendering on a desktop screen. The visualization aims to immerse the user into a three-dimensional scene designed for public demonstrations.

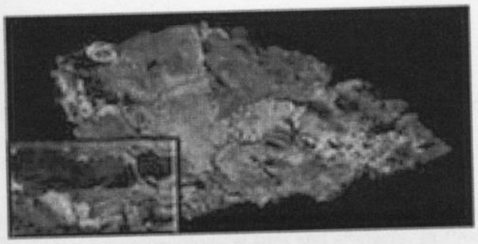

Figure 2: *Final point-cloud by registration of the photogrammetry and laser scanning data and summa cavea: laser scanner and photogrammetric point-cloud.*

5. Stereoscopic 3D Visualization of the Theatre

The aim of the visualization is to replicate humanâĂŹs vision and translate the 3D content on to the 3D display using a virtual stereoscopic setup of the scene acquired from the theatre of Paphos. The technique relies on presenting two slightly different images on to the retinas of our eyes, which the brain automatically blends into a single view or a spatial representation. Subtle right-left dissimilarities in the images create the perception of depth and can be manipulated to creative advantage. Illusionary depth perception accommodates solidity that creates immersion and realization of objects in the Cartesian space, therein lies the stereoscopic virtual reality for archaeology.

6. Scenario analysis

The scenario is brainstormed according to the chosen S3D technology. According to our findings and comparison of various S3D Technologies (anaglyph, polarized, infitec, LCD shutter glasses) circular polarization technique will be the main actor of our scenario [Geo10].

Our objective is to produce not just a conventional stereoscopic visualization by using visual effects as presented at the cinemas but a scientific visualization where there is no image distortion and the visualization must to simulate a virtual environment of the theatre by replicating human vision and translate it exactly as it is on the 3D display accommodating the correct scale, that is known as "orthostereoscopy" [Men09]. Based on given physical parameters that is the interocular distance of our eyes that is the horizontal deviation in between the centre of our retinas, the horizontal size of the 3D display and the average distance of the viewer from the display, the scenario for the translation of the virtual camera intrinsic and extrinsic parameters can be register so to produce the S3D composition of the theatre revealing its architecture at its current physical state.

7. Implementation

The S3D framework is conceptualized based on our scenario analysis. The framework uses a methodical way of capturing, editing and producing the S3D theatre of Paphos. The software tools(open and free source) to be used are:

- Blender for S3D scene set-up
- StereoPhoto Maker for S3D image composition
- AviSynth fro real time video presentation

7.1. Depth script analysis

Stereographers create a depth script in order to accumulate hyperstereo or hypostereo effects, which is not our case. Our objective is to maintain true perspective without distortion of geometry, having a 1:1 roundness factor in between the real and virtual environment presented on the display. The roundness factor is part of the artistic palette in stereography and by maintaining the roundness factor of 1 we accumulate the orthostereoscopic condition that is with perfectly shaped volumes [Len82].

The following depth formulas ratios are computed:

$$HISD/ED = CGFPD/I$$

$$VDD/ED = CGFPD/I$$

$$CGCPHS = HISDx(I/ED)$$

Translate FOV of the cameras (FOV in radians)

$$FOV = 2xatan(CGCPHS/(2xCGFPD))$$

where:

- CGCPHS: Computer Generated Convergence Plane Horizontal Size
- CGFPD: Computer Generated Focal point Distance
- ED: Eyes Distance
- FOV: Field of View
- FPD: Focal Point Distance
- HISD: Horizontal Image Size of the Display
- I: Interaxial
- VDD: Viewer Distance from the Display

If we substitute these equations with the given physical parameters such as average eye distance ($ED = 2.4''$), horizontal image size of the display (HISD = 1 meter), CG interaxial ($I = 2.4''$) we are able to compute the remaining parameters such as distance of the viewer from the display (VDD = 1 meter), focal distance of the virtual cameras to the subject (CGFPD = 1 meter) and the convergence plane horizontal size (FOV) so to create an orthoscopic virtual rig. The CG convergence plane horizontal size of the two cameras or the FOV can be expressed in radians and that is equal to 53.130°. In order to replicate human vision we must converge the cameras slightly inward so to create zero parallax on to the focal point of the scene. In order to compute the angle of convergence we substitute the following formula [Len82]. $Tan = I/(2CGFPD)$ Where I is the interaxial distance and CGFPD the distance from the camera to the subject or the focal point distance. If we substitute this formula with the given parameters we find the angle of convergence of the two cameras in radians and that is equal to 16.951°.

7.2. Blender as the virtual enviroment

Blender is used for the stereoscopic virtual set up of the theatre environment and in order to do the orthostereoscopic rendering we replicate as 3D models our 3D display and the physical projection space so to fit the theatre's geometry inside the CG display and the CG cameras inside the CG projection space. The orthostereoscopic rig produces the human frustum for a specific display geometry. By mimicking human vision we have created an orthostereoscopic condition that will generate immersive stereoscopic images. Objects will appear sized exactly as they are in the CG models, scaled to the display's width, with perfect roundness factor of 1:1.

7.3. Rendering and Post Production

Based on the calculated stereoscopic set up, the virtual left/right cameras are created with the analogous depth script parameters. The timeline of Blender is used for the interpolation of the movement of each model through time. When finished the theatre model is ready to be rendered at a sequence of high resolution interlaced PNG still images. StereoPhoto Maker is used for the side-by-side compostion of the left/right images and AviSynth is used for the real time video presentation of the images (Figure 3,4).

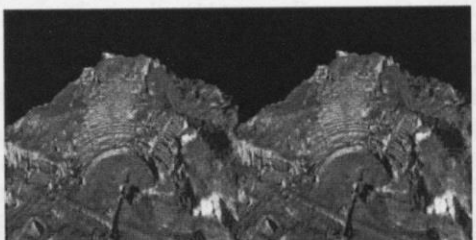

Figure 3: *Composed Side-by-side still image from the theatre of Paphos rendering.*

8. Conclusions

The integration of laser scanner and aerial photogrammetry has demonstrated to be efficient and flexible to create with richness of detail and accuracy 3D models of cultural heritage. The outcomes can be used for different purposes as 3D and 2D documentation, conservation, monitoring and dissemination. Finally by having accurate 3D data obtained by this two methodologies we are able to post-produce a qualitative orthostereoscopic visualization.

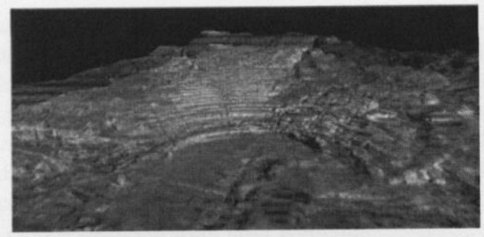

Figure 4: *3D TV "Row interleaved" conversion and projection of side-by-side imagery. When the viewer wears polirization glasses the S3D depth is simulated.*

In the "modern digital era" the future on S3D technologies looks promising, and this time will be here to stay and overcome its previous problematic flaws. Unfortunately, not all Government or private funded Archaeological sectors are documenting S3D prior to their preservation or restoration in a way that will be an essential medium of the 3D pipeline. That is the time for initiating the process by using a low cost S3D processing pipeline as used for the theatre of Paphos.

9. Acknowledgments

This research is the result of a collaboration between: CYI Science and Technology in Archaeology Research Center (STARC), Interdepartmental Archaeology Center (CISA), CNR Institute for Technology Applied to Cultural Heritage (I.T.A.B.C.).

The authors gratefully acknowledges support through the EC project 3D-COFORM. 3D-COFORM is a co-funded Large Scale Integrating Project and has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n°231809.

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