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A flexible platform for the creation of 3D semi-immersive environments to teach Cultural Heritage

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ABSTRACT

The virtual visualization of historical objects opens the door to a variety of new teaching applications in the classroom. In this study, we present a flexible platform for the creation of semi-immersive 3D environments. First, we describe the software and hardware tools that generate the 3D models and the Virtual Reality Environments. We then present an optimized design methodology, adapted to the generation of light 3D models of sufficient visual quality for teaching purposes. The most suitable option for such purposes proved to be CAD tools coupled with extensive use of image textures on low-resolution 3D meshes. Finally, we report an ad-hoc teaching method to test the platform during a short teaching session on Cultural Heritage and Computer Graphics for high-school and undergraduate students. The evaluation of their experiences, based on post-session surveys, points to the effectiveness of this approach to communicate different types of knowledge and to stimulate student learning.

1. Introduction

The visualization of an historical object in the form of a 3D model is a holistic experience for the spectator, especially when compared with traditional visualization techniques, such as paintings, which limit the experience to fragmentary perspectives. This aspect is especially important, if the main goal of the visualization experience is to gain a better historical understanding of the background to the object and its characteristics, as is so often true for teaching experiences like visits to museums and art galleries. Before the turn of the century, limited computer-processing capabilities meant that the use of 3D Cultural Heritage models generated rendered images off-line, giving the images only very limited advantages over traditional painting (Novitski, 1998). However, the recent development of 3D graphic design hardware and software has led to new approaches for the analysis and dissemination of Cultural Heritage, most of which include real-time rendering, such as virtual museums (Carmo and Cláudio, 2013), Virtual Reality 3D rooms (Chow and Chan, 2009), serious games (Anderson et al., 2010), etc.

Real-time rendering in virtual environments prompts a variety of different questions. The first one is: which technique is the best to create the complex, but at the same time light 3D models that have to be visualized? Different approaches have been proposed to create 3D digital reconstructions of Cultural Heritage: photogrammetry, topographic techniques using a Geodesic Station, laser scanning and the use of CAD tools or hybrid technologies that combine two of the aforementioned approaches. The second question is: which visualization platform is the most suitable for the target audience to interact with the 3D models? Some answers to this question are virtual museums, Internet portals, and immersive or semi-immersive environments for one or more persons. And finally, the last question refers to the purpose of the generated virtual environment: historical and archaeological research, educational experiences, and management and conservation tasks. All these possibilities and their relations in the case of complex 3D models are discussed in Section 2, on the state-of-the-art, because high-quality 3D models are not easily rendered in real time and limit end user interactivity with the virtual reconstruction in many applications, especially those related to teaching.

This paper presents a flexible platform for teaching various topics, especially related to Cultural Heritage, 3D Modelling and Virtual Reality, through a 3D semi-immersive environment based on existing hardware and software technologies. The development of such a platform implies different multidisciplinary research: mainly in teaching methodologies, but also considering hardware and software integration and the standardization of 3D design methodologies. We describe the hardware and software associated with this flexible platform used for the virtual reconstruction of an historic–artistic monument and discuss its educational uses. The study goes further still by developing specific methodology for this

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task and reporting on a final example of its use: a short teaching session (Virtual Reality applied to Cultural Heritage) during the tenth Science Week of the University of Burgos was organized to stimulate interest in historical buildings and to introduce students to 3D Computer Graphics. This methodology is useful for developing light 3D models of medium-level detail, suitable for visualization in a Virtual Reality environment with real-time rendering and human interaction. It obtains a final rendering of sufficient quality for teaching and interpretation of the artistic and historical values of the building. With these reasons in mind, we chose CAD tools and images of medium-to-high quality as the methodology for this virtual reconstruction. Finally, the main novelty of this study is the evaluation of the effect or suitability of semi-immersive environments to teach different disciplines at high-school and university level, unlike most of the existing bibliography that focuses mainly on the software tools and the hardware to create the 3D models and the semi-immersive environment that is outlined in the following section. In our case, the different knowledge disciplines to be taught simultaneously are: 3D modelling, 3D animation, art history, and the history of Cultural Heritage. Its multidisciplinary educational approach is especially appropriate in modern-day society.

The paper is structured as follows: Section 2 presents a discussion about the related work on real-time visualization of complex 3D models and their application to teaching purposes; Section 3 describes the hardware and software that comprise the flexible platform; Section 4 describes the process followed to build the virtual reconstructions used in the semi-immersive environment; Section 5 shows a case study of the flexible platform in the context of a teaching session on 3D modelling and Virtual Reality that includes an analysis of the objectives achieved in the session. Finally, Section 6 summarizes the conclusions and future lines of work.

2. Related work on real-time visualization of complex 3D models

Following the open questions presented in the Introduction, different techniques are used to create complex models of various Cultural Heritage items: from small finds to archaeological sites taking into account the modality of the 3D models (preservation, documentation, research, promotion, etc.). Real-time rendering is required for many teaching purposes, such as augmented-reality applications (Wu et al., 2013) and immersive environments (Jimenez Fernández-Palacios et al., 2015). Therefore the discussion over the suitability of the different techniques will be restricted to 3D models and real-time rendering applications.

Photogrammetry mainly uses 2D images to reconstruct 3D surfaces. Due to the availability of image acquisition devices and the quality obtained in the 3D reconstructions, photogrammetry appears to be the standard technique for creating 3D models of existing small objects (Carmo and Cláudio, 2013), such as ceramic pieces (Remondino and El-Hakim, 2006; Herrmann and Pastorelli, 2014). Over the last 10 years, research into photogrammetry has been focused on the reconstruction of larger-sized objects (Koutsoudis et al., 2007) and on the automation of the 3D surface generation process (Remondino and Rizz, 2010). But complete automation of the reconstruction of 3D surfaces is still an open research topic, in particular for huge items like architectural scenes and very complex geometries, like man-made objects (Herrmann and Pastorelli, 2014; Remondino and Rizz, 2010). In this last case, it involves very irregular objects and the 3D models used to be very heavy, because the algorithms try to extract as much information as possible from the images. Another disadvantage of photogrammetry is its requirement for a level of user interaction in the different steps of the 3D reconstruction and modelling pipeline, restricting its use mainly to experts. Therefore, there are two main disadvantages to the use of photogrammetric creation of 3D models for teaching purposes: the need for experts to create the 3D models and the high weight of the meshes in the case of irregular objects (Pavlidis et al., 2007; Martin et al., 2010; Cheng and Jin, 2006; Gobbetti and Marton, 2004; Fabio et al., 2010; Callieri et al., 2011).

Laser scanners and other similar kinds of sensors are able to take optical measurements of the distance between the acquisition device and any surface, generating point clouds that have to be converted to 3D surfaces by means of automated or semi-automated procedures (Martin et al., 2010, 2014). These techniques are very suitable for huge items, like architectural scenes, although they present some disadvantages, due to their high cost, weight and the usual lack of good texture (or, in some cases, the problem is to match image textures with 3D surfaces) (Remondino and Rizz, 2010). Although very accurate 3D models can be generated with these devices, their heavy meshes make them more useful for documentation and research, than for on-line render applications like teaching packages and virtual museums (Carmo and Cláudio, 2013; Jimenez Fernández-Palacios et al., 2015).

Although many experiences try to combine photogrammetry with 3D range sensors (Remondino and Rizz, 2010; Martin et al., 2010), their results are mainly useful for research and documentation purposes, and they have a very limited application to teaching. Especially, if the object is mainly destroyed or lost, these techniques are of little or no use. In such cases, the most common approach is to use CAD tools (Lucet, 2009; Styliadis and Sechidis, 2011; De Paolis, 2013; Chen et al., 2013) to create the 3D models in consultation with experts in that particular historical period. The alternative might be the use of parametric modelling, but this technique is mainly suitable for the generation of cities with standard building characteristics and may not be suitable for the generation of complex irregular surfaces, like the altar piece of a church from the Middle-Ages for example (Chevrier, 2015). Finally, there are also some examples of hybrid technologies that combine CAD tools and 3D range sensors (Chow and Chan, 2009; Guidi et al., 2005). The first approach generates 3D models of higher accuracy, but presents two serious disadvantages: (1) the creation of the virtual object is complex, because the scanners only provide point clouds rather than 3D digital surfaces, and it is not easy to match the 3D model with the texture image (Martin et al., 2010); and, (2) the re-creation is too heavy to render in real-time on standard computers in medium-sized universities and business enterprises (Remondino and El-Hakim, 2006; Gobbetti and Marton, 2004).

As pointed out, careful consideration should be given to the visualization technique that is chosen from among the various available options and to the final use of the 3D model with which the target audience will interact, when selecting the method for the creation of a 3D digital reconstruction of Cultural Heritage. The final uses reported in the bibliography mainly refer to: public presentations of historical artefacts and structures in virtual museums (Carmo and Cláudio, 2013; Herrmann and Pastorelli, 2014; Gobbetti and Marton, 2004; Fabio et al., 2010; Callieri et al., 2011; Martin et al., 2014; De Paolis, 2013) or over the Internet (Chow and Chan, 2009; Wang et al., 2008), historical and archaeological research (Jimenez Fernández-Palacios et al., 2015; Martin et al., 2010; Cheng and Jin, 2006; Lambers et al., 2007; Lucet, 2009), educational experiences (Chen et al., 2013; Champion, 2008) and management and conservation tasks (Wachowiak and Karas, 2009). Different visualization techniques have been proposed over the past twenty years, going further than simple rendering images for these final uses: 3D animations with interactive dialogues (Champion, 2008), real construction of the 3D meshes by means of