

VirtualTour: A System for Exploring Cultural Heritage Sites in an Immersive Way

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Abstract—In this paper, we propose VirtualTour. This is a virtual reality app for Apple iOS 8 (tablets, smartphones) supporting the easy and natural exploration of Cultural Heritage sites captured with 3D scanning technologies or modeled by artists. VirtualTour proposes a novel approach for exploring virtual sites by exploiting modern mobile devices (tablets or phones) and their embedded sensors. The navigation is constrained to follow a pre-defined path in the virtual space; the user can progress on the path either by manipulating a simple slider or directly walking in real-world (the device sensors detect user's steps and progress accordingly in the virtual visit). The view is rotated according to mobile device's rotation (again, using the device sensors). The main focus of this app is to provide a mobile access to hidden or inaccessible sites (e.g. caves, temples, buildings, etc), using 3D representation and breaking the usability barrier that often hinders the navigation in complex models on top of mobile devices.

Index Terms—Virtual Reality, Mobile platforms, Real-time Rendering.

I. INTRODUCTION

In the last few years, mobile or wearable virtual reality has gained new interest amongst the industry and researchers. The rapid development of new technologies such as high quality head mounted displays, accurate and cheap motion sensors (e.g. accelerometers, gyroscopes, depth cameras, etc.), localization sensors (e.g. GPS, compass, etc.) etc. have led to new opportunities that just a few years ago were not possible to achieve with off-the-shelf components. This renaissance of virtual reality is happening in both research and practical applications, such as computer games, movies, documentaries, learning, urban planning, etc.

In this work we propose a system, *VirtualTour*, offering virtual exploration of Cultural Heritage (CH) sites on mobile devices based on a natural interaction approach; a few easy to understand (and to be tracked) actions performed by the user in the real world are translated into navigation instructions in the virtual world. To achieve this goal, we have exploited embedded sensors and the fast hardware of modern mobile devices.

II. RELATED WORK

In the last few years, the diffusion of mobile devices such as smartphones and tablets supporting 3D visualization has ignited the development of Virtual Reality (VR) and Augmented Reality (AR) applications for CH. VR and AR can be used to create virtual museums or virtual visits to places which may be not accessible to the public. Moreover, they can provide the virtual visitor with additional information, directly

related to the specific location/focus or the interest and profile of the specific user.

An example of virtual museum has been recently presented by Pecchioli et al. [7]. They designed a web application providing a virtual tour which was primarily meant as a support to the real visit of the museum.

Researchers have also suggested how to present the historical content of CH; from the data acquisition to the data visualization. Aliaga et al. [1] have proposed a framework for the digital exploration of CH objects.

Other systems, such as the one proposed by Wojciechowski et al. [10], have been specifically developed to allow the museum staff to build with ease virtual exhibitions using VR/AR technologies. Wojciechowski et al. have presented a system called ARCO that allows to create a virtual exhibition starting from pre-designed X-VRML visualization templates.

Usability of interaction and of the overall virtual museums is also an important subject of research. Among several works on this subject, Pescarin et al. [8] have proposed some evaluation tools to examine users and the usability of the interfaces in order to improve the production phases of virtual museums.

Visual quality is another parameter to take into account when designing a VR/AR system. Some techniques can help to improve the presentation of CH artifacts. The system presented by Ridel et al. [9] is designed to improve the readability of the object details that are difficult to distinguish due to deterioration. To reach this goal, the 3D model is analyzed in order to capture convexities and concavities. Then the system interactively projects on to the real object an expressive 3D visualization that highlights its features. The user interaction is based either on an electromagnetically tracked prop or on optical tracking of the user's fingers.

Other examples of VR/AR applications designed for CH on mobile platforms are: the augmented reality application for animating paintings proposed by Lu et al. [5], that allows to view them through a mobile device and was also used to assess how AR technologies can affect the learning or observation of art in a museum; the digital guide proposed by Miyashita et al. [6] is based on augmented reality and developed with two main goals in mind: to provide a visitor with information to enable her/him to fully understand a piece of art, and to help her/him to navigate into the exhibition space in a meaningful path.

Regarding the visualization of complex models on mobile devices, as the one proposed in VirtualTour, the work by Di Benedetto et al. [2] shares some similarities with our

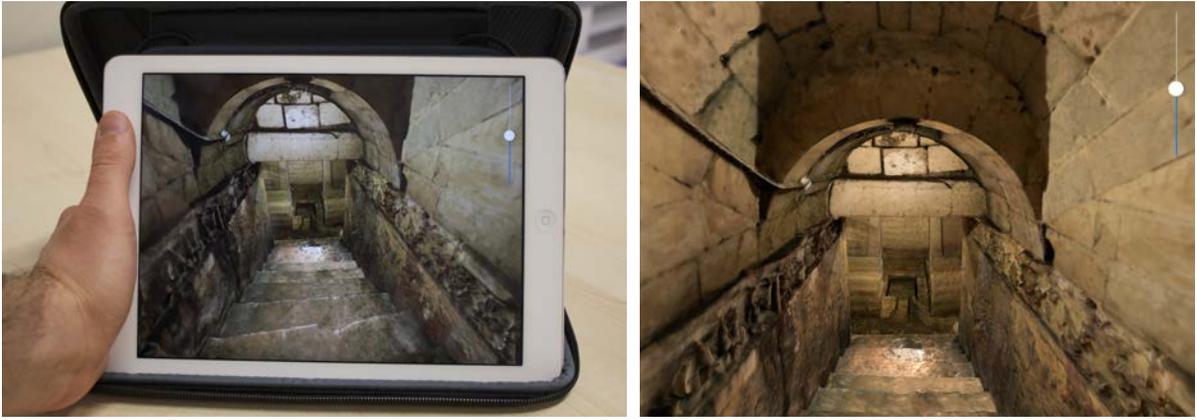


Fig. 1. An example of renderings of the Palmieri crypt: on the left side, a photograph of VirtualTour running on the first generation iPad Air. On the right side, a screenshot taken from VirtualTour.

approach. However, their navigation path is automatically computed with metrics and little control on it. This may not create a path which is relevant for a CH site exploration; i.e. connecting rooms in a path which do not share relevant features or meaning. In our system, exploring paths are manually generated with a swift interface in order to give full control to path-planner to create the most interesting visit from a cultural heritage point of view. Moreover, their solution does not exploit mobile devices sensors such as the gyroscope and the accelerometer as VirtualTour does.

III. VIRTUALTOUR

VirtualTour is our solution for easily providing a virtual visit opportunity to CH sites which are not accessible, either temporarily (e.g. a renovation/refurbishment) or permanently (e.g. the site is located in a private property or destroyed) to visitors such as tourists, students, researchers, etc. Thanks to the progress of 3D digitization technologies, producing the 3D models of the interior of a building, a church, cave or any other CH environment is nowadays quite straightforward and cheap. This is also due to the consolidation of structure-from-motion or photogrammetric acquisition technologies. Our goal is, therefore, to design an instrument, based on mobile technologies, that should allow to anyone to virtually visit a not accessible nearby CH monument. VirtualTour can be also employed for planning a visit in advance, or for re-enjoying a particular pleasant visit (but in these latter cases other VR technologies, based on the more immersive head-mounted displays could be more effective).

VirtualTour includes two main subsystems:

- Viewer3D: a real-time renderer for 3D models, specifically designed for mobile devices;
- RealMove: a navigation system which exploits the embedded sensors of mobile devices for driving the navigation interaction.

A. Viewer3D

Viewer3D is an OpenGL|ES 2.0 real-time renderer that we have developed for the iOS 7 and iOS 8 platforms. This is based on the VCG library [3]. The setup of the renderer

requires only a few lines of code and it is encapsulated inside a UIView. This makes the renderer extremely handy, because a UIView is the basic iOS widget for visualizing graphics on the screen; it can be conceived as a window in desktop systems terminology.

Once the renderer is ready, 3D models can be rendered by simply loading them and assigning a shader. Viewer3D supports different file formats, including the PLY and OBJ formats. These are the de-facto standards for 3D scanned models and 3D modeling packages, so their support is crucial in our renderer. Viewer3D allows to define different attributes over the vertices of a mesh; to encode normals, texture coordinates, colors, ambient occlusion, etc. This increases the flexibility of the system to cope with different needs.

Concerning the performances, our Viewer3D can achieve up to 60 fps while rendering a 3D model composed by 2M triangles, with a texture and using a Phong lighting shader on an iPad Air 1st gen. and an iPhone 5S (without the need of streaming from the flash memory).

B. RealMove

Supporting free navigation in a complex 3D space is quite challenging when we do not dispose of sophisticated interaction devices. Even more challenging when we have only a small screen and use a mobile instrument (where at least one hand is busy since it has to hold the device). Therefore, we need different approaches, alternative to the usual ones implemented for desktop applications.

One solution could be to reduce our capability of freely navigating the space, to simplify interaction and maximize easy of use. One solution could be to endorse a *constrained navigation* approach: if we can accept a pre-defined navigation path through our architecture, then reducing the degree of freedom in navigation has a positive impact in the management of the interface. VirtualTour endorses this approach: the user can navigate inside the virtual reconstruction along a pre-defined path (either walking forward or backwards). The use of a pre-defined path is not only justified by GUI-related reasons, but it can be also beneficial to guide the user to important areas of the virtual sites; guiding her/him and preventing her/him to get lost or stuck in areas which are not important for the

specific story-telling purposes. This saves times for the user while keeping her/him fully engaged.

Content creators, e.g. archaeologists, can create the pre-defined path inside the 3D model by placing a few waypoints in any 3D modeling tool. In our case, we extended a desktop OpenGL renderer to handle the insertion of waypoints. Then, a cubic Bézier curve is created and employed to smooth the path, e.g. in order to avoid camera orientation discontinuities during a sharp turn, see Figure 2.

The speed along the path is controlled by the user. There are two mechanisms for controlling the speed: a slider rendered in view space (standard GUI interface) and directly by walking in the real-world (natural interface).

- **Speed slider.** This is a classic GUI slider (see the top-right corner of the screenshots shown in Figure 1) that can be activated by a single finger, also while holding the tablet. Moving the slider upward means a constant forward speed (i.e. moving forward), moving the slider in the middle means zero speed (i.e. steady state, no movement), and moving it downward means a constant backward speed (i.e. moving backward).
- **Walking.** This allows to drive navigation by directly walking in the real-world. We have implemented a step-counter [4] by using the accelerometer sensor of the mobile device. Note that for achieving the best quality in step detection a user needs to provide her/his height and weight (these are requested at the start-up time of the app).

When the user has enough room, she/he can move in the real-world. At each step the step-counter is activated and it fires an impulse to the virtual speed in VirtualTour enabling a movement. This means that if the user stops to walk in the real-world, there is no movement in the virtual-world. The virtual speed can be increased for real-world places with limited room.

The above interaction modes allow to drive the dynamic change of the view location. But what about the *view direction*? Conversely to view location (that is constrained on the pre-defined path), view direction is left totally free. The user should be totally free to look in any direction, following her/his personal interest and curiosity. This is implemented very easily by endorsing the *window-over-the-world* metaphor. Our mobile device is our window over the world, so to modify the view direction the user has simply to move the mobile device (her/his virtual window) to the requested direction of view. The interface is extremely natural: if we want to see what is slightly above the current view, we have only to move in that direction the tablet/phone. Therefore, we can rotate the device in the 360 degree around our head to inspect the entire space around us. This is similar to what we do while inspecting a panoramic image. The efficient renderer enables to have no lag in producing images and the visual feedback is following smoothly the change of view. Again, we use embedded sensors for understanding how the user is moving the device in space; i.e. gyroscope and the compass.

C. A Case Study: the Palmieri Crypt

We tested our VirtualTour app to navigate the 3D scanned model of the Palmieri crypt, a Messapian tomb built in the 4th

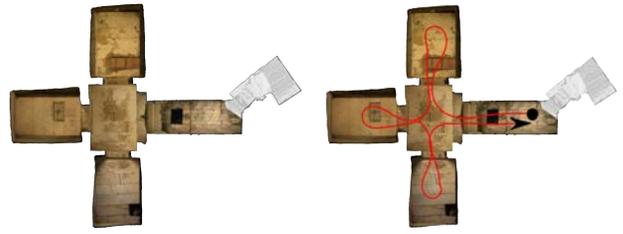


Fig. 2. A case study: On the left side the map of the Palmieri Crypt in Lecce, Italy (top-view). On the right side, the same map with the pre-defined path (in red) created by visit planners for VirtualTour.

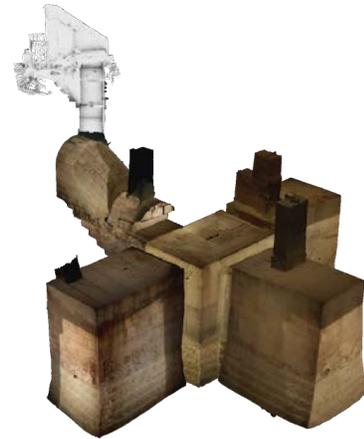


Fig. 3. An overview of the Palmieri Crypt 3D model.

century B.C. located in Lecce (Italy), see Figure 2. This burial vault is located below a garden in a private house; even if it is a masterpiece of that local civilization, it is not accessible to the public due to property and security issues. The limited accessibility of the crypt makes its case study perfect for virtual reality exploration with the VirtualTour app.

The 3D model of the Palmieri crypt was acquired by CNR-IBAM using a time-of-flight scanner together with photographs for mapping the color information of the tomb. The finalized reconstruction used for real-time visualization is around 917,000 triangles. Note that the acquisition process was performed in one of the few times when researchers had the permission to enter and work into the site. After the generation of the 3D model with color information, a global illumination solution was computed inside Cinema4D and baked into six 2048×2048 24-bit textures, see Figure 3. The resulting textured model can be rendered in real-time at around 60 fps by the Viewer3D subsystem, see Figure 1.

Although a proper evaluation has not been performed yet, we showcased VirtualTour to the public at MUST museum in Lecce. We got a positive feedback from the audience which generally enjoyed the app. In that occasion, the public was seated and the possibility to have the speed slider was appreciated.

IV. CONCLUSIONS

In this paper, we have presented VirtualTour, an app for mobile devices for exploring virtual-site leveraging on real-

world interactions. We achieved an engaging virtual exploration by exploiting the latest smartphones and tablets computational capabilities, and their sensors.

For future works, we would like to expand the interaction system. For example, it would be interesting to control the virtual environment lighting or other actions by coupling another small mobile device (e.g. a smart watch) with the main device. Another important future work would be to properly evaluate our system by running a user case study with different virtual sites.

ACKNOWLEDGMENT

We thank the anonymous reviewers for their feedback and suggestions to improve the paper. This work was supported by the EU FP7 grant 607737 (VASCO) and the PON R&C (2007-2013) Cod. PON04a2_D (DiCeT).

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