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Virtual and augmented reality for rich interaction with cultural heritage sites: A case study from the Roman Theater at Byblos

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ABSTRACT

The conservation and valorization of our cultural heritage has become one of the priorities of the international community. Accordingly, many technological applications are being developed with a cultural object as the focal theme of interest. This paper presents a detailed account of the construction of a computerized model of the Roman Theater of Byblos, one of oldest continuously inhabited cities in the world. Central to the paper is a historical study, which yielded the formation of a hypothesis on the original shape and details of the theater, which today retains very little of its original structure. Another major part of the paper is the detailed description of the procedures for the creation of both a virtual and augmented reality application of the Roman theater.

1. Introduction

The full appreciation of cultural heritage sites often presents substantial challenges to casual visitors and tourists. The partially destroyed state of these sites and the lack of contextual clues about the functions of their various spatial elements and significance of their architectural features make it difficult to interpret the sites and get a sense of their relevance and importance.

Virtual and augmented reality technologies promise to alleviate some of these difficulties by providing historically accurate reconstructions and relevant contextual information to allow for a richer and more impactful visitor experience. Users wear 3D stereo viewers and headphones, and optionally hold a control pad, to be immersed in a realistic, interactive, and much enhanced environment. In this immersive world, they can navigate or be guided through a historical site that has been augmented with virtual recreations of missing features and enhanced with narratives about the meanings and roles of its elements.

Both on-site and off-site experiences can be enriched in this way. On-site, a video stream of the actual (often partially destroyed) site can be overlaid with a virtual model that augments the heritage site to reveal missing historical elements. Off-site, a 3D replica of the actual site can be overlaid with the virtual model to recreate the historical site. This immersive first-person experience is far more engaging to the general public than a mere walk through the ruins and allows lasting impressions of artifacts, landscapes, and cultural sites to be formed.

In this paper, we report on a system developed for creating such an immersive augmented experience for the Roman Theater at Byblos. Byblos, located along the Mediterranean Sea coast at approximately forty kilometers north of the Lebanese capital Beirut, is one of the oldest continuously inhabited cities of the world. Modern scholars date back its existence to at least the Neolithic Period (around 8000–4000 BCE) (Dunand, 1954). The main characteristic of the city is the superposition of ruins belonging to a succession of civilizations spanning 7000 years of history.

Of particular interest in the Byblos archeological ruins is a Roman Theater, which dates back to the year 218 CE. Little remains of the theater and what still stands is in a poor state, which makes it very difficult for tourists to appreciate its function and its value from a simple visit. The Roman Theater is therefore a prime candidate that could benefit from technological interventions to better highlight to visitors its features, its purpose, and its appearance in the past.

A number of challenges had to be overcome in order to design and implement practical systems to allow seamless and effective user interaction with Augmented Byblos. In this paper, we describe these challenges and the solutions we developed for them. A video of a virtual tour through the augmented site is attached.

The remainder of this paper is structured as follows. Section 2

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Fig. 1. (left) Byblos Roman Theater in its current state, (right) Bacchus mosaic that was found inside the theater.

presents the methods used to generate a 3D computerized model of the existing site, Section 3 details the theoretical analysis leading to a hypothesis of the missing parts of the theater and includes a description of the developed archeological object, Section 4 discusses the development of an augmented reality application while Section 5 details its virtual reality counterpart. The paper concludes with Section 6.

2. Reconstruction of the existing Roman Theater at Byblos

The Byblos Roman Theater was discovered in the late 1920's by Archeologist Dunand, (1954). Today, as shown in Fig. 1 (left), the theater consists of the following: of the original cavea (auditorium/seating area), only the first five rows remain with seven sectors divided by stairs. The orchestra's semi-circular ground was covered with a simple white mosaic with a black border. At the center of the orchestra, there used to be a finely detailed mosaic representation of the Roman god Bacchus (also known as the Greek god Dionysus), the god of the theater. The mosaic is now in the Lebanese National Museum and is shown in Fig. 1 (right). The raised floor of the pulpitum (stage) has five niches adorning its side, each defined by two Corinthian type columns and a pediment. A stone altar that was found at the foot of the seating area opposite to the center of the stage was probably used prior to any performance in a religious ritual to obtain the blessing of the gods. Postholes along the edge of the first row of stone seats in which wooden posts could have been set: perhaps for an awning to shade the audience, or a low barrier to separate the audience from the orchestra area.

2.1. 3D computer modeling of existing structure

To generate a 3D computer model of the theater, three steps are required; namely, (1) extracting a 3D point cloud of the object, (2) fitting geometric primitives to the point cloud, and (3) texturing.

2.1.1. 3D point cloud generation

Traditionally, a 3D point cloud of a scene is extracted using 3D lasers (*e.g.*, Leica[1]); however, such equipment is prohibitively expensive and the mapping requires careful setup of the laser at different locations throughout the mapping. Alternative methods of point cloud extraction use stereo cameras or Kinect[2] systems. Stereo cameras are limited in range and the Kinect cannot be used outdoors because of the noise caused by sunlight. A 3D point cloud of a scene can alternatively be extracted using a single camera, by taking overlapping images of the same scene and estimating 3D coordinates by triangulating matched features across images. The camera motion (rotation and translation) between different viewpoints is obtained using projective geometry techniques. This entire process is known as Structure from Motion (SfM).

SfM techniques suffer from several limitations. First, SfM methods produce dense point clouds at the expense of processing time and hence are considered offline methods. Furthermore, the solutions for structure are ambiguous up to an unknown scale. Finally, as any other visual-based technique, their success relies on a critical number of detected features to succeed. In other words, SfM fails when looking at a texture-less scene such as a uniformly colored wall.

For our application, these limitations were not critical. First, time was not a factor in our application and SfM was left to iterate for several days to extract the point cloud. Second, outdoor environments (such as in archeological sites) are rich in features, which are distinctive and ideally suited for SfM solutions.

2.1.2. Mesh generation and texturing

Given a dense 3D point cloud, the standard workflow for generating the three dimensional models to be used in a virtual environment consists of (1) connecting the points to generate a three-dimensional triangle mesh that approximates the geometry. This is done by a spatial Poisson surface reconstruction algorithm that doesn't rely on heuristic spatial partitioning or blending and as a result is highly resilient to data noise; (2) decimating the dense triangular mesh to reduce it to a manageable size, from tens of millions of triangles to a few thousand representative ones preserving the original topology and a good approximation to the original geometry; (3) applying texture maps to give the geometric model a realistic visual appearance. This is conveniently done here because the texture atlas can be readily produced from the images acquired for the 3D reconstruction; (4) applying normal maps which control light reflections to allow the low polygon meshes to recover the subtle details needed for realism without an increase in polygon count.

We will not discuss the details of the algorithms of this workflow but only note that the main practical concern in the model reconstruction is to balance two conflicting demands: one is for increased realism which requires large and expensive meshes, and the other is for small meshes that can be handled at interactive rates for stereo display. Balancing these two concerns requires some trial and error.

3. Construction of the hypothetical historical model

Analyzing the existing structure and synthesizing a hypothetical model of the missing structure proved to be challenging due to the scarcity of the remains. In addition, the theater's displacement from its original position meant the need to be critical of the disposition of the stones and the preciseness of the relocation procedure, thus the challenge to align the theater with a typical, perfect, geometrical model. Nevertheless, to surmount these challenges, multiple sources were used to inform the process of reconstruction and approached the specific geometry of the remains in a critical manner. The Vitruvian model was

[1] http://lasers.leica-geosystems.com.
[2] www.xbox.com/en-GB/xbox-one/accessories/kinect-for-xbox-one.