Image-based 3D Shape Reconstruction of Byzantine and Paleochristian Monuments

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Abstract. In the last decade, visual 3D object surface reconstruction has been increasingly applied in the fields of cultural heritage preservation and archaeology. In this paper, we present a variety of state-of-the-art algorithms and commercial software used in 3D reconstruction and employ one of them for generating 3D monument surface models of some of the most popular Paleochristian and Byzantine monuments located in Thessaloniki, Greece.

Keywords: 3D Surface Reconstruction, Computer Vision, Cultural Heritage.

1 Introduction

Acquiring accurate 3D models of real-world objects has been a long-standing problem in computer vision and graphics. Over the last decade, 3D reconstruction techniques capable of capturing and reproducing the 3D object or scene shape and appearance have proven their value in a variety of scientific fields such as architecture, engineering, etc. In recent years, 3D object reconstruction has also a very positive impact in digital cultural heritage presentation and preservation. Some of its most common usages in that area are: 1) virtual museum exhibitions, 2) interaction with virtual objects, without risk of damage, 3) visualization of scenes that are restricted or impossible to reach by audiences in the real world, 4) reconstruction of historic monuments that no longer or only partially exist. Currently, there are many commercial applications in the market for reconstructing 3D scenes providing more than pleasing results.

2 Overview of 3D Reconstruction Techniques

Most 3D reconstruction techniques proposed in the corresponding literature are range-based solutions, involving the direct measurement of three-dimensional geometric information of an object using active sensors. Techniques based on structured light (Salvi, Pagès, & Batlle, 2004), (Caspi, Kiryati, & Shamir, 1998), use sensors that project a specific light pattern and extract the geometry from projection pattern on the object surface. In (Callieri, Cignoni, Dellepiane, & Scopigno, 2009), the authors use time-of-fight laser scanners and sophisticated noise-filtering techniques to generate a model of

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Florence's Statue of Neptune. Other methods use triangulation-based sensors. In most cases, a laser beam is projected on the surface to be scanned and after its reflection, the beam is captured by a camera. The point of reflection, the camera and the laser emitter form a triangle. The distance between the camera and the laser emitter, which is the one side of the triangle is known. The angle of the laser emitter corner is also known. The angle of the camera corner can be determined by looking at the location of the reflection point in the camera's field of view. The location of the point of the reflection can be calculated using these pieces of information and basic laws of trigonometry. These methods provide exceptional precision and they have been adopted in several digital preservation missions (Vrubel, Bellon, & Silva, 2009), (Arbace, et al., 2013).

Though range-based techniques provide shapes with a high level of detail and accuracy, they usually suffer from low level of automation and high costs. Image-based methods provide an alternative solution capable of producing at times realistic models with comparable level of detail. The automation comes mainly from the implementation of "Structure from Motion" (SfM) and "Multi-View Stereo" (MVS) algorithms. The baseline SfM algorithm consists of: 1) feature extraction, 2) feature matching, 3) triangulation and bundle adjustment. Feature extractors such as SIFT (Lowe, 2004) and SURF (Bay, Ess, Tuytelaars, & Gool, 2008) are used for feature extraction and their matching in images taken from different viewpoints or images that differ only in terms of scale and illumination. Triangulation and bundle adjustment (Triggs, McLauchlan, Hartley, & Fitzgibbon, 2000), (Engels, Stewenius, & and Nister, 2006) methods are the final steps for estimating the camera parameters and create an accurate point cloud of the scene. Given the estimated camera parameters, MVS techniques (Furukawa & Hernández, 2015) are optionally followed to make the point cloud more dense. Finally, surface reconstruction algorithms (Boissonnat, 1984), (Bolitho, Kazhdan, Burns, & Hoppe, 2007) use the point cloud to create polygonal surfaces. Mapping generated textures is a common practice for coloring these surfaces. Some popular commercial software performing image-based 3D reconstruction are PhotoScan[1], 3DF Zephyr[2], Smart3DCapture[3], 123D Catch[4], etc.

3 Proposed Approach

Among the different solutions that have been proposed for 3D object surface reconstruction in the corresponding literature, we decided that the most approachable are the ones that are based on RGB images. In addition, due to the difficulties and costs of setting a network of calibrated cameras around a monument, we selected 3DF Zephyr, a commercial software that performs state-of-the-art 3D reconstruction using uncalibrated images based on the principles of SfM and MVS. We examine and evaluate image-based 3D reconstruction on three Paleochristian and Byzantine monuments of Thessaloniki using two variations, as far as data collection is concerned.

[1] PhotoScan, Agisoft, http://www.agisoft.ru
[2] 3DF Zephyr, 3DFlow https://www.3dflow.net/
[3] Smart3DCapture, Acute3D http://www.acute3d.com/smart3dcapture
[4] 123D Catch, Autodesk, http://www.123dapp.com/catch

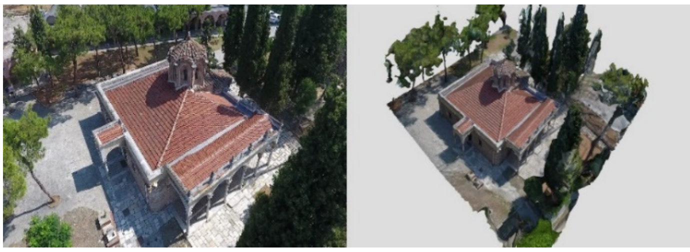
a)  b)

Fig. 1. The Vlatadon monastery. (a) An RGB image captured from a drone. (b) Visualization of the 3D reconstructed model is shown.

3.1 3D Reconstruction Using Images from Drones

For this task we selected two of the fifteen Paleochristian and Byzantine monuments of Thessaloniki that were included in the UNESCO World Heritage List in 1988. The first is the Vladaton monastery. It was founded between 1351 and 1371 AD by the empress Anna Palaiologina along with the monks Dorotheus and Markos Vlatis. Only the catholicon survives, from its original structure. The second selected monument is the church of Saint Nicholas Orphanos. Based on its interior decoration, the church was built at the beginning of the 14th century during the Paleologian period of the Byzantine Empire and it used to be a catholicon of an older Byzantine monastery.

Collecting images in both monuments consisted of mostly orbiting a drone around them at different heights, respecting always the corresponding flight regulations. However, these regulations, along with avoiding collisions with nearby objects (trees, buildings, etc.), would had a negative impact in capturing the close-by details of each monument. For that reason, we collected additional images from ground cameras, solving this problem partially.

a)  b)

Fig. 2. The church of Saint Nicholas Orphanos. (a) An RGB image captured from a drone. (b) Visualization of the 3D reconstructed model.

Overall, 3DF Zephyr was capable of handling the size of the collected images creating a visually pleasing result. Still, we managed to minimize the software processing time and improve the 3D model quality, by selecting images manually from the collection, rather than feeding the software with the entire footage. In addition, masking out-ofinterest regions with the software provided tool had a positive impact too. Images captured from drones and used in 3D reconstruction along with images of the corresponding generated 3D models are shown in Fig. 1 and Fig. 2.

3.2 3D Reconstruction Using Images from Google Maps/Earth

For this task we selected Rotunda, another monument of the fifteen Paleochristian and Byzantine monuments of Thessaloniki, which is also included in the UNESCO World Heritage List. Rotunda was constructed in the beginning of the fourth century, on the turning point between the pagan with the Christian world, probably intended to be used either as a mausoleum for Galerius or as a temple dedicated to some ancient God. Not long after it was built and during the years of Byzantine Empire, Rotunda was turned into a Christian church. In 1430 AD the Ottomans conquered Thessaloniki and in 1590 AD Rotunda became a mosque in service until the city liberation in 1912 AD.

The 3D reconstruction of Rotunda was made as a plan of extracting simple models with relative low-level of detail, using the minimum available resources, without using self-collected images either from the ground or from drones. For this purpose, we imported images of the monument publicly available on the Internet. Our main source was Google Maps/Earth. We followed the same technique in collecting images that is used in 3D reconstruction shooting missions, which is capturing Rotunda structure from many viewpoints and angles as possible. Images of the model that we managed to create are shown in Fig. 3.

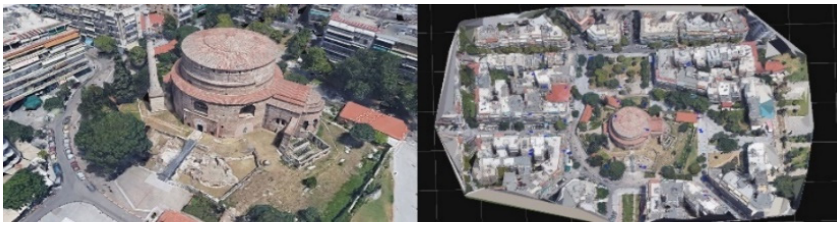


Fig. 3. Visualization of Rotunda 3D reconstructed model from different viewpoints.

4 Conclusion

In this paper, we examined different approaches used for 3D monument reconstruction. By deploying a state-of-the-art commercial software, we managed to generate models of some Paleochristian and Byzantine monuments located in Thessaloniki following two different approaches regarding visual input data. The results, generated with the purpose of simple visualization, were very pleasing.

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