Journal of Cultural Heritage 15 (2014) 73–79

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Case study

Multi-image 3D reconstruction data evaluation

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ARTICLE INFO

Article history:
Received 9 October 2012
Accepted 10 December 2012
Available online 18 January 2013

Keywords:
3D range scanning
Structure-From-Motion
Dense multi-view 3D reconstruction
Total station survey
3D data comparison
Unmanned aerial vehicle

ABSTRACT

A number of software solutions based on the Structure-From-Motion (SFM) and Dense Multi-View 3D Reconstruction (DMVR) algorithms have been made recently available. They allow the production of high quality 3D models by using unordered image collections that depict a scene or an object from different viewpoints. In this work, we question the quality of the data produced by a commercial SFM-DMVR software. An Ottoman monument located in the region of Xanthi, Greece has been selected as a case study. We attempted to quantify the quality of the SFM-DMVR data in relation to the data produced by a Time-of-Flight terrestrial 3D range scanner. We have implemented a number of comparisons between different parts of the monument in order to assess the mesh deviations and the reconstruction's accuracy. In order to further ensure the validity of our evaluation phase, we performed additional distance measurements between feature points on the monument's surface by using a total station and empirical measurements. The applicability of the SFM-DMVR method was questioned by creating a complete 3D digital replica of the monument.

1. Research aims

In this work, we are evaluating the accuracy of the data produced by a multi-image 3D reconstruction technique that is of a lower cost in terms of hardware requirements, knowledge background and man-hours when compared with 3D range scanning. For the produced data evaluation, we have performed the 3D digitisation of the same monument with other methods such as terrestrial 3D laser scanning, total station surveying and empirical measurements. We compared the data produced by each method in terms of surface deviation and distance measurements accuracy. The main aim of our research is to objectively quantify the quality of the 3D model produced by the image-based method, to evaluate the methods applicability in a real case scenario and to provide objective evaluation indicators regarding the advantages and limitations of the image-based 3D reconstruction method.

2. Introduction

The use of 3D content derived from the cultural heritage domain has dramatically increased over the last decade. At present, a number of initiatives in the form of research and development projects are focused on establishing 3D documentation as an affordable, practical and effective mechanism that allows the content enrichment of cultural heritage digital libraries with 3D digital replicas [1–3]. Nowadays, 3D digitisation is considered as a common practice in the cultural heritage domain [4]. Most of the currently available hardware solutions produce high quality results. However, they introduce an increase in project's budget not only because of the equipment involved but also because of the data processing procedures that require advanced knowledge in areas such as terrestrial surveying and 3D data processing [5,6]. A cost-effective and efficient way in terms of hardware requirements, knowledge background and man-hours for producing high quality 3D digital replicas of real world objects is always a prerequisite for a digitisation project.

In this paper, we discuss the idea of replacing a 3D range scanner with a digital camera and a commercial software solution that implements the Structure-From-Motion (SFM) and Dense Multi-View 3D Reconstruction (DMVR) algorithms. We have selected Agisoft PhotoScan [7] as one of the major commercial SFM-DMVR representatives currently available. We consider the software as an

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1296-2074/$ – see front matter
http://dx.doi.org/10.1016/j.culher.2012.12.003

all-to-one software solution for the production of digital 3D replicas of monuments. We assess the applicability of the method by creating a complete exterior 3D model of a monument using both terrestrial and aerial photography. We evaluate the quality of the resulted 3D mesh by comparing it against the data captured by other methods such as terrestrial 3D laser scanning, total station surveying and empirical measurements.

The rest of this paper is organised as follows. In Section 2, we describe some of the major SFM-DMVR software solutions that are currently available along with references to related works that also attempt to provide suggestions of the method's applicability. In Section 3, we give a historical outline of the monument and we continue by describing the digitisation procedures being followed. In Section 4, we discuss the 3D reconstruction procedure and Section 5 presents the data comparison and evaluation results. We conclude in Section 6 by outlining the important findings.

3. Related work

A number of software solutions, implementing the Structure-From-Motion (SFM) and Dense Multi-View 3D Reconstruction (DMVR) algorithms from image collections have been made available to the broad public over the last years. The SFM method uses a number of unordered images that depict a static scene or an object from arbitrary viewpoints and attempts to recover camera parameters and a sparse point cloud that represents the 3D geometry of a scene. The method mainly[1] uses the corresponding features, which are shared between different images that depict overlapping areas, to calculate the intrinsic and extrinsic parameters of the camera [8]. Many systems involve the bundle adjustment method in order to improve the accuracy of calculating the camera trajectory, to minimize the projection error and also to prevent the error-built up of the camera tracking [9]. Snavely et al. proposed a method that allows the exploration of images that have been organised in 3D space by using Bundler, an open source SFM system [10,11]. A similar Web-based system is being currently offered by Microsoft [12].

Furthermore, Wu et al. have recently developed a version of bundle adjustment that uses hardware parallelism [13,14]. Their software also integrates the work presented by Furukawa et al. that is able to ignore non-rigid objects (e.g. passing pedestrians) [15]. The EU funded project 3D-COFORM has implemented an SFM-DMVR system as a Web-service [16]. Comparable systems have been created by Autodesk [17], Viztu Technologies [18] and Acute3D [19].

In addition, companies offer multi-image-based 3D reconstruction solutions as standalone applications. Eos Systems Inc. offers PhotoModeler Scanner [20]. The software is able to reconstruct the content of an image collection as a 3D dense point cloud with the help of photogrammetric targets. Towards the same direction, Agisoft offers PhotoScan [7]. This software solution can merge the independent depth maps of all images and produce a single vertex painted point cloud that can be converted to a triangulated 3D mesh of different densities. Moreover, Pix4D developed the Pix4UAV software that is able to create 3D digital elevation models from image collections captured by UAVs [21].

As the popularity of such 3D reconstruction solutions is being increased, several authors are attempting to evaluate the quality of the produced data. Neitzel et al. [22] and R. Opitz et al. [23] have questioned the quality and performance of some of the above software solutions in creating 3D digital elevation models. Jeroen De Reu et al. [24] and M. Doneus et al. [25] have demonstrated the use of Agisoft PhotoScan as a cost-effective method for the recording of archaeological excavations while Nguyen et al. [26] have subjectively compared the results produced by their own SFM-DMVR system against some of the previously described systems.

4. 3D digitisation session of the Ottoman monument

In this section, we provide some historic information about the monument and we describe the data collection procedures that have been followed and the equipment being used.

4.1. Case study: the Kioutouklou Baba Bekctashic Tekke

The monument is located in the middle of a cultivable area on the west coast of the Vistonida lake in Xanthi, Greece. It is considered as one of the most important Ottoman monuments in the area and it may have been built in the late 15th century. It was possibly built on the ruins of an Orthodox Christian temple that was dedicated to Saint George Kalamitziotis [27], while for the Muslims it is considered as the grave of a Whirling Dervishe, named Kioutouklou Baba [28]. According to Lowry [28] the term *tekke* (gathering place for Dervishes) is erroneous as the monument is a tomb (*türbe*).

4.2. Collecting data

The fieldwork was separated into five sessions. The first two involved the terrestrial and aerial photo shooting of the monument. Then, the terrestrial 3D laser scanning session took place followed by the total station survey and the empirical measurements session.

For the terrestrial photo shooting session a DSLR Nikon D40 at 6.1 MP with an 18–55 mm lens along with a tripod have been used. On the other hand, for the aerial photo shooting session, a remote controlled helicopter has been used. The UAV was equipped with a three axis pan-tilt-roll remote controlled camera head (360° on the horizontal axis, 220° on the vertical axis and a rolling ability of 60°). A DSLR Canon EOS350d at 8.1MP with an 18–55 mm lens has been used for the aerial photo shooting session. The total number of photographs that has been used for the generation of the 3D model of the monument was 652 (469 terrestrial photos and 183 aerial photos). The average distance of the camera from the monument's surface was estimated at 4 m.

Furthermore, an Optec Ilris-3_6D time-of-flight range scanner has been used [29]. The system's specifications indicate a minimum distance of 3 m between the scanner and the surface to be scanned. The system offers 7 mm standard deviation error for measurements implemented at a hundred meters distance and a 2 cm maximum distance between two sequential points at a thousand meters distance. The integrated digital camera of the scanner has a 3.1 MP CCD sensor but the colour quality is considered to be poor when compared with similar systems.

A total of 24 partial scans were captured. The average distance from the monument was 16.55 m while the average distance between two consecutive points was 1.37 cm. A complete digitisation of the monument using the range scanner was not achieved. Scaffolding constructions was necessary in order to capture the top of the monument and this was out of the scope and breadth of this work. Nevertheless, the range scans covered both high and low-curvature areas that were enough for validating the quality of the data produced by PhotoScan.

In addition, a number of distinct and visibly strong feature points on the surface of the monument were selected. These points had a random spatial distribution on the surface of the monument. A total of 33 points were measured using a Topcon GPT-3005 N total station [30].

Finally, the empirical measurements session involved the measurement of short distances between several details on the surface

[1] There are SFM methods in the literature which do not rely on the corresponding information [36].