3D PHOTOREALISTIC MODELLING OF STONE MONUMENTS BY DENSE IMAGE MATCHING

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ABSTRACT:

In this paper we present a methodology to derive accurate 3D photo models of a World Heritage site by means of close range photogrammetry. A freestanding monument inside the Petra Archaeological Park in Jordan close to the gate, the Djin Block No. 9, is chosen to determine the benefits of standalone dense image matching techniques to build up photorealistic models in 3D. 16 colour images acquired with a Canon EOS 1Ds Mark III digital camera are used to generate the photorealistic model. Processing starts after carrying out a self-calibration bundle block adjustment. Ground control points are used to scale and rotate the solution. Dense image matching constrained to the epipolar geometry without resampling the original images is used to determine the colour point clouds. Different parameters are analysed for matching as well as different thresholds for filtering. The point clouds are triangulated to eventually build up a TIN model. Finally, accurate texturing with Z-buffer techniques follows to provide colour information to the 3D model. The presented approach is suitable for off-the-self digital cameras and yields highly accurate 3D photorealistic models with multiple overlapping images taken around the monument. The image-based methodology presented herein with the SLR digital camera can be considered either a serious alternative to other much more expensive approaches based on range-based devices (e.g. terrestrial laser scanners) or a complement to record cultural heritage.

1. INTRODUCTION

3D modelling is a challenge in both photogrammetry and computer vision when dealing with complex objects and sites. Moreover, rigorous 3D modelling requires no extrapolation of data sets. It means that the project has to be carefully planned and executed independently of the surveying techniques and methods to document the archaeological site.

With the progressive introduction of active techniques such as the terrestrial laser scanning for the documentation of cultural heritage in the last decade, there is a general trend of replacing image-based photogrammetry by range-based photogrammetry. It can be quickly scrutinised after checking the large amount of papers dealing with laser scanning not only in scientific meetings but also in journals.

Integration of both laser scanning and image-based photogrammetry is recommended to get highly accurate texturing in archaeological documentation (Al-kheder et al, 2009; Navarro et al, 2009; Lerma et al, 2010), not only with visible images but also with thermal infrared images (Cabrelles et al, 2009).

There are places and sites around the world where it is hardly recommended to carry heavy, large or even expensive equipment. However, digital cameras are extremely portable and easy to use. This paper addresses the topic of 3D photorealistic modelling of a freestanding cube-shaped monument inside the Petra Archaeological Park, the Djin Block No. 9 (Fig. 1) not only because of its weathering condition

(Akasheh et al, 2005) but also because it has been photo-textured previously in 3D (Cabrelles et al, 2009; Navarro et al, 2009). A comparative study will report in the future the differences achieved between the integrated approach with laser scanning and photogrammetric texturing, and the standalone image-based photogrammetric approach with dense image matching.

Figure 1. View from the West of the Djin Block No. 9 (Petra)

2. METHODOLOGY

The presented approach follows seven steps:
1. Data acquisition on site, mainly imagery and ground control points.

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2. Self-calibration bundle adjustment of the block of imagery.

3. 3D transformation of the results achieved in Step 2 to the reference frame defined by the ground control points.

4. Dense image matching.

5. Filtering of outliers or gross errors.

6. Meshing.

7. Texturing.

All the computations from Step 2 up to 7 are performed with our in-house photogrammetric FotoGIFLE software.

2.1 Data acquisition

A total of 16 colour images were collected, including normal and convergent imagery, as well 4 stereo pairs for the 4 sides of the tomb and 1 additional for the top (Fig. 2).
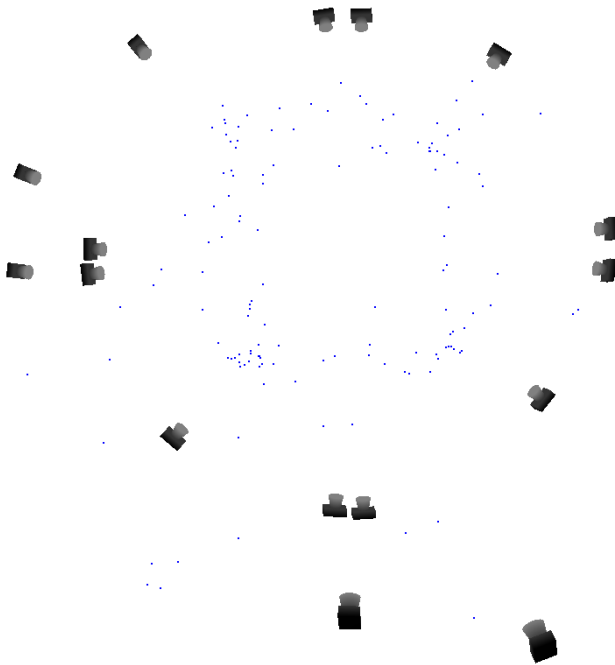

Figure 2. Camera shots around the monument

Images were taken considering that two photogrammetric steps were going to be carried out to yield the 3D point clouds of the Djin Block No. 9: on the one hand, self-calibration bundle adjustment; on the other, stereo image matching. In addition, 6 ground control points were measured to transfer the scale and the orientation of the tomb in object space.

2.2 Self-calibration bundle adjustment

To achieve maximum reliability in the results, the whole block of images is adjusted using the well-known self-calibration bundle adjustment method. The number of observations is 1393 and the number of unknowns 538 for the 16 images and 145 tie points. The RMS values of the image coordinates are 0.35 for x and 0.47 for y. The solution included 7 additional parameters (2 principal point offsets, 1 principal distance, 3 radial distortion parameters and 1 decentring distortion parameter) for the digital camera Canon 1Ds Mark III with Sigma lens 15-30 mm at 15 mm.

2.3 3D transformation

Once determine the relative orientation of the whole block of images, 6 ground control points around the tomb are identified to determine the 3D transformation that eventually will allow us to compare the present results with previous and/or future ones. Table 1 displays the discrepancies achieved in object space.

Point	ΔX	ΔY	ΔZ
5011	0.010	-0.011	-0.016
5013	0.001	-0.011	-0.011
5000	-0.006	0.008	0.008
5014	-0.001	-0.002	0.007
5008	0.001	0.006	0.018
5010	-0.005	0.011	-0.006

Table 1. Object space discrepancies achieved after the 3D similarity transformation

2.4 Dense image matching

Once all the parameters are in the same reference system defined by the ground control points, dense stereo matching is used to recover the surface of the tomb from the stereo pairs. The output of the image matching is normally a dense point cloud for the requested area; it can also be used to determine a depth map (Schouteden et al, 2001). It can be the whole overlapping area or just a small piece that can be used to determine the right set of parameters for the matching (Fig. 3). In addition, the area of interest can be interactively selected in order to speed up the matching.

Figure 3. Stereo pair with the selected area for matching on the left image (top)

Candidates for conjugate features between images fulfil at least two criteria: first, cross-correlation coefficient above a

predefined threshold; second, distance to the epipolar constraint bellow a predefined threshold (Heipke, 1997). Fig. 4 displays the point cloud output corresponding to the area of interest selected in Fig. 3.

The ill-conditioned problem of matching has to be always present. There exist alternatives to reduce the effect of matching ambiguities or wrong conjugate features such as the ordering, the parallax and the gradient of parallax constraints. Furthermore, the pyramidal estimation scheme is highly recommended to deal with large disparities.

2.5 Filtering of outliers or gross errors

Due to the aforementioned problem of the ill-conditioned matching, filtering is required to delete wrong estimates i.e. 3D coordinates in object space.

In the approach presented herein two threshold filters are applied: first, a distance filter that is used to delete points away the main surface; second, an angular filter to delete points away the parallax angle. Table 2 displays the results achieved after different set ups; only the reference (template) window was changed.

Template Window	Conjugate features (#)	After filtering (#)	Removal (%)
5 x 5	7836	6188	21,0
11 x 11	10380	10071	3,0
17 x 17	11501	11411	0,8
23 x 23	10789	10734	0,5

Table 2. Percentage of conjugate features deleted after filtering

A grid of 1 cm in object space is selected for the surface representation of the area selected in Fig. 3. Fig. 4 displays the resulting effect of applying the two threshold filters on the selected area for the 17 x 17 template window. It is worth mentioning the removal of a large number of features with outliers and gross errors.
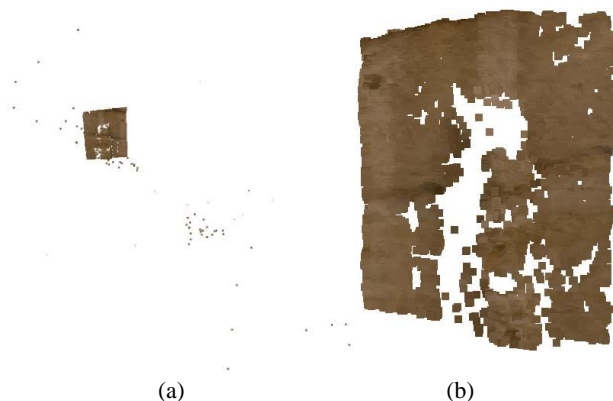

(a)   (b)

Figure 4. Coloured point cloud: a) Original; b) Filtered

2.6 Meshing

Meshing is the next step used to cover the whole 3D model of the monument. A triangulated irregular network (TIN) following a Delaunay triangulation was used to cover the whole Djin Block No. 9. Fig. 5 shows the results of the TIN mesh. As the area is on top of the monument, there exist a large amount of unfilled triangles as well as occlusions from only one stereo

pair. It could be solved either using more stereo pairs from different attitudes, or using wide-baseline setups (Helmut, 2008).
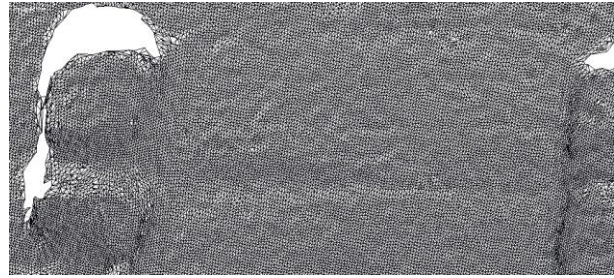
(a)

(b)

Figure 5. 3D model: a) Wireframe; b) With lights on

2.7 Photorealistic texturing

A 3D photo model is an object model where the texture information is taken from images (Dorffner and Forkert, 1998). Photo models are also known as photorealistic models. The visibility analysis should always be performed in order to determine which triangles are intersected by the rays between each raster point and the projection centre. The visibility analysis applied herein follows the ZI-buffer approach (Lerma et al, 2010). Fig. 6 displays a close-up view of the Djin Block No. 9 whereas Fig. 7 displays a general view of the high resolution 3D photo model.

Figure 6. Close-up view of the photorealistic model

Figure 7. Photorealistic model of the North and East sides of the Djin Block No. 9

3. CONCLUSIONS

The image-based photogrammetric is suitable for off-the-self digital cameras and yields maximum quality with multiple overlapping images taken around the monument. It requires good estimates for both the interior and the exterior orientation parameters. Results show that it is possible, on the one hand, to build up highly accurate 3D models with conventional cameras (without any need to carry heavy and expensive equipment), on the other, to drape high quality textures from the most convenient positions around the monument.

The photogrammetric approach based on imagery acquired with digital cameras can be considered a serious alternative to other much more expensive approaches mainly based on range-based devices such as terrestrial laser scanners. It can be successfully used to record archaeological monuments and sites. On the other hand, it can also be used to complement 3D projects that might mainly require laser scanning as a first choice.

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