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EXPERIENCES IN PHOTOGRAMMETRIC ARCHAEOLOGICAL RECORDING

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ABSTRACT

Photogrammetric textured representations of archaeological sites, and above all orthorectification, combine geometric accuracy with visual detail (regarding damage or decay), thus providing a suitable basis for conservation. Yet, orthoprojection in archaeology still poses difficult problems. At the examples of two ancient Greek sites, certain issues are discussed and illustrated. First, in most cases sites need to be recorded from considerable heights above ground with special low-cost camera platforms (balloon, modified fishing-rod etc.). A usual consequence of 'unstable' camera elevators is poor control over image rotations, responsible for irregular strip geometry; bundle adjustment is further complicated by unknown interior orientation of lightweight non-metric cameras and strong distortions of wide-angle lenses. A second crucial aspect dealt with here is the authors' approach for precise surface modeling to ensure products of both geometric accuracy and high iconic quality; this entails surface description through a careful combination of breaklines and densely sampled spot elevations for handling edges and surface discontinuities. Regarding laser scanning, now being extensively tried in the context of archaeology, experiments carried out here confirmed that it could indeed replace tedious photogrammetric 3D modeling in several cases. However, it is rather clear that laser scanning cannot in fact totally replace photogrammetric modeling. This is due not only to problems posed by shape, size, location and surroundings of many archaeological objects, but also to problems emerging mainly with respect to edges. It is concluded that simple means of image acquisition and careful photogrammetric handling can produce results of high geometric and visual quality, while tiresome photogrammetric modeling can partly (but sometimes cannot) be replaced by laser scanning. Functional synergy of the two approaches is a delicate matter to be further investigated.

1. INTRODUCTION

Among deliverables required by most archaeological services, line drawings now face an ever-growing competition from raster products, notably orthomosaics, which are now a standard photogrammetric product. Indeed, these constitute powerful textured representations, combining geometric accuracy with a wealth of detail, suitable for conservation and restoration planning. But archaeological orthoimaging has its own peculiar aspects when compared to its conventional aerial counterpart, as recently outlined by Mavromati et al. (2002) based on experiences from the collaboration with the Greek Ministry of Culture.

Summarily put, archaeological sites generally need to be recorded from above or horizontally using a raised camera. According to location – densely built areas, sites accessible only on foot – and often under constraints of poor financial resources, flexible low-cost camera platforms must be devised to meet a variety of conditions (Karras et al., 1999; Mavromati et al., 2002). Even if monitors are adapted to cameras, however, such inherently 'unstable' elevators do not allow full control over image tilts, being thus responsible for irregular strip/block geometry. The same is true for imaging distances and resulting scale variations, further aggravated by large object extensions in depth (these also cause strong differences in perspective between adjacent images). Furthermore, mainly ordinary light non-metric cameras, of small or medium format, are used in this context. The unknown interior orientation and considerable distortion of wide-angle lenses, usually used in these cases, add to the typical difficulties facing phototriangulation tasks in archaeology. At least to the authors' experience, archaeological recording under such circumstances appears as a rather 'generic' photogrammetric problem.

Not least, of course, among the peculiarities of archaeological recording one meets precise 3D surface modeling to ensure geometric accuracy and visual quality of results. Not only a prerequisite for orthoprojection, accurate 3D modeling also provides useful information on morphology or deformation, being a tool in its own right in evaluation and restoration processes. Unlike several architectural items, shape of archaeological objects may often be very irregular (one is tempted to say 'arbitrary'), distinguished by extreme changes in relief, 'breaks', 'ridges', edges or discontinuities, a substantial part of which have been caused by damage. This entails modeling of surface patches almost perpendicular to each other or strongly protruding structures. Surface triangulation, under these circumstances, is a highly crucial issue. The authors discuss and illustrate their photogrammetric approach in this respect (see also Mavromati et al., 2002).

Of course, photogrammetric surface point collection is mostly a tedious manual task, as automatic DSM generation in archaeology still remains an open question (Baratin et al., 2000). Laser scanning, on the other hand, is a powerful technology, capable of collecting vast numbers of surface points in far shorter times, and can thus provide the 3D support for orthoprojection (Monti et al., 2002). However, apart from the high cost and the obvious difficulties (large volume of data, difficult to manage; noise), a laser scanning approach faces problems of post-processing for creating triangulated meshes suitable for the existing orthophoto software (Böhler et al., 2001; Balletti & Guerra, 2002); perhaps the question of surface discontinuities is, among these, the most important (e.g. Boccardo & Comoglio, 2000). And besides, not every archaeological site is accessible to laser scanners as it may be to photography.

The aspects of archaeological orthoimaging, referred to above, are discussed and illustrated at the examples of two Greek sites.

2. BUNDLE ADJUSTMENT

As also outlined in Mavromati et al. (2002), this is a key issue in archaeological orthoimaging, irrespective of the mode of 3D modeling. For reasons mentioned above, recovering reliable exterior orientation parameters may well not be a trivial task. Regarding interior orientation, full self-calibrating bundle adjustment may often be infeasible, mainly due to limited extension in object depth but also unfavourable strip geometry or inaccuracy and low identifiability of control points (mostly simple natural detail points). On the other hand, full pre-calibration may not be always practicable, particularly if different non-metric cameras are being used (as in the case of the Department of Surveying & Photogrammetry of the Greek Ministry of Culture).

Karras & Mavromati (2001) have indicated that, in most cases, employment of the ‘nominal’ camera parameters (ignore principal point of analogue cameras; use nominal focal length as the camera constant) does not considerably affect accuracy. But this is not so for radial lens distortion, especially of the wide-angle lenses. Typically, the authors pre-estimate distortion separately, by line fitting to distorted straight linear features; this correction has consistently yielded satisfactory results and may even treble accuracy (Karras & Mavromati, 2001).

A first task presented here was to record a 180 m long façade of the ancient Greek castle in Aigosthena (~300 B.C), severely damaged by the 1981 earthquake. Because it is situated on a steep rock surrounded by trees, horizontal recording was made using a raised medium format Fuji camera with a 45 mm wide-angle lens (Fig. 1). The object consisted chiefly of planar surfaces, developments of which were finally mosaicked. Yet a certain part showed considerable depth, thus requiring orthorectification (cf. Fig. 5). Photogrammetric 3D modeling was inevitable, as under the circumstances it was not possible to employ a laser scanner. Based on 6 images (mean scale 1:300), the mean RMS error of bundle adjustment in XYZ for the 68 control points was 1.3 cm (2.1 cm without correction of distortion).

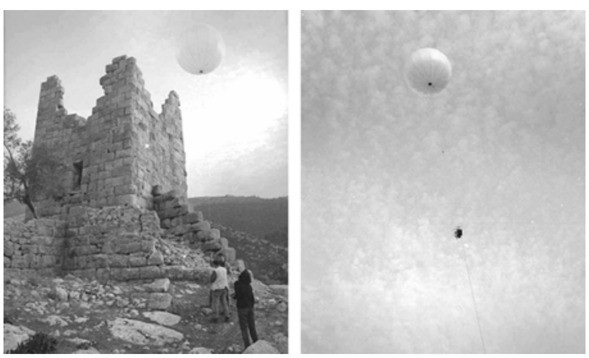

Figure 1. The meteorological balloon at the Aigosthena Castle.

The results are indeed satisfactory (radial distortion of the particular lens was rather small). Other aspects of successful adjustment are outlined in Mavromati et al. (2002), notably problems due to poor adherence to flight planning resulting in demanding image geometry. As shown in Fig. 2, in both vertical (Karras et al., 1999) and horizontal photography rotations about the vertical axis are the least controllable. Image recording on a mildly windy day in February produced large ϕ-tilts up to 15° (Fig. 3).

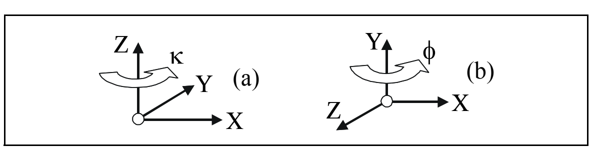

Figure 2. Critical rotations (a: vertical, b: horizontal images).

In such situations, rather small stereo-bases are needed to secure adequate overlap, along with ample control and tie points, measured carefully on the image with its strong perspective distortions due to surface relief and image tilt. Differences in imaging distances are also to be kept within certain tolerances. Besides, dense recordings are necessary also for avoiding occlusions and ensuring the required photo-texture; in fact, here all six images have been actually used in the process of orthorectification.

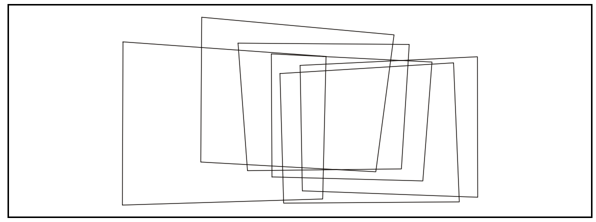

Figure 3. Footprints of the six horizontal images.

3. GENERATION OF 3D SURFACE MODELS

Locally imprecise description of complex surfaces causes ‘eroding’, ‘stretching’ and ‘melting’ effects on the resampled images. Most commercial software, as the one used here, describe object surface as a 2.5D DSM, i.e. with a single elevation value at each planimetric location (fully 3D description requires special software; e.g. Knyaz & Zheltov, 2000). Thus, photogrammetrically collected heights and breaklines are typically integrated by a 2D Delaunay triangulation into a surface mesh. In our experience, a most usual problem in archaeological orthoimaging is modeling surfaces almost orthogonal to each other (formation of ‘vertical’ triangles). In such cases, the software must be ‘assisted’ by suitable collection.

As a protection against ‘arbitrary’ triangulation, Mavromati et al. (2002) have reported on a collection scheme depicted in Fig. 4. For each segment d of a breakline, representing the top edge, three points are collected at the bottom: two correspond to its endpoints (A, C) and one (B) is close to its middle. Though unquestionably tedious, this process ‘forces’ triangle formation to adapt itself faithfully to surface form.

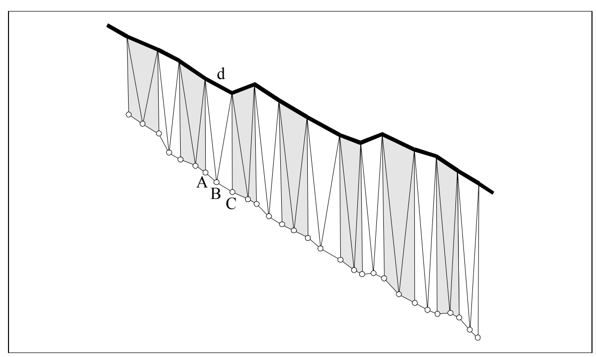

Figure 4. Breakline and points forming ‘vertical’ triangles.

Figure 5. Initial image and partial view of the shaded model.

In Fig. 5 the initial image shows the morphology of the object; also, a partial view of the 3D model is also seen. It is clearly observed that surface edges have been faithfully modeled to ensure geometrically correct orthoprojection. Examples of orthoimages of two 'arches' are presented in Fig. 6, along with the original images. Perspective deformations have been removed, thanks to the adopted modeling scheme. Finally, Fig. 7 gives the full 3D model of the area and the resulting orthomosaic.

Figure 6. Images (left) and corresponding orthoimages (right).

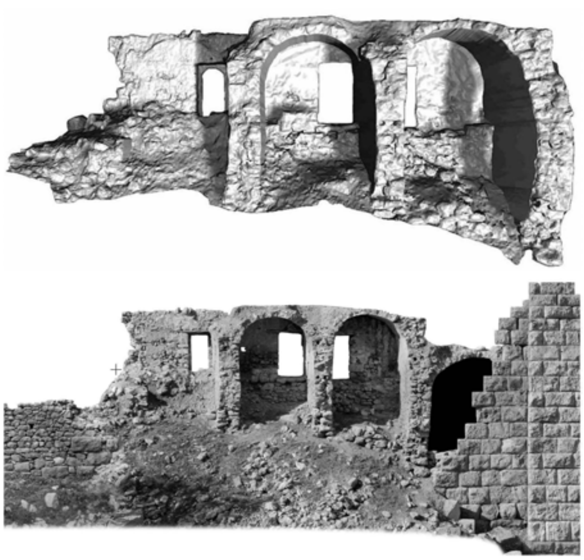

Figure 7. Shaded 3D photogrammetric model and orthomosaic.

These examples, also founded on the experiences from previous projects presented in Mavromati et al. (2002), indicate that the adopted strategy is suitable for geometric image transformations of both geometric accuracy and visual quality. As pointed out above, object location and surroundings actually ruled out any thought of experimenting here with laser scanning. To this end, a site was surveyed which had already been fully mapped photogrammetrically (Karras et al., 1999; Mavromati et al., 2002).

4. EXPERIMENTS WITH LASER SCANNING

For this archaic site in Athens, 7 images were chosen which had been acquired vertically with a small format camera and 28 mm lens (scale 1:1100). The mean RMS error in XYZ for 100 control points was 3.7 cm (five times smaller than that of the solution without correction of lens distortion). The site has very irregular relief with successive vertical 'falls' and a marked slope. Photogrammetric point and breakline collection was performed in the mode described above. The resulting surface model and the orthomosaic were very satisfactory indeed. In Fig. 8 one can see a shaded view of the 3D model.

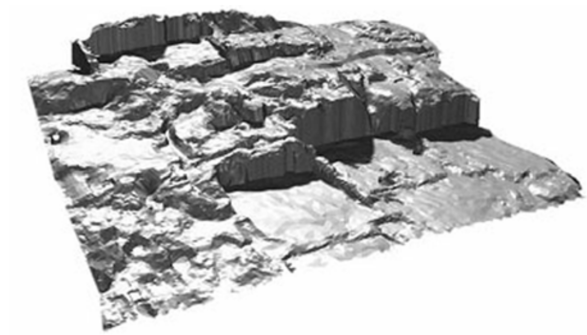

Figure 8. Part of the shaded 3D photogrammetric model.

Fig. 9 shows an image of the object together with a further view of the shaded model showing the success of reconstruction.

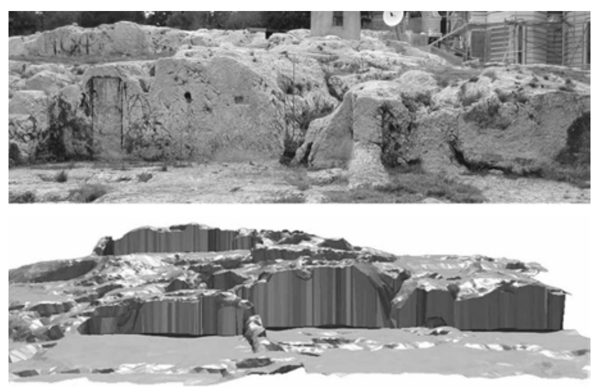

Figure 9. View of the object and shaded 3D model.

The site was surveyed using a CYRAX 2500 scanner at a resolution of about 5 mm. A total of four stations were used, of course not enough for wholly capturing the object but sufficient for the experiment. Point clouds were automatically triangulated within a commercial software package, to provide a direct ('unedited') support for orthoprojection, which would then be compared to the product from the photogrammetric surface model. While all relatively smoothly shaped areas were orthoimaged in practically identical manner from both sources, this was not the case at the edges. Indeed, 'vertical' triangles were slightly deformed, as is clearly seen in Fig. 10. This resulted in image 'blurring' and 'erosion' in the vicinity of discontinuities. Examples are given in Fig. 11. As noted by Bitelli et al. (2002), use of laser-derived models for orthophoto generation does not directly give satisfying results (depending on shape, data density etc.); thus editing of the model is needed, particularly as regards discontinuities.

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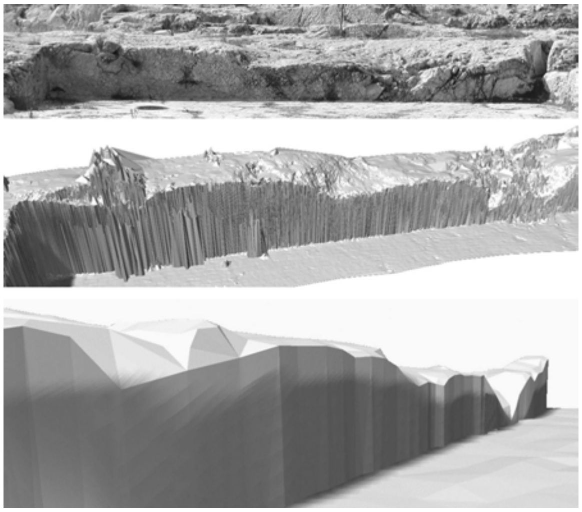

Figure 10. View of the object (above), model from the laser scanner (middle) and photogrammetric model (below).

Yet it seems that, apart from removing noise, an editing process might not always be practicable. Unlike regularly shaped architectural objects, for instance, in archaeological documentation local object morphology is often far from being 'obvious' without stereoscopic viewing. On the other hand, stereoscopic observation of a dense point cloud, superimposed on a photogrammetric stereo model, is clearly an extremely demanding task.

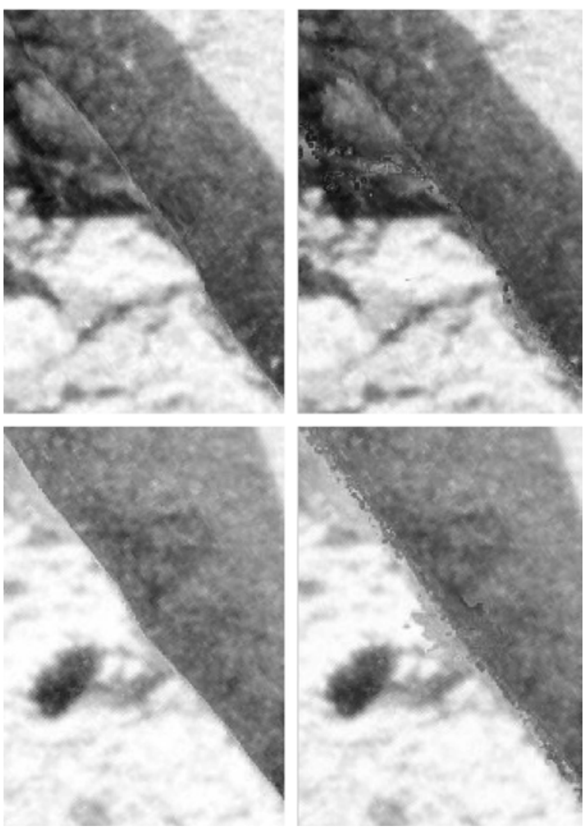

Figure 11. Details of orthoimages from the photogrammetric model (left) and from the laser scanner (right).

Thus, it appears that regarding 3D modeling with laser scanning for orthorectification, photogrammetry may still have to play a complementary role in both detecting and correcting erroneous or missing parts and also in describing discontinuities through breaklines and points (Bitelli et al., 2002).

5. CONCLUSION

The authors' experience indicates that, with ordinary non-metric cameras carried by simple 'unstable' platforms, rigorous photogrammetric procedures allow the generation of high quality end products, even for the demanding surfaces often encountered in archaeological mapping. Regarding 3D modeling, photogrammetry, when carefully performed, allows faithful surface representation. Its tiresome and time-consuming aspects can be significantly avoided, in many cases, through laser scanning. Certain current limitations of the latter, however, indicate that even in 3D modeling photogrammetry still has a significant role to play.

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