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# DIGITAL ORTHOPHOTOGRAPHY IN ARCHAEOLOGY WITH LOW-ALTITUDE NON-METRIC IMAGES

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## ABSTRACT

Combined with elevation data, orthomosaics are now among the main (end or intermediate) photogrammetric products for archaeological documentation. But DEM collection/editing and orthorectification/orthomosaicking may well necessitate powerful tools – according to object size, scale, accuracy requirements and, hence, number of images and scanning resolution. Here, digital photogrammetric workstations in their new, relatively low-cost, versions are obvious choices. On the other hand, imagery may be non-metric taken from 'unstable' platforms. This paper discusses our experiences with the Intergraph ImageStation SSK system in the photogrammetric documentation of an archaeological site in Athens with abrupt changes in relief. Taken from a small balloon with a 35 mm amateur camera and wide-angle lens, the 12 images formed a strip of unconventional geometry (large variations in scale and rotations), for which extensive geodetic control was available for checking purposes. Correcting radial symmetric lens distortion proved to be of paramount importance for reliable elevations and paralax-free models. It was concluded that, given certain conditions, digital photogrammetric workstations may indeed be efficient in handling demanding image configurations from non-metric sources.

## 1. INTRODUCTION

Archaeological excavations present their own peculiarities regarding photogrammetric documentation. Usually, they stretch horizontally and, consequently, must be recorded from above. On the other hand, mapping in large scale is required to ensure products of sufficient detail. The question of low-altitude recording has been met with a variety of platfoms. At the one end is helicopter photography with its high financial costs and problems in inhabited areas; at the other end, simple devices, such as tripods, may be used. Both alternatives have been successfully applied in archaeology (Georgopoulos et al., 1999), among various other platfoms such as balloons or kites. Indeed, for specific questions one may well work out specific answers.

But if low-altitude recording is to be practiced on a routine basis for both metric and simple archiving purposes, as in the case of the Department of Surveying and Photogrammetry of the Greek Ministry of Culture, then a "global" system is needed, adaptable to as many tasks as possible. Such a system must be low-cost; suitable for different environments; handled by one, or at most two, persons. An answer to this has been the small meteorological balloon carrying a light small-format amateur camera.

Such images may be used either for simple documentation or for creating metric products, starting from ordinary rectification and ending in more sophisticated photogrammetric results. Among the latter, orthophotography is becoming increasingly popular, thanks to its wealth of visual information 'from above' which often reveals interrelations of structures and functions of archaeological interest. But phototriangulation, collection of the required ground relief data, as well as the process itself of orthorectification and mosaicking, call for powerful software. The new PC-based versions of digital photogrammetric workstations are expected to respond to this need. Thus, the question would be: to which extent is imagery from non-metric sources, taken from 'unstable' and not fully controllable platforms, suitable for photogrammetric systems basically designed in a different context? To this end, the Intergraph ImageStation SSK system was used here to orthorectify a strip of images, acquired 'routinely' in the described way, of an archaeological site with abrupt changes in relief.

## 2. IMAGERY AND CONTROL

The basic idea for a platform was to use a small balloon (Fig. 1), normally employed for meteorological purposes, which is preferably filled with helium. Its low cost lets it be regarded as 'consumable' but it can also be re-filled more than once if handled carefully. At a diameter of ~1.5 m, it raises a weight of 1 kg. Hence, a light non-metric 35 mm camera, the autofocus Nikon F70, is mounted for imaging with vertical or horizontal axis. As a rule, the wide-angle Nikon 28 mm lens is used in order to avoid high altitudes.

An archaeological site in Athens was the object to be recorded. The 100×30 $m^2$ area of interest is slopy, its two ends having 20 m difference in elevation. Besides, localised changes in relief are numerous; there are also vertical 'faces' up to 2 m high. The 'flight' was planned for image scale ~1:1000, having its axis along the narrow negative dimension to cover the area in a single strip. A basic idea was to record densly aiming at an 80% overlap to allow convenient choice later. Projection centres had not been premarked on the ground, while camera orientation and alignment were kept visually. This, and a slight wind, produced images with strongly varying overlap (which at places was just adequate), large scale differences (fluctuation in 'flying' height above ground) and relative rotations. In particular, the 12 selected images had (see Fig. 2):

- mean height H above ground: 31 m (scale 1:1100)
- maximal differences $\Delta H$: 8.5 m (scales 1:970 - 1:1270)
- maximal angular differences between adjacent images: $\Delta\omega = 5°$, $\Delta\varphi = 13°$ and $\Delta\kappa = 19°$.

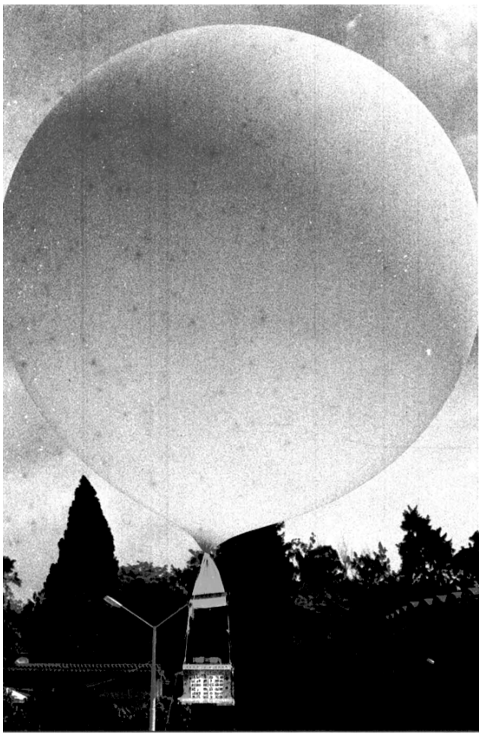

Figure 1. Meteorological balloon used as camera platform

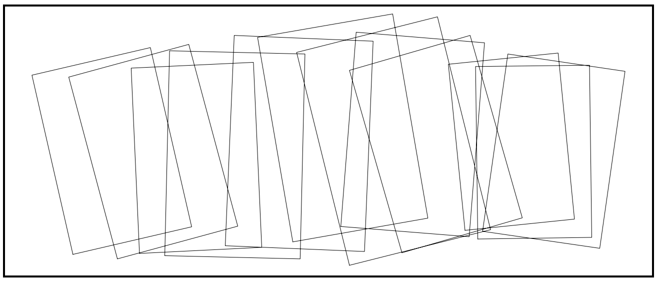

Figure 2. Image coverage

The black-and-white negatives were scanned with 7.5 µm pixel size in a PS1 PhotoScan scanner. Referred to the ground, pixel size was 8 mm which suffices for identification of detail (indeed, photographic scale had been fixed in view of this high resolution). Affine transformations, relating digital image and negative plane, were based on the coordinates of the 4 image corners. The RMS errors were in the range of 3-11 µm (0.5-1.5 pixel). Besides, unknown scale and/or affine deformation is introduced from the reference film dimensions measured with a precision glass ruler. When using amateur imagery, one has to live with such uncontrollable error sources.

For these images, abundant ground control was available consisting of 88 well distributed natural detail points. But, despite their high nominal precision, the object morphology did not permit to reliably identify on the screen points identical with those marked on paper prints by a different person in the field. Consequently, the actual accuracy of control and check points is assumed to be ±3-5 cm in planimetry and ±3 cm in elevation.

## 3. BUNDLE ADJUSTMENT

Initially, the strip was adjusted using the 'nominal' camera constant and ignoring principal point and radial symmetric lens distortion. As the SSK software does not include self-calibration, the idea was to test to which extent camera calibration can be simply by-passed, especially if a wide-angle lens in a non-metric camera is used. The solutions relied on densly chosen tie points (65 in total, average of 2.7 rays / point), and different numbers of control points. Respective a priori precision of image and control points was 8 µm and 4 cm. The results are shown in Table 1.

Table 1. Triangulation without image correction

| | | | |
|---|---|---|---|
| Control Points<br>Check Points | 88<br>– | 60<br>28 | 24<br>28 |
| σï (ìm) | 19.4 | 20.1 | 19.9 |
| *Control Points* | | | |
| RMS in X,Y (cm) | 6.4 | 7.0 | 9.5 |
| RMS in Z (cm) | 10.4 | 10.9 | 13.0 |
| *Check Points* | | | |
| RMS in X,Y (cm) | – | 6.6 | 10.1 |
| RMS in Z (cm) | – | 24.8 | 26.3 |

It is seen that standard errors of unit weight are almost 3 pixels, with extemely large errors occurring in the ground coordinates, particularly in height where computed check points deviate from their geodetically measured positions by about 9 times their estimated precision; in fact, the reconstructed surface was heavily 'curved' at places. This situation is, of course, reflected in large y-parallaxes, and clear mismatch of detail from successive stereomodels.

Since no further information was available on the geometric camera characteristics, the observations were inserted in the BINGO triangulation software. Camera constant and principal point would be unreliably estimated due to the object's poor vertical extension (indeed, no visible improvement was seen with these three parameters included in the adjustment). Thus, only a set of additional parameters was employed (the 12-parameter Ebner model) of which 6 emerged as being significant, drastically lowering the standard error of unit weight to σï = 6.6 µm. But to estimate radial symmetric distortion of the lens (generally assumed as the primary source of non-projective errors) one may well use simpler techniques; therefore, it was decided to introduce it as a known correction of interior orientation in the sense that normally it can be known beforehand. The distortion curve used is shown in Fig. 3. The SSK adjustment results (which compared to those of Table 1 differ only in this respect) are seen in Table 2.

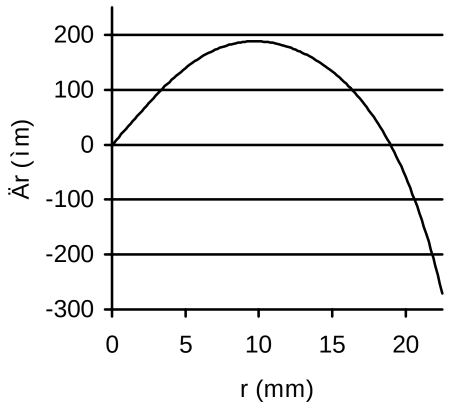

Figure 3. Lens distortion curve of the 28 mm lens

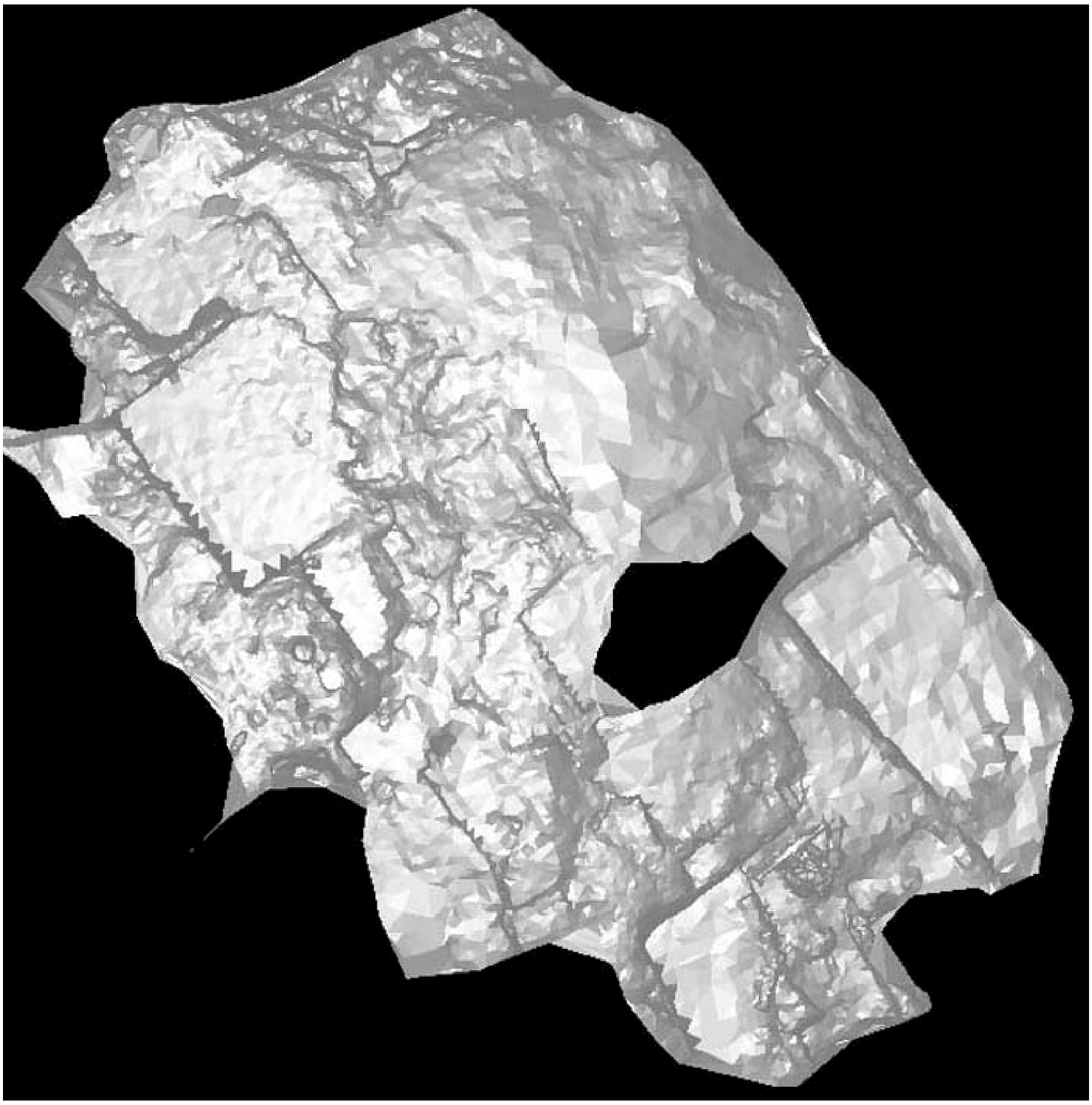

Figure 4. Shaded TIN of part of the site viewed from above

| Table 2. Triangulation with corrected lens distortion | | | |
|---|---|---|---|
| Control Points<br>Check Points | 88<br>– | 60<br>28 | 24<br>28 |
| $\sigma_{ï}$ (ìm) | 7.5 | 7.9 | 7.9 |
| *Control Points*<br>RMS in X,Y (cm)<br>RMS in Z (cm) | <br>4.2<br>3.3 | <br>4.5<br>4.1 | <br>4.5<br>3.6 |
| *Check Points*<br>RMS in X,Y (cm)<br>RMS in Z (cm) | <br>–<br>– | <br>4.3<br>5.9 | <br>5.4<br>7.4 |

Compared to Table 1, these results witness a striking improvement simply due to correction of lens distortion. In planimetry, check point deviations fall within the estimated accuracy; in elevation, the deviations are about twice as large as the estimated error and are acceptable, too. Indeed, if 60% of the format is used for orthorectification, these deviations introduce planimetric displacements maximally just reaching the estimated planimetric error. The results are satisfactory for orthoimaging at the prescribed 1:200 accuracy level. To exhaust the potential of such a camera, lens and image scale, targeted control should be a primary concern (of course with self-calibration).

## 4. DEM COLLECTION AND ORTHORECTIFICATION

It had been noticed in ealier work with a different software (Georgopoulos et al., 1999) that archaeological objects of this type generally resist automatic DEM collection mainly due to their low texture and 'whiteness'. Hence, surface points were collected manually in densities conditioned by local relief. Epipolar images were created, although the 'recompute on-the-fly' option could well have been adopted. Collection was adapted to the demanding morphology of the site, with its many 'breaks' and 'falls', by inserting numerous dense breaklines in all areas with considerable height differences from their vicinity. In order to faciliate generation of 'near-vertical' triangles, points were placed at the bottom of the vertical faces just 'underneath' the breaklines; obviously, special care was taken to avoid any planimetric coincidence of such points with their respective breaklines. This tedious process has been worthwhile as the final description of relief, which is the cornerstone of reliable orthorectification, is indeed satisfactory (TIN visualisations are seen in Figs. 4 and 5).

Finally, orthorectification and mosaicking were carried out with the standard SSK tools. Only the central image parts were used, resampled to a 7.5 mm object space resolution (≈ pixel size of initial images). Fig. 6 shows part of the orthomosaic draped on the surface. As expected, due to the dense ground sampling, the RMS planimetric deviation of 50 control and check points, representing the final orthomoisalc accuracy, was satisfactory (5 cm).

## 5. CONCLUDING REMARKS

A small balloon carrying a non-metic camera is regarded here as a potentially 'global' system for routine recording in archaeology, thanks to its flexibility (vertical or horizontal photography; suitable not only for 'open' areas; negligible weight etc.) and low cost. Certain problems in executing the 'flight' plan may be solved by means of a monitor and careful handling. Although the system also carries a light medium-format 45×60 mm$^2$ camera, 35 mm wide-angle images were used here in the Intergraph SSK digital photogrammetric workstation to produce orthoimages. It was established that the software could accommodate the unconventional configuration (large variations in rotations and scale) to produce orthoimages of good quality. Basic prerequisite was the correction of radial symmetric lens distortion, without which very large deformations are expected, at least when using wide-angle views (although distortion might be easily estimated in advance, an option for self-calibration is indeed welcome). A further condition for reliable surface description was the insertion of numerous breaklines and related points, indispensable in case of similar relief. As a concluding remark, one would point out that, in archaeology, today's digital photogrammetric workstations seem capable of exploiting 'difficult' amateur imagery for producing demanding results.

## REFERENCES

Georgopoulos, A., Karras, G., Makris, G., 1999. The photogrammetric survey of a prehistoric site undergoing removal. The Photogrammetric Record, 16(93), pp. 443-56.

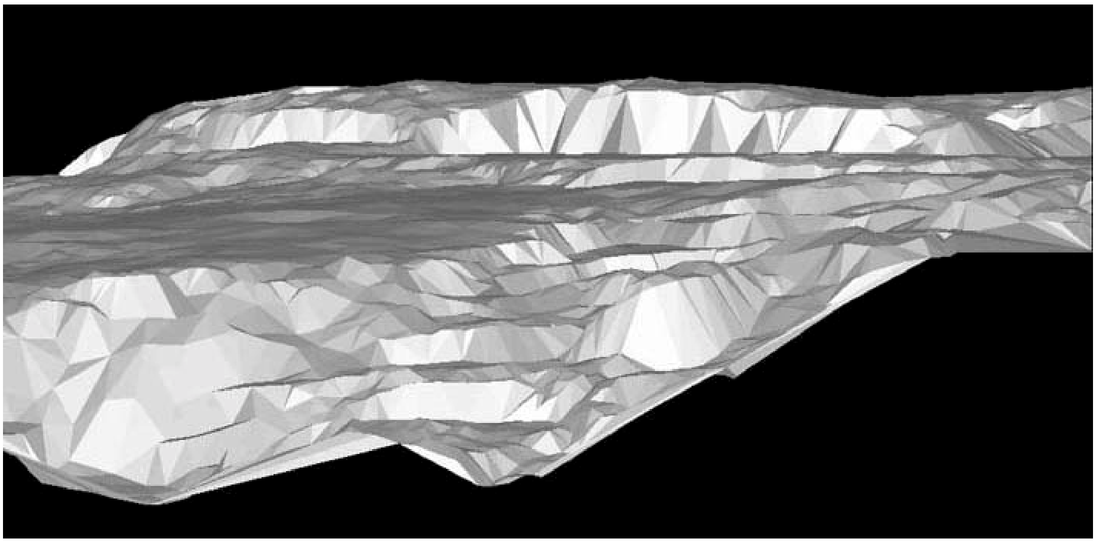

Figure 5. Shaded TIN of part of the site viewed from the side

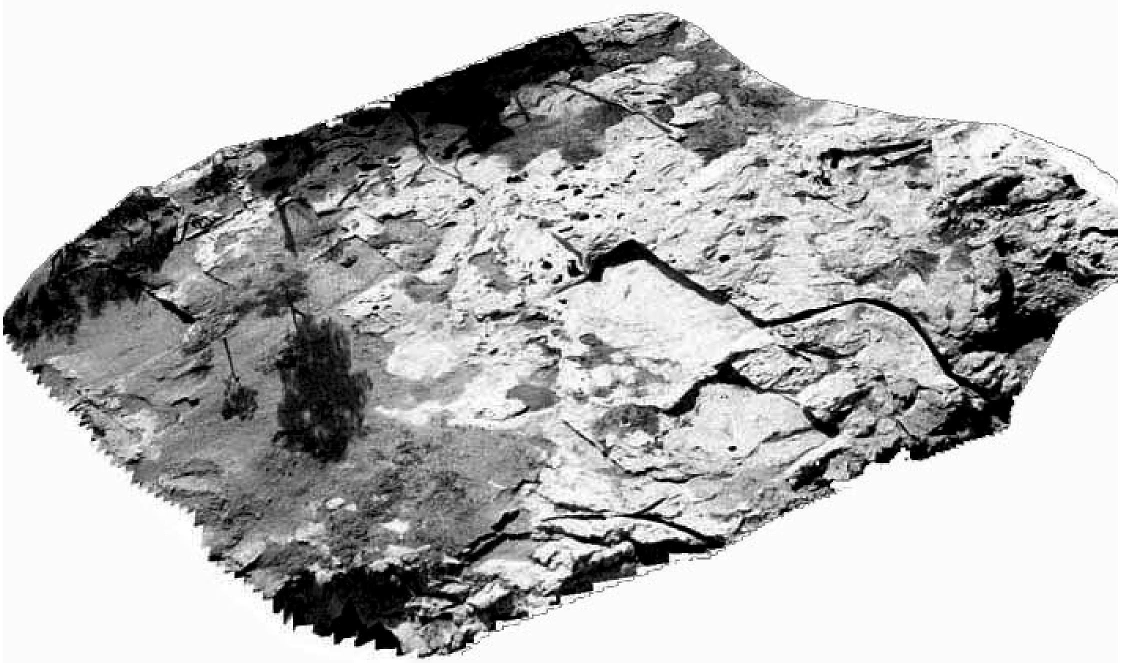

Figure 6. Part of the orthomosaic draped on the ground surface.