LOW-HEIGHT AERIAL PHOTOGRAMMETRY FOR ARCHAEOLOGICAL ORTHOIMAGING PRODUCTION

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ABSTRACT:

In the framework of the Joint Archaeological Mission of the Universities of Bologna and Lecce at the ancient town of Soknopaiou Nesos (Fayyum, Egypt) a wide-range of geomatic methodologies were experimented (GPS, total station surveys, low-height aerial and close-range photogrammetry, Visual Reality ecc.). The surveys were conducted with the aim of recording metrical and non-metrical information inside a common reference system. The paper deals with the use of low-height aerial imagery carried-out by a balloon-kites system equipped with a non-metrical camera. Descriptions of the preliminary results obtained through a self-calibration process of the camera, the use of images within a digital photogrammetric station for orientation, plotting, surface modelling and orthomosaicing are also reported.

1. INTRODUCTION

The use of orthophotos in Archaeology and in general for Cultural Heritage applications is becoming quite common due to their property of combining metrical characteristics together with an high level of photographic detail, useful to evaluate colours, material, decay, textures, etc. (Mavromati et al., 2002). The problems in non-aerial orthophoto production are nevertheless specific and some open problems till remain (Baratin et al, 2000). The paper deals with the experience carried out in a low-height aerial photogrammetric survey for orthophoto production in Archaeology.

The ancient town of Soknopaiou Nesos (Davoli, 1998), dating to the Greco-Roman period, is located northward of Birket Qarun Lake, in Fayyum (Egypt). The $660 \times 350 \text{ m}^2$ area of interest is located on a *kom* in a desert region. The terrain elevation is about 20 m with height differences of few metres within the site. Perimetrical walls of temple's *temenos* show elevations somewhere higher than 10 m above ground.

Accurate modern maps are not yet available for this very interesting site, and conventional terrestrial surveying techniques are not always suitable due to the sand covering a large number of buried structures.

In February 2002, the site was the subject of a first topographic survey by total station by the Archaeological Mission from the Universities of Bologna and Lecce. During this campaign, other different geomatic techniques were also applied, from GPS to aerial and close-range photogrammetry and also photographic visual reality.

Due to the difficulties encountered in retrieving existing airborne photogrammetric strips of the area, and the operational problems in realizing a new one in this region, an autonomous system was designed and realized to undertake low-height aerial photogrammetric and photographic surveys for mapping purposes. The data has been in particular used to produce an orthomosaic able to supply a metric description of the site (complementing the survey performed by total station) and to permit a better understanding of the semi-buried structures and their relationships.

2. GPS MEASUREMENTS

GPS is a reliable global georeferencing system, supporting a maximum accuracy of the centimetre level, so can be considered one of the main tools to homogenise the reference system within a wide range of field applications; some examples come from Archaeology (e.g. Bitelli & Vittuari, 1997). Both static and dynamic positioning are possible, and using geodetic GPS receivers a wide variety of solutions can be reached, from the georeferencing of single points to kinematic surveying of structures and complex sites. GPS is commonly used to assist aerial photogrammetry, for Ground Control Points (GCP's) determination and sometime to collect onboard the camera shot positions.

In our work GPS static surveys with long sessions were firstly used to connect the Soknopaiou Nesos reference point to the International Terrestrial Reference Frame (connection to GPS permanent stations of Matera-Italy, Ankara-Turkey and Malindi-Kenia), while Stop-and-Go method was adopted to obtain the coordinates of 59 - signalized and natural - ground control points (figure 1 and 2) useful for large scale mapping.



Figure 1. Stop-and-Go GPS surveying of a natural ground control point.



Figure 2. The position of the ground control points reported on the old drawing realized by K.R. Lepsius in 1843 and reproduced in (Davoli, 1998).

With the aim to obtain a general morphological description of the site, kinematic technique was finally applied, measuring a large number of paths with a well defined distribution; from the interpolation of the points acquired, with an high accuracy, a DTM was produced, while the orthometric heights were obtained applying a geoidal undulation value.

3. THE PHOTO-ACQUISITION SYSTEM

The system designed and realised for low-height aerial photoacquisition is based on balloon or kites and a radio-controlled device to pilot the camera (digital or film-based); the main components are shown in figure 3. It was specifically designed for a semi-metric Leica R5 35 mm camera.

For the first survey of Soknopaiou Nesos, conducted in February 2002, the atmospheric condition suggested the use of balloon (fig. 4), and, for some logistic problems, the necessity of a light-weight non-metric camera instead of the semi-metric one. The inevitable degradation in accuracy was accepted, considering also the purpose of the work and the test phase for the instrumentation. A Canon EOS 500N, 35 mm, film based camera with 24 mm lens was adopted and 140 photograms were acquired.

Due to the extension of the area and the photo-equipment the "flight" was planned for image scale of about 1:3000 - 1:4000. It must be stressed that, nevertheless the system was designed for a numerical control of rotations (tilt and pan), irregularity in balloon flight path, wind and movements along strips covertures caused an imperfect control of tilts and distances between shots and furthermore scale variations occurred.

In figure 5 a stereoscopic pair of aerial images, with a slightly different scale, is shown.



Figure 3. Acquisition system: a) Camera cradle b) Command unit to pilot the camera during the image acquisition phase.



Figure 4. Acquisition of images by the balloon system over the temple area.

4. PHOTOGRAMMETRIC DATA PROCESSING

Due to the unconventionality of the strip geometry, only a subset of 20 images was preliminary used to test the feasibility of the digital photogrammetric data processing.

The images were digitised by means of the photogrammetric scanner RasterMaster (Wehrli & Associates, 1994).



Figure 5. Example of an aerial stereoscopic pair for the Soknopaiou Nesos site.

The RasterMaster allows scanning negatives and slides, up to 250 x 250 mm dimension, with a 2116 dpi geometric resolution and a 24-bit radiometric resolution. Geometric accuracy is ± 4 µm, with 1 µm of repeatability, on the whole scanning area. The digital images, obtained by the scanning procedure with the maximum geometric and radiometric resolution, with about 3090 x 2100 pixel dimension (20Mb), were saved in TIFF file format.

Next paragraphs briefly describe the data processing, consisting of orientation, DEM extraction, orthophoto production, further to an indispensable self-calibration procedure.

4.1 Self-calibration of the camera

In order to obtain inner orientation parameters of the non-metric camera, the self-calibration module (Camera Calibrator) of Photomodeler v4.0 (EOS Systems Inc., 2000; Hanke et al., 1997) was used.

Photomodeler allows camera self-calibration (for non-metrical cameras or camera/scanner combinations): working with unstable non-metric cameras, it is often necessary to perform the self-calibration as a part of the photogrammetric project, adopting also different parameters for each photo. In our case, thanks to the fixed infinite focus, it was possible to estimate a unique set of parameters to describe inner orientation and radial distortion.

Due to the geometry obtainable from unstable platforms like balloons or kites, and the reduced number of GCPs clearly identifiables, in this kind of surveys is normally not possible to perform self-calibration on the field, contemporary to data acquisition. Camera Calibrator can perform the bundle adjustment analytical model for calibration by using several images of a plane test-field, supplied with the software. Of course, photos must be taken with the same focusing condition of the application case and, due to the planarity of the test-field, by a convergent scheme of acquisition (figure 6); moreover, to successfully recover the principal point position, it is recommended to take some photos with the camera rolled through 90° .

Figure 7 shows the results of the calibration procedure.



Figure 6. Calibration test-field and acquisition scheme.



Figure 7. Calibration results: camera parameters and radial distortion curve and coefficients.

Finally, since the edges of the slides were wrongly cut in two photos by the photographic laboratory, it was necessary to artificially realize the lost frame corners in the digital images, in order to recover the image reference system. To this aim, the real dimensions of the photograms were determined by means of measurements performed on a set of 15 slides by a Digicart40 (Galileo-Siscam) analytical stereoplotter. The results, showed in table 1, allow assuming a 36,128 x 24,200 mm image format.

edge ₁₂	24.212	rms ₁₂	0.013
edge ₂₃	36.168	rms 23	0.071
edge ₃₄	24.186	rms ₃₄	0.010
edge ₁₄	36.169	rms ₁₄	0.092

Table 1. Mean values and r.m.s. of edge dimension measurements (mm).

4.2 Image orientation and Aerial Triangulation

The photogrammetric processing was carried out by a PCI APEX workstation, particularly implemented for the treatment of aerial images. Figure 8 shows a scheme of workstation main components.



Figure 8. PCI APEX workstation scheme.

The managing software APEX (Aerial Photo Elevation Extraction) consists of almost 60 application functionalities that mainly allow data import (images, DTMs, coordinates files etc.), inner orientation, automatic or manual aerial triangulation, automatic DTM extraction and manual editing and, finally, ortophoto production and mosaicing.

For the case study, it was necessary to use two stereoscopic pairs in order to obtain a first ortophoto of the entire *temenos* area and a third couple to include also the entrance to the temple.

Inner orientation was performed with an affine transformation, by measuring the corners of the image frame. The triangulation procedure, realized by a bundle adjustment analytical model, encountered some difficulties mostly due to the anomalous strip geometry, characterised by different photo scale and arrangement variability of images, and to the arduous identifiability of control points that obliged to separately process the stereoscopic pair related to the temple entrance. Nevertheless the orientation process achieved satisfying results, with a global elaboration r.m.s. of 0.68 pixel and a maximum residual of 0.2 meter on control point coordinates.

4.3 DTM extraction

By using the APEX image correlation algorithms, DTMs of the oriented stereoscopic models were automatically extracted. Figure 9 shows the software window of the extraction methodology settings.

In particular, the "adaptative" method was selected, leaving the software the opportunity of choosing the suitable correlation strategy, and a TIN format because it makes easier the manual post-editing operation. In our case, indeed, it was necessary a manual editing (top and base) along the *temenos* walls, that cause sharp elevation discontinuities, and in sandy areas where the homogeneous photographic tone makes very difficult the correlation procedure.

DTMs, with a medium cell size of 20 cm, were extracted separately for each model, and then merged together in order to produce an orthomosaic.

The realization of a good surface model is certainly a key factor in the case of a site with a geometry like Soknopaiou Nesos, and in a lot of other archaeological situations (e.g. Mavromati et al., 2002); this issue needs further investigation to develop the best strategy for these cases, taking in account the capabilities of the modern powerful digital photogrammetric workstations.

View/Edit ATE Method	_ 🗆 ×
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O Non-Adaptive ATE	
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Adaptive ATE Filters	
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Height Width	
Smoothing Low 💌	
Precision High 💌	
TIN Breaklines None	
TIN Masspoints No thinning 💽	
OK	Cancel

Figure 9. "View/Edit ATE Method" window for DEM extraction methodology settings.

4.4 Orthomosaicing

The Ortho/Mosaic functionality of APEX allows performing in a unique step the resampling and mosaicing of the input images on the base of a selected DTM. It is also possible to realise a manual or automatic radiometric balancing of the images in order to achieve the homogeneity of the mosaic. The final product can be an image in GeoTiff format.

With the aim of the production of an orthophoto of the whole *temenos* area, bilinear transformation was used as resampling strategy and, thanks to the fairly good homogeneity of the input images, it was not necessary any radiometric adjustment.

A ground sample distance of 0.10 meters was chosen. Like for the DTM extraction, the orthophoto production pointed out problems along the *temenos* walls due to an effective deficiency of radiometric information caused by the acquisition geometry (figure 10).





Figure 10. Example of resampling along a high *temenos* wall: a) original digital image; b) failure due to lack of information on one side of the wall.

The site surveyed could be suitable for the application of the True Orthophoto, but unfortunately in this case the number of available images was not sufficient.

Figure 11 shows a portion of the orthomosaic for the temple area.



Figure 11. Example of a orthomosaic for the area surrounding the temple.

CONCLUSIONS

In the survey of the Soknopaiou Nesos site by aerial low-height photogrammetry several aspects of the current trends in archaeological surveying are addressed: use of unusual camera platforms, non-metric cameras and self-calibration, aerial triangulation, automatic digital surface model generation, orthophoto production and mosaicing.

The preliminary results indicate that these non conventional methods and instruments can represent a good solution in terms of cost-efficiency and that orthomosaic is a really interesting product for mapping and documentation in Archaeology. Some technical questions remain open, for instance related to the surface modelling and to the use of true orthophoto, but in any case the adoption of this kind of product could represent an important step for a reliable description and documentation of archaeological sites, and a fundamental base for GIS establishment.

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