

LOW-HEIGHT AERIAL IMAGERY AND DIGITAL PHOTOGRAMMETRICAL PROCESSING FOR ARCHAEOLOGICAL MAPPING

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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, high resolution satellite imagery, etc.). The surveys were conducted with the aim of recording metrical and non-metrical information inside a common reference system for the development of a GIS for the archaeological area.

The paper deals in particular with the acquisition and processing of low-height aerial imagery to provide very large-scale mapping of the area in support of archaeological researches. A remote controlled system, ad hoc developed for cultural heritage applications, permits to operate both semi-metric and non-metric cameras, lifted by balloon or kites with specific arrangements, in order to systematically take pictures over the study area.

The images acquired during the 2002 campaign by a non-metrical camera, calibrated by field calibration procedure, were processed within a Socet Set digital photogrammetric workstation: aero-triangulation, digital orthoimage generation and mosaicing were realized. The external orientation was established through kinematic GPS-derived ground control points, surveyed within the International Terrestrial Reference Frame ITRF2000; the same kinematic survey provided also a DTM for the entire site.

After a description of the overall approach to the survey of the site by the integration of different techniques, the paper describes the results obtained by this photogrammetric campaign, pointing out specifically the aspects concerning the non-standard image arrangement within the photogrammetric block, the problems arising by the geometrical structure of the buildings (e.g. the presence of very high mud-bricks walls in the *temenos*), and the use and comparison of DTMs derived from image-matching techniques or from GPS surveys.

1. INTRODUCTION

The ancient town of Soknopaiou Nesos (Figure 1), dating back to the Greco-Roman period, is located in Fayyum, Egypt, northward of Birket Qarun Lake; it rises on a *kom* with a characteristic oval shape, with ruins and buildings in mud-bricks. Unfortunately the increasing popularity of desert tourism is seriously risking the good preservation of the site.

From an archaeological point of view the site is not well known and little has been published about it; in the past there have been many excavations (Grenfell and Hunt in 1900-1901, Zucker in 1909-1910, Ahmed Bey Kamal in 1916), but the only scientific research of the area happened in 1932 by the Archaeological Mission of the Michigan University, directed by E.E. Peterson.



Figure 1. A view of Soknopaiou Nesos (from North).

The Italian Joint Archaeological Mission of the Universities of Bologna and Lecce, directed by S. Pernigotti and M. Capasso, started working at the town in 2001, to begin a project of documentation and study of the archaeological remains (Davoli, 2004). The first map of the site was the one produced by K.R. Lepsius in 1843 and reproduced in figure 2 (from Davoli, 1998); in the city are clearly visible the large *temenos*, enclosing

the Temple area, in the North and the long *dromos* in the North-South direction.

During the topographic campaign carried out in February 2002, a wide-range of different geomatic techniques were applied: GPS, total station survey, photographic visual reality, aerial and close-range photogrammetry. Moreover, VHR (Very High Resolution) satellite imagery of the area was subsequently acquired. All the metrical and non metrical information is recorded in a common reference system for the creation of a GIS for the archaeological site and the surrounding area. A similar approach was followed for the site of Bakchias in the same region of Fayyum (Bitelli et al., 2003b).

The paper describes in particular the acquisition and digital processing of low-height aerial imagery to produce very large-scale mapping of the area.

A large number of non metrical images were acquired from an ad-hoc realized autonomous system based on balloon, to face the difficulties in realizing a traditional aerial photogrammetric survey in this region. The data were used to produce an orthophotomosaic of the site, the first digital metric map of this kind for Soknopaiou Nesos; it provides a high-quality detailed photographic and metric description of the numerous, often semi-buried, structures and their relationships.

The work and the obtained results are presented, pointing out the problems concerning the collection of DTM, caused by the non conventional geometry of the photogrammetric block and by the presence of high-rise walls; besides the DSMs derived from various image-matching strategies were compared with the DTMs obtained by the GPS kinematic survey.

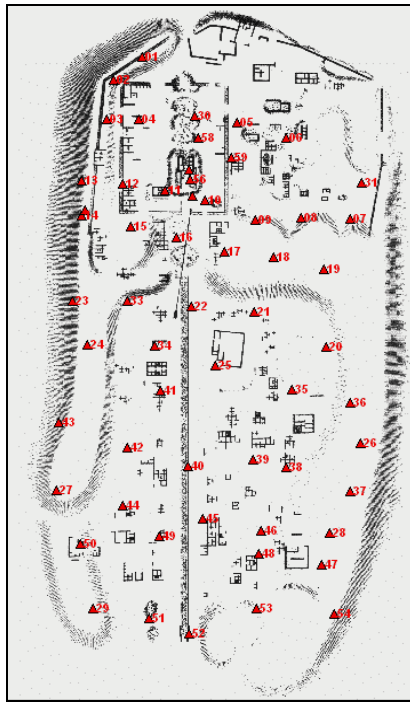


Figure 2. The old map of the city drawn by K.R. Lepsius (1843) with superimposition of the GCPs derived from GPS survey.

2. GPS SURVEYS

The applications of GPS in Archaeology are numerous and refer to the determination of the absolute position of reference points, the detail survey of single structures, the kinematic surveying of the ground surface of entire sites. The reliability of this global system and its possibility to achieve high accuracy, together with its productivity, make it the main technique able to frame together the whole metrical information collected at the site in a common reference system (Bitelli and Vittuari, 2000).

Regarding Soknopaiou Nesos site, long time GPS observations were firstly conducted on two reference points established in the area, connecting them to the IGS permanent stations of Matera and Noto (Italy), Nicosia (Cyprus), Ankara (Turkey) and Malindi (Kenia); GPS allowed to link the coordinates of local reference points to the International Terrestrial Reference Frame ITRF2000, and moreover to insert previous surveys, referred to local reference frames, into ITRF. The accuracy of the absolute positioning came out at the sub-decimetre level, certainly redundant compared to the common requirements of archaeological surveying.

At the same time, Stop-and-Go method was adopted to obtain the coordinates of 59 – signaled and natural – ground control points (figure 2), to be used in photogrammetric exterior orientation (Bitelli et al., 2003a).

In order to realize a general Digital Terrain Model (DTM) of the entire area, kinematic surveying was finally conducted, following paths chosen to describe the morphology of the site. About 20000 points were measured with a good accuracy (in the order of some centimetres). Figure 3 shows the planimetric scheme of GPS measured profiles.

From the interpolation of the points acquired, a complete DTM of the site was produced (figure 4).

The orthometric heights were obtained applying the geoidal undulation values obtained from the EGM96 geoidal global model.

3. PHOTOGRAMMETRIC DATA PROCESSING

As mentioned, images were acquired by a low-height aerial photo-acquisition system specifically developed for this kind of applications (Bitelli et al., 2001): the system is based on balloon or kites and a radio-controlled device. During the survey conducted in February 2002, a 35 mm non metrical Canon EOS500N film based camera was adopted instead of a photogrammetric camera. The camera was calibrated by a field calibration procedure (Bitelli et al., 2003a).

In relation to the area extension, the acquisition system characteristics and the wide angle 24 mm lens adopted, a flight height of about 100 meters was planned, involving an image scale of about 1:4000. Considering the archaeological requirements and the organizational and logistic constraints, this value of photo-scale can constitute an acceptable solution to have an high level of detail in the products provided by digital photogrammetric processing (DTM, orthophotos, base layer for GIS establishment).

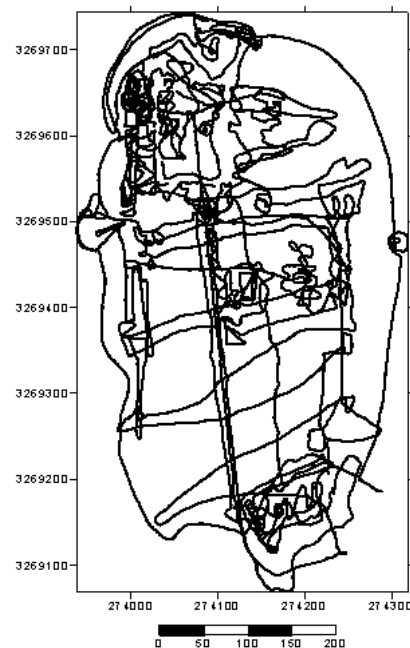


Figure 3. Planimetric scheme of the GPS profiles.

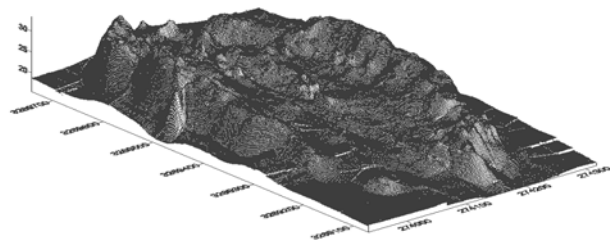


Figure 4. 3D view of the DTM obtained by GPS survey.

Strong wind during the survey and the consequent irregularity of balloon flight path, made the numerical remote control inadequate to impose the defined camera orientation. In total about 140 photos were acquired with a resulting coverage geometry characterised by irregular overlap and camera tilt besides large image scale differences.

Selected images were digitised by a Wehrli RasterMaster RM2 photogrammetric scanner with maximum geometric and

radiometric resolution (2116 dpi, 24-bit). Obtained bitmaps with size of about 3090 x 2100 pixels were saved in TIFF file format. The photogrammetric processing, carried out by a Socet Set v5.1 workstation, was concerned with a subset of 14 images chosen in order to cover the *temenos* and *dromos* areas (Figure 5). Inner orientation was performed with an affine transformation by using the image frame corners; values of the residuals were less than one pixel.

Triangulation procedure, realized by bundle adjustment analytical model, encountered some difficulties due to unconventional strip geometry: indeed the irregular image overlap does not fit with the Socet Set triangulation module requirement of a strict distribution scheme for points connecting contiguous models and strips. However, the process achieved satisfying results with a maximum residual of 0.20 m on the control point coordinates. Figure 5 shows the distribution of the control points used for exterior orientation.

Next paragraphs describe the subsequent procedures of DTM extraction and orthomosaicing.

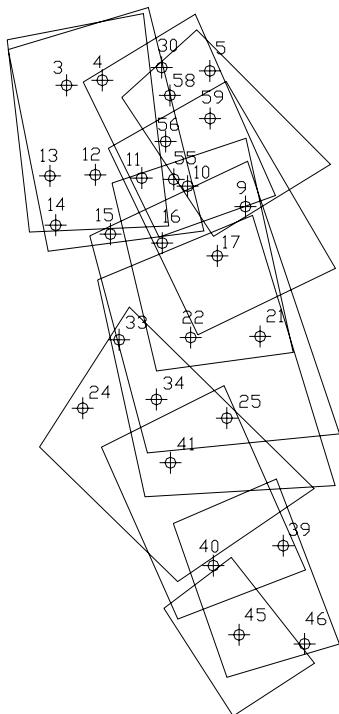


Figure 5. Image coverage and distribution of control points for the selected area.

3.1 DTM extraction

DTMs of the stereoscopic models were automatically extracted by means of Socet Set image matching algorithm implemented in the Automatic Terrain Extraction (ATE) module, based on HRC (Hierarchical Relaxation Correlation) algorithm.

In particular, due to various morphologies that characterize Soknopaiou Nesos area, “adaptive” correlation method and TIN format were chosen, in order to adopt the most suitable correlation strategy in each zone and make easier the successive interactive editing operation.

Comparison between manual and automatic extracted DTMs, depicted in Figure 6, points out an effective working of ATE module: about 81 per cent of points shows an absolute value of the difference lower than 30 cm. The biggest differences are localized close to structures or in sandy areas and so they are connected with sharp height variation or with homogeneous

image texture, that makes difficult the image matching procedure.

The experiment was conducted on sample areas with different kinds of morphology.

In order to improve the automatic process result in correspondence of such areas, we experimented the opportunity of using seed DTMs to initialize ATE process.

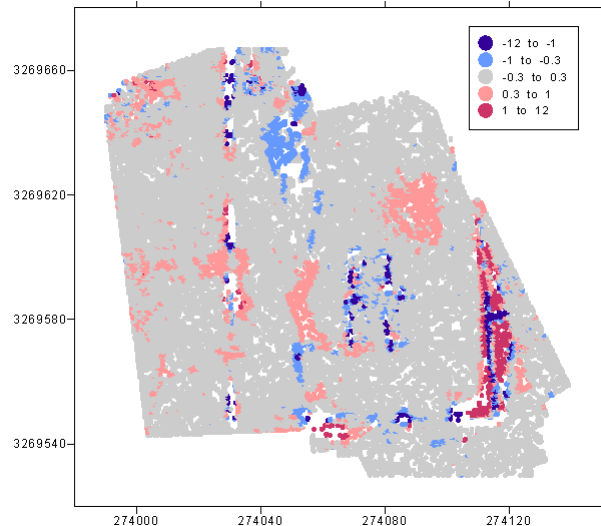


Figure 6. Classified plot of residuals between automatic and manual DTMs (automatic minus manual, meters).

In particular, DTMs with about 1 m medium inter-post spacing were extracted in each test area by using three different automatic collection modalities:

- without any pre-existing elevation data;
- starting from seed points obtained by kinematic GPS survey (only terrain information);
- starting from seed points derived from a manually measured DTM with grid spacing of about 3 m.

We report here the results obtained for a test area (Figure 7) characterized by abrupt elevation changes due to a *temenos* wall.



Figure 7. Test area around a *temenos* wall.

Figure 8 and Table 1 show the comparisons between each automatic DTM (correlated points) and a manually measured one. In both the b) and c) cases, using seed DTMs does not improve substantially image matching results. Similar conclusions were obtained for the other test areas.

In our case of study, indeed, it was possible solving DTM mistakes only by a post editing process. In particular, in the neighbourhood of structures, top-and-base breaklines were introduced; instead, in some sandy areas, manual editing was conducted point by point.

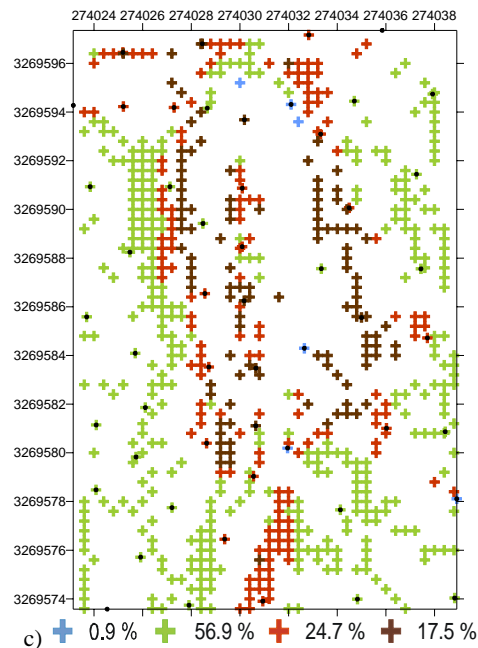
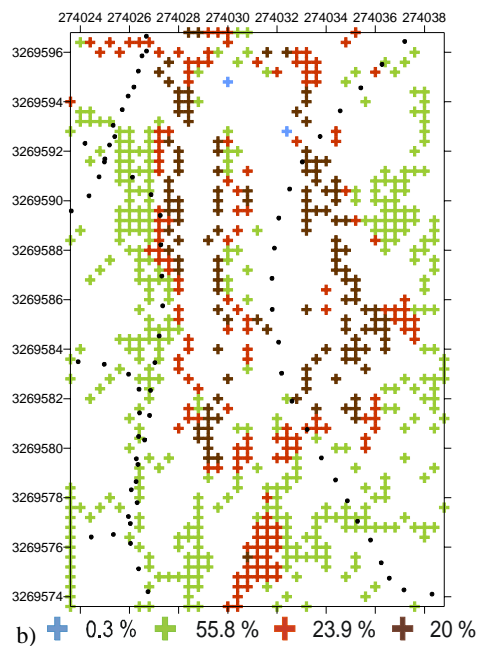
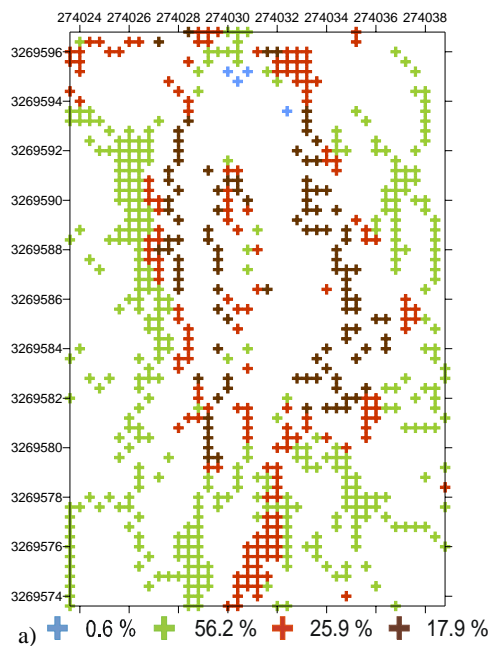


Figure 8. Test area: classed plot of residuals (m) between automatic and manual DTMs. Black dots represent seed points.

	a)	b)	c)
Minimum	-1.89	-0.54	-0.94
Maximum	3.04	3.00	2.53
Mean	0.34	0.36	0.33
Standard deviation	0.39	0.37	0.35

Table 1. Test area: statistical summary of residuals between automatic and manual DTMs (values in m).

Finally, we compared the elevation data coming from kinematic GPS survey with those deriving from photogrammetric DTM. As in above reported tests, ± 30 cm was considered the maximum tolerable value for the differences between GPS and photogrammetric elevation data. That limit comes from considering the image scale, the mean stereoscopic base of about 40 m and the pixel size.

Observing figure 9, showing a portion of the comparison, it can be noted that the higher inconsistencies are localized around West *temenos* wall. This trend is explainable considering that this area is covered only by two images with a little stereoscopic base (about 10 m): in such condition we could accept up to ± 1 m differences. Such a problem stresses that small format low-height photogrammetric systems do not allow for an accurate control of the base and of the flight height.

As for the rest, however, differences are acceptable except for really localized problems coming from structures or shadows.

The DTMs study has therefore showed the effectiveness of ATE module in producing digital surfaces; it must be observed that the automatic procedure can give problems when the aim is the contour representation, because image matching extracts points without an interpretation of object morphology.

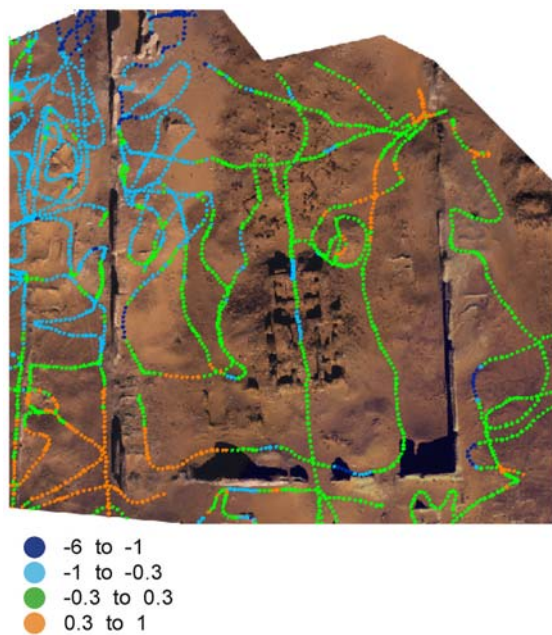


Figure 9. Residuals in elevation between kinematic GPS points and photogrammetric edited DTM in the *temenos* area (GPS minus photogrammetry, value in m).

3.2 Orthomosaicing

ATE products are suitable for the generation of orthophotos and orthophotomosaics, very interesting tools for documentation and conservation of Cultural Heritage due to their capability to combine metrical information with a qualitative and photographic description of the objects.

For the studied site, as already underlined, a post-editing process of the photogrammetric DTM was however necessary in areas with particular problems of homogeneous texturing or with sharp height variations. The orthophotos, characterized by a ground pixel size of 20 cm, were obtained by using bilinear transformation as resampling method, and, in a unique step, mosaicked together obtaining the orthophotomosaic showed in figure 10, relative to the area surrounding the *temenos* and the *dromos*.

The availability of large scale aerial imagery could be a mean to integrate and complement terrestrial survey. The comparison (figure 11) between orthophoto and vector representation coming from a topographical terrestrial survey conducted by the archaeologists, both into the same reference system, confirm a very good agreement and furthermore exemplifies the possibility of recognizing by the image the structures not easily identifiable by a terrestrial survey (see in the middle-right of the image). Conversely, it must be stressed that direct on-the-field examination of semi-buried structures by the archaeologist could provide in other cases a better interpretation.



Figure 10. Orthophotomosaic for the area surrounding the *temenos* and the *dromos*.



Figure 11. Superimposition of orthomosaic with vector drawing derived from topographical terrestrial survey (detail for a flat area near the *Temenos*).

CONCLUSIONS

The work confirmed the possibilities of digital photogrammetry in archaeological applications, even using non standard data acquisition methods and instruments, and make evident the benefits of integration of modern geomatic techniques in this framework.

Digital photogrammetric techniques, and specifically generation of DTMs and orthophotos can constitute today an invaluable tool for complete and rigorous archaeological surveying. The tests carried out for Soknopaiou Nesos site confirmed the potentialities of Automatic Terrain Extraction techniques, specially in term of productivity, but also the necessity, for every image matching procedure, of appropriate a-posteriori data analysis and manual editing. This editing process has been fundamental in order to obtain a satisfactory surface model of the interested area, which is the cornerstone of a reliable orthorectification.

This last product, despite the existing problems in comparison to the standard aerial case, can finally become a standard result in Cultural Heritage documentation and surveying.

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