

3D MODELLING OF THE ACROPOLIS OF ATHENS USING BALLOON IMAGES AND TERRESTRIAL LASER SCANNING

V. Tsingas^{a,*}, C. Liapakis^b, V. Xylia^a, D. Mavromati^c, D. Moulou^c, L. Grammatikopoulos^a, C. Stentoumis^a

^a Elliniki Photogrammetriki Ltd., Ipsilantou 66, 15121 Pefki-Athens, Greece - (vassilios.tsingas@elpho.gr, lazaros.pcv@gmail.com, christos.stentoumis@gmail.com)

^b Geotech O.E., Perikleous 41 and Thetidos 2, 15344 Gerakas-Athens, Greece - cliapakis@geotech.gr

^c Greek Ministry of Culture, Acropolis Restoration Service, 10 Polygotou Str.. 10555 Athens, Greece - (mavromatid@yahoo.com, thmoullou@hotmail.com)

Commission V, SS/19

KEY WORDS: 3D Modelling, DSM, True Orthophotos, Close-Range Photogrammetry, Terrestrial Laser Scanning, Balloon, Cultural Heritage, Athens Acropolis

ABSTRACT:

The paper focuses on a description of the techniques, both photogrammetric and geodetic, used for the data acquisition and processing concerning the project “Development of Geographic Information Systems at the Acropolis of Athens”. Aiming at the development of a Geographic Information System which will incorporate large-scale orthophotomosaics for the walls, an orthophotomosaic of the top view of the site, as well as a dense textured 3D surface model of the walls along with the rock, the project is divided into three basic tasks: the geodetic, involving field measurements for the generation of a polygonometric network and terrestrial laser scanning of the walls along with the Erechtheion monument, the photogrammetric one involving image acquisition, orientation, DSM generation and orthorectification, and finally the development of the GIS. This contribution underlines particularly the methodologies applied highlighting simultaneously the potential of combining photogrammetry and state-of-the-art geodetic techniques (laser scanning) for an accurate 3D modeling of cultural heritage sites.

1. INTRODUCTION

The geometric recording of one of the most important archaeological sites worldwide, the Acropolis of Athens, is a challenge for any surveyor and researcher in the field of surface modelling. The current work is part of the project “Development of Geographic Information Systems at the Acropolis of Athens”, financed by the European Union and the Government of Greece, and supervised by the Acropolis Restoration Service, Hellenic Ministry of Culture. The partners in this project are Elliniki Photogrammetriki Ltd (Elpho), Athens, Geotech O.E., Athens, ETH (Swiss Federal Institute of Technology), Zurich, National Research Council, Canada, Institute for Mediterranean Studies, Foundation for Research & Technology (FORTH), Rethymno, Crete, with external cooperators, Leica Geosystems, Switzerland and Basis Software Inc., USA (see Moulou and Mavromati, 2007).

The project started in June 2007, will finish end of 2008 and its goals can be summarized as follows:

- Establishment of four new trigonometric points (combined with the three old ones) covering the whole monument.
- Establishment of a new polygonometric network.
- Production of true orthophotomosaic at a scale of 1:50 (pixel size 5mm) of the north, west, east wall façades.
- Production of true orthophotomosaic at a scale of 1:25 (pixel size 2mm) of the wall areas, where significant, ancient architectural members exist that were built in the wall (areas of special interest).

- Production of true orthophotomosaic at a scale of 1:100 (pixel size 10mm) of the top view of the hill and generation of the necessary Digital Surface Model (DSM) of the hill.
- Production of full 3D surface models (and phototextured surface models) of the rock, the walls (outer and inner) and Erechtheion derived from 3D laser scanning at a resolution of 1cm for the areas of special interest, 5 cm for the rest of the walls, including its interior façades and 0.5 cm (or even better where it is needed) for the Erechtheion.
- Development of a GIS based on the above-mentioned orthophotomosaics and other geodata and the existing architectural plans, aiming at constituting a valuable documentation and restoration management tool.
- Connection of the GIS with the upgraded documentation database and publication on the Internet.

Undoubtedly, most of the above deliverables are basic photogrammetric products, denoting the importance of photogrammetry and terrestrial laser scanning in the geometrical and textural documentation of archaeological monuments.

In the last years, photogrammetry has incorporated new technologies capable of sampling large amount of surface points at very fast rates, indicating its synergy with range-based modelling, as an essential demand in heritage documentation and conservation applications. The fusion of the aforementioned techniques overcomes significant problems concerning especially the manual collection of 3D points with stereoscopic viewing, which is a time-consuming process and

* Corresponding author, vassilios.tsingas@elpho.gr.

requires too much manual effort. Indeed, it has been proven by the photogrammetric practice that reconstruction of such complex objects using automatic DSM extraction algorithms (area/feature based matching) is in most cases impracticable, due to occlusions and big scale differences among images.

Furthermore, special treatment is needed regarding the planning of the imagery, since the strong relief of the ground along with the height variations of the monuments (Parthenon, Erechtheion, Propylaia and the temple of Athena Nike) may lead to occluded areas in the images. On the other hand, the rough anaglyph requires the exploitation of specialized “true-orthophoto” methods for the orthophotomosaic production, since conventional orthorectification programs suffer from double projections and displacement artefacts.

2. DATA ACQUISITION

2.1 Imagery

Organization skills were required in order to handle the huge amount of data and bypass the difficult outdoor conditions which are the main difficulties in such applications. Several difficulties had to be handled like heat and especially windy weather on the hill, many obstacles (scaffoldings and cranes), the rough terrain with rocks and scattered marble pieces, the lack of a closed or wind-protected place for parking of the balloon during night, very irregular surface with occlusions, and especially on walls holes and vegetation, trees obscuring sight especially for terrestrial laser scanning, and many and moving tourists.

A group of five people constituted the field team, which was in charge of controlling the digital camera equipment. It is stressed here, that in order to follow the general rule which prohibits the use of any motor vehicle (helicopter or UAV) above the Acropolis monument, a balloon system had to be employed, consisting of a gyroscopic GPS-supported base (Figure 1) where the camera was mounted on, and a helium balloon with three meters diameter carrying the equipment in the air, fact that made the image acquisition cumbersome and time-consuming. The 22 MP (5336 x 4008 pixels) Mamiya ZD camera was used, having a medium format of 48 x 36mm, 9 μ m pixel size, 12 bit radiometric resolution and a wide angle lens of 45mm. The base was hanging much lower than the balloon to minimize effects of balloon sudden movements due to wind on the base and the camera. The flight plan was designed and controlled by Aerotopol software (www.aerotopol.de) allowing the real time monitoring of the system through a bluetooth connection between the GPS and the laptop. The correct positioning of the balloon according to the flight plan was controlled with the wireless transmission of GPS measurements to the laptop. In some cases, when GPS signal was lost due to disturbances in Acropolis, a WEB camera on the balloon and wireless transmission of images on a monitor were used to guarantee that the camera image to be taken was centered at the correct position. The image of the WEB camera was compared with a pre-computed orthophoto on the laptop or a person standing at the pre-planned nadir, to ensure the correct nadir position of the image to be acquired. A correct kappa of the acquired images was performed by manually turning the balloon via strings. The camera could be tilted in the vertical direction manually to be able to image other objects like the walls (s. Figure 1 right). The average flying height of the camera for the top view was chosen at 22m above ground

(image scale \approx 1:500) giving a ground pixel size of 5mm, adequate for the resolution of the final orthophotomosaics. The images had 75% forward and sidelap, ensuring the multi-image coverage of all areas in the site and, therefore, an accurate DSM production and no occluded areas in the orthophotomosaic. A special flight planning was adopted in areas with strong anaglyph and/or large monuments with scaffoldings and cranes (Parthenon, Erechtheion, Propylaia).



Figure 1. The balloon system (left) and the gyroscopic device mounted with the camera (right).

The architectural and historical aspect of the site is not concentrated only on the visible erections of the hill, but also on the surrounding walls, valuable for the quantity of material from various Acropolis structures built into them (Moulou and Mavromati, 2007). Thus, the walls (north, south, east and west) were recorded at an average distance of 5m (image scale \approx 1:100), with a pixel size smaller than 1mm on the ground. The overlap between adjacent images was preserved at 65% in x direction, while a 35% (conventional image configuration) was selected for the y direction, since multi-image coverage was not a demand (the wall surface is modelled by laser scanning). The images were to be used for orthophotomosaics, texturing of the laser 3D model and possibly fill-in of gaps in the laser 3D model by photogrammetric stereo measurements. Furthermore, the balloon was used to take images of the surrounding rock from the top, while the Mamiya was also used to take images of the interior side of the walls.

Additional digital cameras were used in the project. Two Canon 5D, one for taking high dynamic range (HDR) images by using multiple exposures for texturing the Erechtheion (El-Hakim et al., 2008), and one for image-based 3D modeling of the Erechtheion (Remondino et al., 2008). An additional Canon 400D was used with the laser scanner (see Section 2.2), especially for texturing the vertical parts of the Acropolis rock.

For the Mamiya, in total, 1300 images were collected for the top view (Figure 2), while 1700 images were captured for the outer and inner part of the walls. Lastly, about 500 images were collected for the Erechtheion and the surrounding rocky area around the wall of Acropolis. To ensure a good quality of the image measurements, radiometric corrections and enhancement took place through histogram matching.

A very dense network of signalled ground control and check points has been established and geodetically measured for the top view images. About every other second image nadir point

was signalled with a 7 x 7 cm, mostly black and white, adhesive target stuck on PVC. For the walls, due to difficulties in placing signalled points there, only a few signalled points were used in accessible areas. Further control and check points were well-defined natural features measured with a total station and points transferred from the laser scanning intensity information (see Section 2.2).



Figure 2. The hill of Acropolis (aerial photo). In the center the Parthenon, left the Propylaia, at the top Erechtheion, on the right the old Acropolis museum.

2.2 Laser scanning

For the point cloud collection, the Trimble GX 3D scanner (time-of-flight) was deployed. The range of the instrument extends up to 300m, with an accuracy of 2.5 mm at 100m distance, and measuring speed of 5000 points/sec. A total of 146 scans were collected from 53 different scanning positions, covering the wall façades (inner and outer sides) and the surrounding area, including the rock. In Figures 3 and 4, two point clouds are shown of the south and east wall respectively. The points are textured with the intensity map from the laser scanner allowing the identification of specific components of the monument. This information gives additional image-identifiable ground measurements on the object, which can be treated as control points during the bundle adjustment of the wall images from the digital camera.

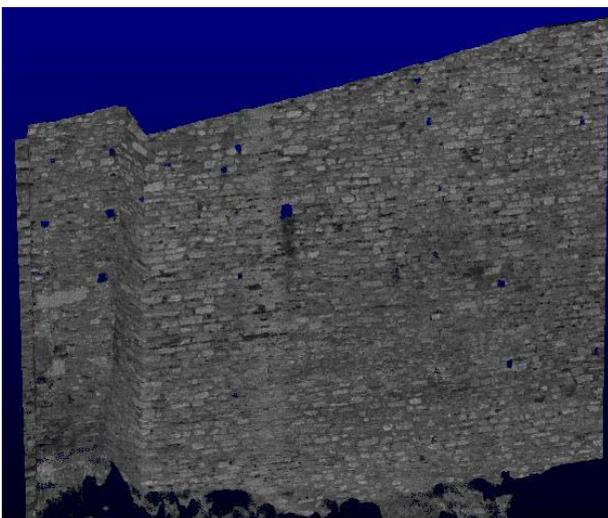


Figure 3. Part of the point cloud in the south wall.

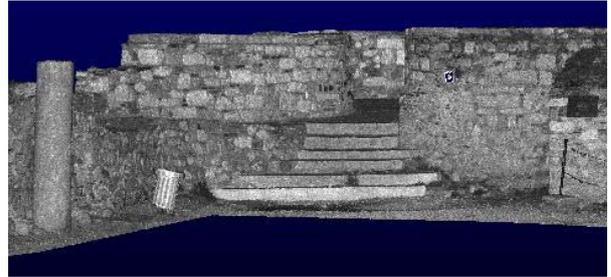


Figure 4. Part of the point cloud of the interior east wall showing the Belvedere at the NE side of the Acropolis wall.

Special targets such as spheres and adhesive objects were used in the scans in order to co-register partial scans to a common system. For example, the scanning of a particular sector of the wall took approximately one hour, giving in total 2 million 3D points. This is in agreement with the project specifications, whereby the resolution of the point cloud had to be 10mm for the walls.

As a separate task, the laser scanning of Erechtheion was carried out by two other scanners (Surphaser 25HSX and Leica HD3000). This approach is described in more details in a different paper (El-Hakim et al., 2008).

3. PROCESSING

3.1 Camera calibration

The internal geometry of the camera was recovered through bundle adjustment with the Leica LPS software using a network of 29 control points measured with accuracy less than 2mm.

Camera parameters	A posteriori $\sigma_0=0.3069$ pixel	
c (mm)	46.0998	± 0.0136
x_0 (mm)	0.0393	± 0.0063
y_0 (mm)	0.0424	± 0.0063
k_1	$-4.0207000e-05$	$\pm 3.9364e-007$
k_2	$1.9295000e-08$	$\pm 4.9547e-010$

Table 1. Calibration results (parameter values and standard deviations) for the 5m distance imagery (walls).

Camera parameters	A posteriori $\sigma_0=0.2867$ pixel	
c (mm)	45.7830	± 0.0110
x_0 (mm)	0.0535	± 0.0074
y_0 (mm)	0.0347	± 0.0074
k_1	$-4.0700000e-05$	$\pm 3.8924e-007$
k_2	$2.0735000e-08$	$\pm 4.4342e-010$

Table 2. Calibration results (parameter values and standard deviations) for the 22m distance imagery (top view).

Two adjustments were performed, one at a distance of 5m concerning the images of the walls and a second one using

imagery from 22m (top view). In both cases, 20 images of strong geometry (converging images with different k rotation) were oriented using self - calibrating bundle adjustment. The results are summarized in Tables 1 and 2, where c is the camera constant, (x_0, y_0) the location of the principal point and k_1, k_2 the two coefficients of the symmetric radial distortion.

3.2 Bundle adjustment

The exterior orientation of the images was carried out with the photogrammetric workstations of Leica (LPS v9.2), based on automatic and semi-automatic techniques (tie point measurement) followed by stereoscopic checks. The aerial images of the top view were separated into four big blocks and oriented using bundle adjustment triangulation relying on well distributed control and check points. Table 3 shows the results of two such blocks.

		Block1 (top view)	Block1 (east wall)
Number of images		376	137
A posteriori σ_0 (pixel)		0.38	0.41
Control Points	RMS X (m)	0.011	0.009
	RMS Y (m)	0.008	0.004
	RMS Z (m)	0.013	0.006
Check Points	RMS X (m)	0.009	0.004
	RMS Y (m)	0.008	0.006
	RMS Z (m)	0.010	0.007

Table 3. Bundle adjustment results.

Consequently, one can see that the final accuracy is equal to the one specified for the orthophotomosaic generation. Specifically, for the side views of the walls, individual well-defined points from the intensity maps of the laser scanner were selected and used as ground control in the bundle adjustment, ensuring a proper registration of the images against the laser data.

3.3 Range data

The processing of the point clouds was implemented in the software RealWorks (Trimble). As a first step, noise reduction was applied to the points. The different scans were then registered together and against the geodetic system (GGRS 87) using the coordinates of the special targets. The resolution of the unified point clouds was reduced, in order to agree with the specifications of the work (1cm for the walls and 5cm for the rock). The final 3D mesh was produced through a 3D triangulation process, while small holes, in the surface were corrected automatically employing a hole - filling algorithm. Larger gaps in the data were filled with 3D points extracted photogrammetrically from the images of the balloon.

4. PRODUCTS

The digital terrain model of the top view was generated with automatic terrain extraction techniques (LPS and Inpho software) at a resolution of 0.02m and 0.01m, for the top view and the walls respectively. The results were corrected manually using suitable collection techniques (Mavromati et al., 2003), regarding breaklines, improving the final quality (Figure 5).

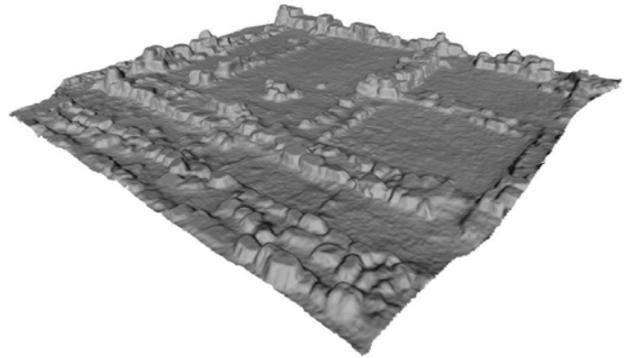


Figure 5. A detailed part of the 2.5D DSM of the top view.

Concerning the walls, the surface data come exclusively from the laser scanner, apart from the cases where there is lack of points (gaps), as it was mentioned before. Additionally, the 3D points from the range scanner were checked through stereoscopic viewing, as a final check of the quality of the registration among the two different data sources: photogrammetry and laser scanning.

An issue arises concerning the generation of the orthophotomosaics, where the employment of a specialized algorithm is a demand. In cases with strong height variations on the ground, conventional orthorectification software may lead to unexpected results such as double projections and artefacts. The principal aspect here is the proper visibility checking of the object surface in the images and the simultaneous detection of surface areas occluded in the initial images used. On that basis, orthophoto production (Figure 6) was performed with specialized true - orthorectification software such as Inpho Orthobox (Ortho Master + Ortho Vista).



Figure 6. Detail of a top view orthophoto.

In addition, the methodology of Karras et al. (2007) was also used, especially in areas where the full 3D mesh (instead of the 2.5D DSM) could not be handled by Inpho's programme due to occlusions in the direction of the ortho-projection.

For the several orthophotos of the walls, the projection planes of the orthophoto subgroups, each subgroup corresponding to a different wall plane, were calculated by plane fitting, using the coordinates of the control points. Finally, the orthophotomosaics were radiometrically corrected in order to create a uniform and homogeneous result.

5. SUMMARY

In this contribution, the basic techniques and methodologies were described, concerning particularly the modelling and orthorectification process, through the synergy of photogrammetry and terrestrial laser scanning. Especially, in the case of cultural documentation, where the accuracy requirements increase dramatically and the visual quality of the final products is indispensable, the fusion of different state-of-the-art methodologies is a demand.

Although aerial photogrammetry has recently made a noticeable progress in the direction of automation (automated orientation and DSM extraction), in close-range applications as this one human interaction is still very important. Especially, during the stage of DSM production, only the stereoscopic check and correction can ensure a “true” 3D model. This holds also for the orthophoto generation, even when specialized true-orthophoto generation software has been employed.

The current project, due to its complexity and archaeological interest can be characterized, as an important case study for similar research, involving large and complex cultural heritage sites.

REFERENCES

- El-Hakim, S., Beraldin, J.A., Picard, M., Cournoyer, L., 2008. Surface reconstruction of large complex structures from mixed range data – The Erechtheion experience. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 37, Part B5 (in the proceedings of this Congress).
- Karras G., Grammatikopoulos L., Kalisperakis I., Petsa E., 2007. Generation of orthoimages and perspective views with automatic visibility checking and texture blending. *Photogrammetric Engineering and Remote Sensing*, 73(4), pp. 403-411.
- Mavromati, D., Petsa, E., Karras, G., 2003. Experiences in photogrammetric archaeological recording. *Proc. XIX CIPA Int. Symposium*, Antalya, Turkey, pp. 666-669.
- Moullou, D., Mavromati, D., 2007. Topographic and photogrammetric recording of the Acropolis of Athens. *Proc. XXI CIPA Int. Symposium*, Athens, Greece (on CD-ROM).
- Remondino, F., El-Hakim, S., Baltsavias, E., Picard, M., Grammatikopoulos, L., 2008. Image-based 3D modeling of the Erechtheion, Acropolis of Athens. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 37, Part B5 (in the proceedings of this Congress).

