Digital Photogrammetry Used for the 3D Reconstruction of the Walls Around the Acropolis of Titani (Greece).

Timothy NUTTENS[1], Alain DE WULF[1], Rudi GOOSSENS[1], Christiane TYTGAT[2], Daniël VAN DAMME[1], Dennis DEVRIENDT[1]

Key words: 3D reconstruction, close range, digital photogrammetry, image matching.

SUMMARY

Close Range Photogrammetry is an alternative -next to classical topographical measurements- to obtain metric documentation about important archaeological objects or monuments. As a partial collapse of the remnants of the walls around the acropolis on the archaeological site in Titani (Greece) proves, accurate metric documents are essential for an efficient monitoring and managing of historical sites. Topographical measurements and digital photographs were taken to use a digital photogrammetric restitution process to elaborate the necessary metric results such as DEMs, orthophotomaps and a 3D virtual reconstruction.
The stereographic images were taken with a non-metric high-end full-frame digital single lens reflex camera (11 Mp). The resulting eighteen stereo couples were processed with the photogrammetric software VirtuoZo™. In the relative orientation it is important to determine sufficient (at least 100 to 150) homological points on both stereographic photographs and these points have to be well spread over the overlapping area of the stereo couple. The errors on the relative orientation may not exceed the limit of $1/5^{th}$ of a pixel. In order to place the stereo model in an absolute coordinate system, at least six ground control points per stereo couple were measured with a total station. The errors on this absolute orientation exceed for none of the eighteen stereo couples the limit of one cm. The processing of the stereo couples shows that the result of the image matching of a stereo couple depends on the quality of the relative orientation, but is on its turn determinative for the quality of the final metric products. A specific editing procedure is performed on the metric results from the photogrammetric restitution, to keep the initially strong deformations at the edges of the walls within tolerances. The orthophotos are then used to compose a 3D reconstruction of the remnants of the walls in CAD software.

The results of this project (DEMs, orthophotomaps and a 3D virtual reconstruction) are very accurate metric documents for monitoring and managing of the Titani archaeological site. The importance of such accurate and metric documents may not be underestimated, as shown by a partial collapse of the wall shortly after the processing of the stereo images. Different solutions are found to handle the problems that occurred during the photogrammetric restitution, so that none of the processing parameters exceeds the limits that were set at the beginning of the project. Most of the problems are due to insufficient contrast in the images and non-ideal viewing points on the terrain and can be solved by manually picking more homological points.

Digital Photogrammetry Used for the 3D Reconstruction of the Walls Around the Acropolis of Titani (Greece).

1. INTRODUCTION

In the 19th century, Ludwig Ross identified the site of ancient Titani in Korinthia. This archaeological site is located about fifty kilometers south-west of Corinth (Peloponnesos, Greece). In Antiquity, it was a very important site in the region but it has remained, so far, a mostly unexplored site (Levi, P., 1982). The sanctuary in Titani was described in detail by Pausanias, who considered the cult of the god practiced on the site as ancient already at his time. None of the buildings and monuments mentioned by the ancient traveler has been located. Fundamental research and mapping of the site was carried out by Ernst Meyer in 1937 (Meyer, E., 1937). The map he made of the site was, and still is, used by different research projects on ancient Titani.

The remnants of the walls surrounding the acropolis of Titani are until now still in a relative good conservation stage. But as was shown in 2006, when a small part of the wall collapsed, the site is in need of conservation actions and photogrammetric documentation. Only the remnants of two towers are left, together with some parts of the wall. The walls are composed out of stabled small, irregular shaped stones, while the remnants of the two towers are built from larger rectangular shaped blocks. The conservation of the complete wall is endangered by different factors, such as erosion, the roots of the trees on top of the hill that keep pushing the stones aside and uncontrolled grazing by goats and sheep. Therefore it was decided in 2005 to document the walls of the acropolis, which are only a small part of the complete archaeological site, by close range photogrammetry and to obtain accurate orthophotomaps, digital elevation models and a 3D virtual reconstruction.

2. FIELDWORK

Using close range photogrammetry, the recording conditions are so that the distance between the camera and the object that’s been photographed is very small. By taking digital images of the monument or the archaeological artifact for photogrammetric restitution, the influence of complex shapes is minimal and the pictures give not only accurate metric information, but also semantic information. The digital elevation models, one of the final products of the digital photogrammetric process, are used to elaborate the orthophotos (Atkinson, K. B., 1980). This recording method can offer a valuable alternative for classical topographical measurements in difficult field conditions or for applications with very complex shaped objects (i.c. irregular shaped stones).


Fig. 1: Overview of the remnants of the wall (Titani, Greece) (Tytgat C., 2005)

The fieldwork was done in the period end September – beginning of October 2005. In a first stage, a visual inspection was made around the remnants of the acropolis walls. This inspection is important to find the optimal viewing and recording points, the optimal position of the base stations for the total station measurements, the recording and restitution scale of the final orthophoto products etc...
To perform the absolute orientation in the photogrammetric process, a large number of ground control points were measured with total station. There has been chosen not to use characteristic points on the walls, but to place manually specific marking points on the walls. The marking points are made of a light cardboard material, so that there is no permanent damage done to the monument. After a while, the cardboard will erode and disappear, leaving no traces on the monument. The signals were placed on the walls so that during the image recording there would be always a minimum of six points visible on each recorded stereo pair.

In a third stage, the digital images were taken, using a Canon EOS 1Ds high-end full-frame digital single lens reflex camera (11 MegaPixel). This is a non-metric camera, which means that this camera has unknown lens distortions and no grid on the image. This makes this type of camera lighter, cheaper and much easier to use. But even with this non-metric camera, it's possible to obtain very accurate results in the photogrammetric process. Each part of the remnants of the wall was photographed from two different positions and with a minimum overlap of 60%, in a progressive way along the length of the walls, taking into account that each stereo couple should include a minimum of six control points within the overlapping area. The pictures were taken in such conditions that the walls were not lighted by direct sunlight, to avoid big shadow parts on the walls and places with little or no contrast. In total, eighteen stereo couples were recorded in order to cover the total extent of the acropolis walls.

3. DIGITAL PHOTOGRAMMETRIC PROCESS

3.1 Coordinate transformation

The coordinates of the ground control points of each stereo couple are transformed to a new coordinate system, parallel to the image base of each stereo couple. It is important for the photogrammetric restitution, that the coordinate system is so orientated that the X-axis is as parallel as possible to the wall. If the X-axis is parallel to the wall in the new coordinate system, the Y-axis points upwards and the Z-axis will point towards the observer.
For the virtual reconstruction at the end of the workflow presented in this paper, an analogue - but reverse - coordinate transformation has to be performed to place the orthophotos back into a general coordinate system.

3.2 Relative and absolute orientation

For the digital photogrammetric processing, the VirtuoZo^{TM} v3.3 photogrammetric software was used. By using the already mentioned non-metric camera, the stereo models were processed in a non-metric way, which means that there is no internal calibration during the photogrammetric process.
The relative orientation is automatically implemented, but the operator still has control of the process. The software automatically searches for homological points, but the operator needs to check whether the indicated points by the software are really homological and represent exactly the same point on the left and the right image of the stereo couple. The RMS-errors of the relative orientation don't exceed the limit of 1/5th of a pixel. For sufficiently accurate results, at least a hundred to 150 homological points in the relative orientation are needed. Where this minimal number of homological points was not reached during the automatic relative orientation, the operator indicates manually homological points until the minimal number is reached. By picking these points manually the operator obtains higher errors, but he must make sure that the error limits are not exceeded. This difficulty to reach the necessary number of points is mostly due to places on the images with little or no contrast or scale differences between parts of both images. Most of the images also contain a lot of background information, such as trees behind the walls or rocks lying in front of the photographed part of the wall. The background information can be very different between the two images, because both images were taken from a different point of view, which makes the automatic recognition of homological points by the software difficult. The best way to improve the quality of the relative orientation is to cut out a rectangular part of the images that contains only the wall with as little background information as possible.

A sufficient number of homological points that are evenly spread over the overlapping area of the stereo couple will improve the quality of the image matching. The image matching is a very important factor in the final quality of the results of the photogrammetric restitution. A small improvement can also be obtained by first selecting the ground control points on both images and then running the automatic relative orientation. That way the software has already some base points to start with the automatic search for homological points.

To place the stereo model in the user defined coordinate system, the operator has to point out at least six ground control points in the overlapping area of the images. There are five points needed to solve the transformation comparisons, and at least one point as control point

(Manzer, G., 1996). The errors in X, Y and Z direction are calculated for each point and an average value is calculated for all the ground control points. The maximum error for all the ground control points in X, Y and Z has been defined at one centimeter. When there is a redundancy of ground control points, the operator can define the optimal number and selection of these ground control points to obtain the most accurate result. The average errors in X, Y and Z direction (mm) for the absolute orientation are represented per stereo couple in Table 1. The results for the absolute orientation of all the stereo couples show that the error limit of one centimeter was never exceeded. Errors smaller than 1 mm have no significant meaning in the interpretation of the results. These errors are too small to be discerned.

Absolute Orientation - Errors			
	X (mm)	Y (mm)	Z (mm)
Stereo-couple 1	8,2736	3,2180	6,9972
Stereo-couple 2	0,0267	0,1578	0,0241
Stereo-couple 3	0,9840	0,8067	2,2030
Stereo-couple 4	0,5773	0,3257	0,6600
Stereo-couple 5	0,5484	0,5850	2,1961
Stereo-couple 6	0,1495	0,0837	1,1255
Stereo-couple 7	0,9218	1,3227	2,2634
Stereo-couple 8	0,8813	1,1822	1,0977
Stereo-couple 9	3,2156	4,3844	3,1303
Stereo-couple 10	3,5239	2,0883	3,0863
Stereo-couple 11	0,7967	0,5159	0,4115
Stereo-couple 12	1,3185	0,9845	1,8579
Stereo-couple 13	0,2085	0,2620	0,3833
Stereo-couple 14	1,9283	1,8430	2,9662
Stereo-couple 15	0,1496	0,3531	0,0331
Stereo-couple 16	1,9528	4,5073	6,1182
Stereo-couple 17	0,7578	2,4062	4,0487
Stereo-couple 18	3,1330	1,4662	3,9337
Average	***1,6304***	***1,4718***	***2,3631***

Table 1: Absolute orientation errors (mm) (Own research).

3.3 Image matching

The following steps in the photogrammetric process are performed automatically by the software. After the epipolar resampling, the stereo model has no more parallaxes, except for the X-parallax, so both images lie in each other’s extension. Other errors, such as the Y-parallax, kappa, phi and omega are eliminated. The difference in X-parallax between two points, an indication of the relative height difference, is calculated during the image matching (Mikhail, E., et al., 2001). In the VirtuoZo^{TM} software, the image matching is based on an image pyramid, area-based and feature-based matching. With feature-based matching, the form characteristics of both images are compared, where with area-based matching it’s the grey value of the pixels that's compared between both images. These two matching algorithms are combined in a image pyramid method, a series of images of the same object but at different resolutions, until a maximum correlation is reached in the image with the highest resolution.

The quality of the result of the image matching is represented by colored 'pegs'. Green pegs indicate the places in the stereo model where there is a very good matching result. In the areas with red pegs, there was little or no image matching.
The example (Figure 2) gives an illustration of the interpretation of the colored pegs. The upper example shows the matching results with not enough and badly spread homological points. The much better quality of the image matching in the lower example, indicated by the larger amount of green pegs, is reached by indicating enough homological points that are well spread over the total length of the wall. Notice the two vertical areas on the wall where there is no image matching. These are the places where a tree, standing in front of the wall, is situated on the left and right image of the stereo couple.

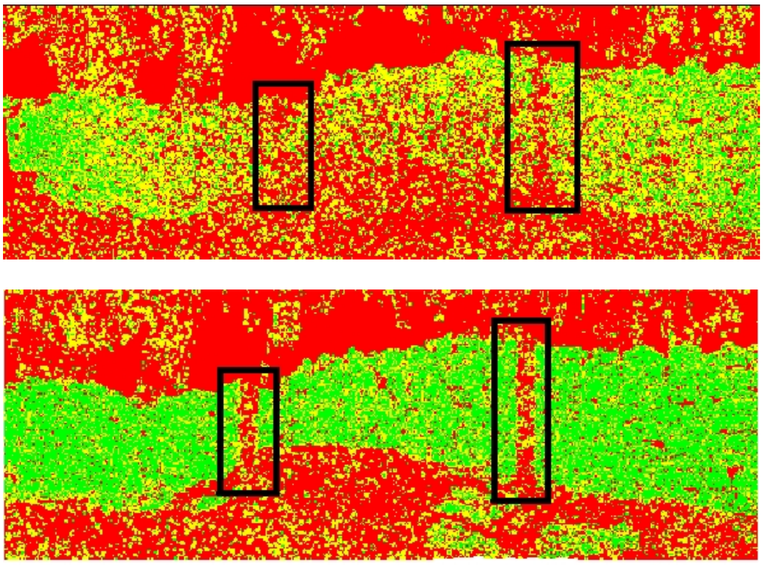

Fig. 2: Examples of image matching result (Own research).

3.4 Editing procedure

The digital elevation models and orthophotos are automatically generated, but the operator can stipulate the level of detail and the resampling method. Deformations in the final result can, in a limited way, be corrected by the operator, by editing the values for the X-parallax for specific pixels. The digital elevation model or the orthophoto can show some deformations at the edges of the walls because there is, in those places, a large height difference. This height difference between the wall and the background on the digital elevation model, causes a stretch of the edges of the wall towards the height level of the background. To solve this kind of deformation, the operator can perform a special editing procedure. By selecting a part of the pixels of the background, the operator can change the height value of this area. As shown in Figure 3 & 4, if the operator changes the height value of the background to a value closer to the height value of the wall, the height difference and so the deformation will be much less. This editing procedure has no influence on the accuracy or on the information of the parts of the DEM or orthophoto that represent the actual archaeological remnants. Only pixels of the background or of other irrelevant information in the stereo model are corrected.

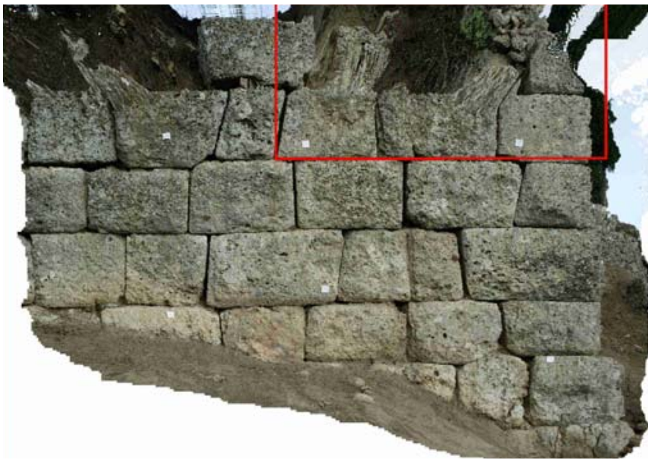

Fig. 3: Deformations at the edge of a wall (Own research). (Own

Fig. 4: Example of editing procedure research).

4. VIRTUAL RECONSTRUCTION

A three dimensional reconstruction of buildings, monuments or archaeological sites is a strong visual illustration and metric tool for scientists and visitors or outsiders. The virtual reconstruction of the orthophotos of the ancient acropolis wall of Titani was performed in AutoCAD.
The orthophotos are imported, one by one, in AutoCAD as raster images and are placed on their local coordinates. By a series of 3D alignment functions, each orthophoto is individually positioned on its correct 3D position in the general user defined coordinate system. By repeating this alignment process for each of the orthophotos, the sequence of these orthophotos represents a virtual image of the remnants of the walls around the acropolis of Titani (Figure 5).

Fig. 5: Virtual representation of the remnants of the walls around the acropolis of Titani (Own research).

5. CONCLUSIONS

The digital elevation models, the orthophotoplans and the three-dimensional virtual reconstruction of the acropolis walls of Titani are very important metric documents and instruments for archaeologists for the documentation, conservation and restoration of the archaeological monument. The importance of this metric information has recently been proven by a partial collapse of the wall. The orthophotoplans, based on images taken before the collapse, are now the only recent metric documents of the walls left.

During the photogrammetric restitution a lot of problems appeared, but solutions were found to become an accurate result at the end. A lot of the problems were due to insufficient contrast in the images, non-ideal viewing and recording points on the rough terrain or the scale difference between the two images of a stereo couple. These problems were the cause that there were not enough homological points determined by the automatic relative orientation. The operator has to select manually more homological points to reach the minimal number of a hundred to 150 points for further restitution.

Through the whole photogrammetric process, some small errors were cumulated. There are the small errors, due to the coordination transformations from the original coordinate system to the local coordinate system for each stereo model. The RMS for the relative and absolute orientation never exceeded the limits. The influence of the operator is important for the interpretation of the error results of the absolute orientation and the editing procedure. The operator determines how much and which ground control points are taken in notice for the absolute orientation and which new value the pixels get in the editing procedure. A small error is also caused with the three dimensional situation and reconstruction of the orthophotos in AutoCAD. Nevertheless, the final results are very accurate and acceptable as metric documents for the further development of the archaeological site of Titani.

REFERENCES

Atkinson, K. B. (Ed.), 1980, “Developments in Close Range Photogrammetry-1”, Applied Science Publishers Ltd., London.

Levi, P., 1982, “Atlas of the Greek World”, Equinox Ltd., Oxford.

Manzer, G., 1996, “Avoiding Digital Orthophoto Problems”, Greve, C. (Ed.), Digital Photogrammetry, An Addendum to the Manual of Photogrammetry, American Society for Photogrammetry and Remote Sensing, Bethesda Maryland, p. 158 - 162.

Meyer, E., 1937, “Peloponnesische Wanderungen. Reisen und Forschungen zur antiken und mittelalterlischen Topographie von Arkadien und Achaia", p. 11 – 16; map I; pl. II – IV

Mikhail, E., Bethel, J. S., McGlone, J. C., 2001, “Introduction to Modern Photogrammetry”, John Wiley & Sons, New York.

CONTACTS

Timothy Nuttens
Ghent University - Department of Geography
Krijgslaan 281 (Building S8)
B-9000 Gent
Belgium
Tel.: +32 9 264 46 56
Fax: +32 9 264 49 85
Timothy.Nuttens@ugent.be