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RAPID PHOTOGRAMMETRIC SURVEY AND GIS DOCUMENTATION OF PRE-HISTORIC EXCAVATION SITES

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CIPA-WG 5

Keywords: near-real time mapping, prehistoric excavation recording, simple methods, GIS

ABSTRACT

In pre-historic archaeological sites the excavation is continuous while all the movable findings and artifacts are removed after their location is recorded. Therefore, the recording phase should be rapid and accurate, for at least two reasons: the accuracy in location as well as the spatial interrelation (topology) of the findings is quite important for the subsequent archaeological study. The recording itself dramatically postpones the excavation time, since it is often performed by the archaeologists themselves using simple but inaccurate and time-consuming techniques.

This paper deals with the development of a rapid photogrammetric scheme, where multi digital images are rectified for the mapping of each excavation hole of 4m x 4m, under the constraint of non-permanent ground control. The digital rectified mosaic is back transferred to the excavation site via internet, printed and interpreted by the archaeologists on site. The photo-interpretation vector information is digitized and overlay on the images. Additional archaeological information is recorded on a GIS system, which contains the images, the vector data and alphanumeric information. The whole procedure is completed within one excavation day, and since the recording is rapid and not distracting to the actual excavation, the production is very high. Real examples from the University excavation at the prehistoric site «Toumba» in Thessaloniki are presented.

1. INTRODUCTION

Mapping of pre-historic archaeological sites is characterized by important differences in contrast to the mapping of usual archaeological sites. Rapid and accurate photogrammetric survey is in demand for at least two reasons: (a) to accurately locate the movable findings and artifacts and (b) since the spatial topology of these objects is very important for further archaeological research. On the other hand, mapping procedures, as usually being used by archaeologists and architects for monuments, buildings, houses etc. can not be used in this case because of the time restrictions..

The scope of this paper is to propose a rapid, effective and accurate photogrammetric process which can achieve the above two basic targets. On one hand photogrammetrists complete a near-real time mapping of the excavation site and archaeologists, on the other hand, have results and tools for their further research.

Research Committee of The Aristotle University of Thessaloniki has financed the research program titled «Improvement of excavation method using photogrammetric techniques and an automated documentation system in the University archaeological site «Toumba» in Thessaloniki».

2. DESCRIPTION OF AREA AND EXCAVATION PROCESS

«Toumba» is today one of the most well known neighborhoods in Thessaloniki. The name of the neighborhood became from an impressive in width and height hill (this is the meaning of word «Toumba» in Greek) which commands the whole area. Today, this area is 3 Km far away from the sea and its highest point has an altimeter of 80 m from mean sea level. The site is on the hill occupying 18000 m^2 and rising 22 m high (Figure 1).

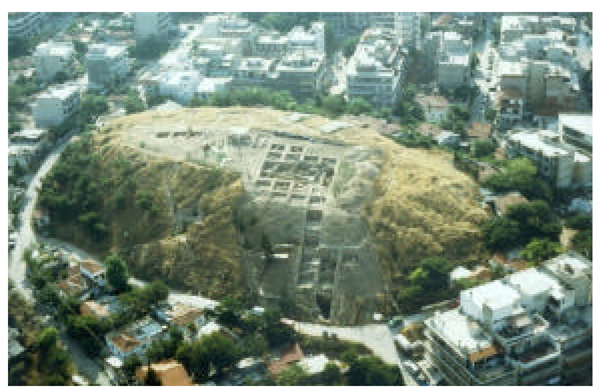

Figure1. Aero-image of Toumba archaeological site (Andreou and Kotsakis 1994)

The archaeological site was a settlement with various uses through time. All the findings indicate that the area has been inhabited at least since the Late Bronze Age (starting

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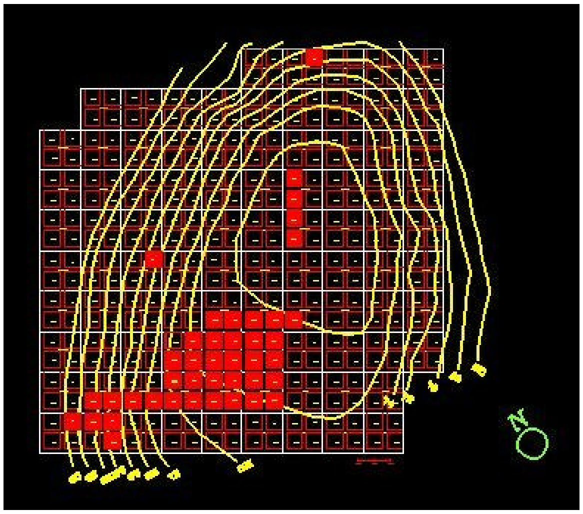

Figure 2. Topographic map showing the areas (fill color) that have been excavated

from 15th century BC) and possibly even in the Middle Bronze Age (in the 15th to 20th century BC).

The excavation process on the site has been continued for more than a decade, with about 7% of the whole area having been investigated (Figure 2). The two main areas that have been excavated cover part of the top and part of the western hillside.

The excavation proceeds on a "grid of cells" (excavation holes) basis. Each cell is a 4m x 4m rectangle and between the cells a pass of 1m width is left. When the excavation proceeds, the passes are eventually destroyed and the neighboring cells are united to bigger areas.

3. MAPPING OF AN EXCAVATION SITE

Mapping of the excavation is a continuous work, in a period of a day, and contains all the steps as shown in the workflow below (Figure 3).

Early in the morning, when an excavation day starts, image acquisition and control points establishment take place in the excavation site. CP's are placed and measured just one time, at the beginning of the excavation period. This is the field work. On the other hand, and before the end of the day, rectified images have already been created and are back transferred via internet to the site, so that archaeologists are able to proceed with the interpretation and the information collection for the GIS development.

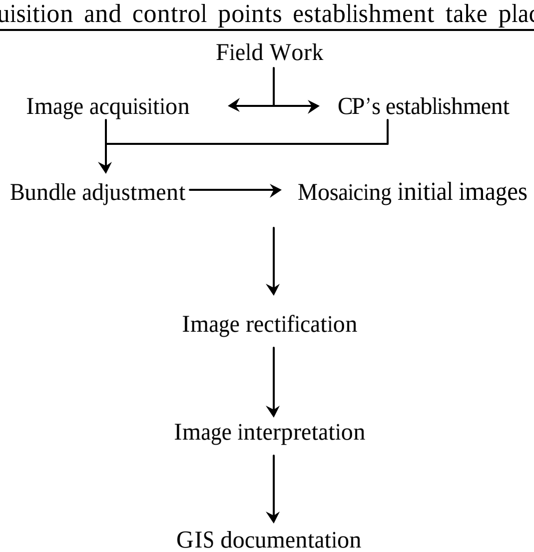

Figure 3. Workflow of mapping procedure

3.1 Image acquisition

Figure 4. Kodak DCS 420

A digital camera has been used for image acquisition, in order to minimize the time for image preparation. In this case, the Kodak DCS 420 digital camera has been used. A number of several images were taken from two stages and from a height of approximately 5 m, using a small ladder. There is one basic advantage and one basic disadvantage using this camera. The advantage is that very quickly, images are ready for further photogrammetric work. On the other hand, the small sensor format, leads the user in taking more images in order to cover the whole object. A number of 10 images, like the one presented in Figure 5 were taken per stage.

KODAK DCS 420 Digital Camera	
Camera:	Nikon N90
Sensor:	1.5 million pixels
	13.8 mm x 9.2 mm
	pixel size 9ìm
	36-bit color
Lens:	Nikon 28 mm, F-mount

3.2 Control point establishment

The other part of the field work is the control point (CP) establishment. It must be mentioned that CP's are placed and measured just one time, at the beginning of the excavation period (~ 1 month). CP's are located in various positions (Figure 5), in the lower level as well as in paries of the excavation hole. The basic problem in the photogrammetric process is that due to excavation progress a number of CP's are lost, mainly these which lie on the floor. This leads to use tie points of a previous day solution as control points in a following day's images.

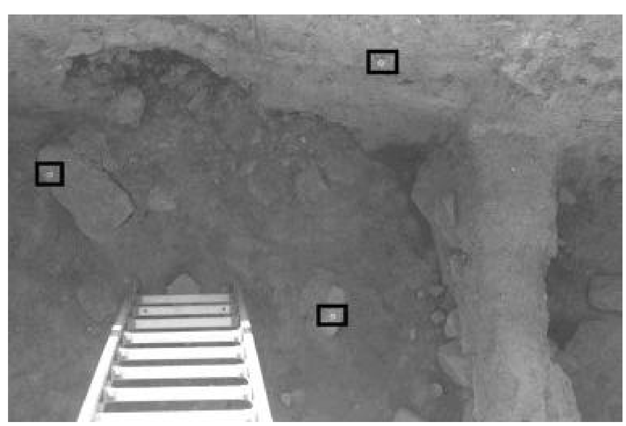

Figure 5. An example for CP's establishment in an excavation cell

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3.3 Bundle adjustment

Images, such as one presented in Figure 5, are inserted in bundle adjustment process, in order to calculate the XYZ coordinates of points that lay in the lower level of the excavation cell. These points are used later, in an image rectification process. In addition, after consulting the archaeologists, tie points are calculated in areas that will not be excavated temporarily. These tie points will be used in a next day bundle adjustment process if the number of control points is not adequate.

When enough control points exists in the bundle process, an RMS error of object coordinates (empirical accuracy in object space) is computed from the comparison of the check points coordinates with the reference coordinates using the formulae (1):

$$\mu_X = \sqrt{\frac{\sum \left(X_i^r - X_i\right)^2}{n_X}} \qquad \mu_Y = \sqrt{\frac{\sum \left(Y_i^r - Y_i\right)^2}{n_Y}} \qquad \mu_Z = \sqrt{\frac{\sum \left(Z_i^r - Z_i\right)^2}{n_Z}} \tag{1}$$

In this case, RMS is ranged 5–7 mm for X and Y coordinates and 12–15 mm in Z coordinate. When not enough control points exists, and tie points from an earlier solution are used as CP's, RMS is ranged 6-8 mm for X and Y coordinates and 15-17 mm in Z coordinate.

3.4 Mosaicing initial images

As it has already been mentioned a number of 10 images (approximately) are taken per cell. These images are mosaiced with an affine transformation:

$$X = a_1 x + b_1 y + \Delta X \qquad Y = a_2 x + b_2 y + \Delta Y \tag{2}$$

without using a scale factor. Common points for transformation are taken only in the ground level of excavation cell because only this part of the image is needed for rectification and moreover for digital drawing production. The result of this process is shown in the upper image of Figure 6 (part of the whole image – 4 images have been merged).

3.5 Image rectification

Points that will be used in image rectification (projective transformation) have already been calculated through bundle adjustment process. These points have the best distribution in the excavation cell and the only restriction is that they must lie in the ground floor.

In any case let's examine how elevation (mainly this which constitutes to the abnormalities of the ground floor) affects the accuracy of the final result (digital drawing).

Figure 6. Upper: The initial image, Below: The rectified image

Equation (3)

$$\Delta r_i = r_i \frac{Z_i}{D} \tag{3}$$

shows the radial shift which will be observed in *i* point due to elevation existence, where Z_i is point elevation and D is the image acquisition distance.

Assume that the maximum permissible error –when designing- in drawing scale is *d* and also that maximum elevation difference appeared in the edge of the image $(r = r_{max})$ which the worse case. A new equation (4) is defined:

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$$Z = \frac{d\,s\,c}{r} \quad (4)$$

where:

d is the designing error, c is the focal length, r is the radial shift, s is the drawing scale and Z is the elevation.

In this case where $c = 28\text{mm}$, $r = 9.2\text{mm}$ (camera format 13.8 mm x 9.2 mm), if the permissible designing error is $d = 1\text{cm}$ in a drawing scale 1 : 20, the maximum permissible elevation difference must not exceed 60 cm. This should be bared in mind when the rectified image is used for digital drawing production. If an object has an elevation difference from the mean level of ground floor (excavation cell) larger than 60 cm, it will not be used in the rectification process.

When points computed from the bundle adjustment compared with the ones from the rectified image, an error of 10-15 mm observed in X and Y coordinates.

3.6 Image interpretation

During the excavation day period, the digital rectified images are back transferred to the excavation site via internet. These images are printed and interpreted by archaeologists. The photo-interpretation vector information is digitized, firstly by hand and later in the office, overlay on the images and saved in digital format. Additional archaeological information is marked on the rectified images and in special paper forms, which consist the indispensable material for database creation.

3.7 GIS documentation

3.7.1 The Space

The hill of Toumba (Figure 1) has been created by continuous deposits of layers through time, pilling up as settlements were built one on the top of the other (Koussoulakou and Stylianidis 1999). But in excavation process it was proved that in most cases, parallel layers were not found in reverse time order. This means that artifacts or elements of earlier layers were found in later layers. This mixing of the archaeological findings, is one of the most interesting things in the case of Toumba archaeological site.

Archaeologists in order to define the relationship between findings and layers, establish a term, stratigraphy. As it was noted (Koussoulakou and Stylianidis 1999), stratigraphy is the recording of the successive deposition of layers and findings in 3D space. So, it was clear and necessary to built a GIS that manipulates 3D drawings. A question appeared on how 2D drawings, became from the photogrammetric process will be "transformed" in 3D drawings. The 2D drawings were overlay one over the other to produce a 3D drawing.

3.7.2 The Time

A classification of time has been done by archæologists, called "phases", to describe findings and artifacts as belonging in a specific phase. Phase can be assigned to a prehistoric object more clearly than its exact chronology and is generally assigned to it by means of the object's characteristics (from, appearance, comparison etc.)

In Toumba site, time was divided into six different phases (Andreou et al. 1990). Some of the them were divided in sub-phases during excavation process because of the complexity of the finds in a specific period.

3.7.3 The Themes

Findings can be divided into two basic categories:

- architectural constructions having different functions (i.e houses, storing places etc.) and
- mobile elements, which are small finds of various materials and uses.

Mobile elements have divided into the following main categories: pottery, stone, metal and bone.

All finding's characteristics are recorded on paper forms during the excavation. This information is used to create the database tables for the GIS.

4. CONCLUSION – FURTHER WORK

In this paper a rapid, effective and accurate photogrammetric procedure is proposed. The technology of digital cameras gives the opportunity to minimize the process time due to the fact that very fast, images are ready for further work. In Toumba case, images were taken using a digital camera early in the morning and a few hours later rectified images were ready for interpretation.

Internet technology was used for sending data from the archaeological site to the lab and few hours later products were back transferred, printed and interpreted by the archaeologists. Digital images and drawings as well as additional archaeological information was recorded in a GIS system.

A basic improvement that is necessary for more rapid and effective procedure is the minimization of used images. A small construction will be useful and offer the ability to acquire images from a height of 6-8 m.

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