Archaeological Surveys in Greece Using Radio-controlled Helicopter

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Key words: Orthophotograph, bundle, platforms, photogrammetric recording and documentation, special methods of surveying and mapping, precision, visualization.

ABSTRACT

This paper reports on the experienced gained from many projects using a radio controlled model helicopter, as a semi-metric camera platform. The modified helicopter carries a Rollei Metric camera and a small video camera as a viewfinder. The combination of low height aerial photography and dynamic platform control, is very attractive to photogrammetrists. Problems as well as solutions, possible improvements and statistics concerning commercial orthophotograph production in seven sites will be discussed.

Speed, overall accuracy and appeal to the end users of the final products, is prosperous. Each case had different difficulties, with Larisa's case being the most challenging, due to its height differences. Karla's site was the biggest project with 196 photos taken, and a 121 photos aerial triangulation. The ancient theatre with vertical walls of up to 3 m height, causing large occlusion with the 50 mm lens, was the most challenging part. The final products were colour orthophotomaps of 1:50 scale. Other major problems which will be analysed are the aerial triangulation, concerning irregularity of aerial photographs, model formation, epipolar imagery generation and tilts, digital terrain modelling and model connection, contour generation and exclusion of man made features, stone plots.

Περίληψη

Το άρθρο αυτό παρουσιάζει την εμπειρία που συγκεντρώθηκε μετά από πολλές αποτυπώσεις αρχαιολογικών χώρων με χρήση τηλεκατευθυνόμενου ελικοπτέρου εξοπλισμένο με μηχανή RolleiMetric 6006. Επιπρόσθετα το ελικόπτερο είναι εξοπλισμένο και με μικρή κάμερα η οποία μεταδίδει στο έδαφος σε πραγματικό χρόνο το οπτικό πεδίο της φωτομηχανής. Ο συνδυασμός αυτός δίνει λύση στο πρόβλημα της επίγειας φωτογραμμετρίας αφού επιτρέπει την τοποθέτηση της φωτομηχανής σύμφωνα με το οπτικό της πεδίο. Τα προβλήματα που παρουσιάστηκαν στη διάρκεια των εφαρμογών και οι λύσεις τους, καθώς και στατιστικά παρουσιάζονται αναλυτικά για επτά περιπτώσεις.
Η ταχύτητα λήψης και η χαμηλή όχλησης του αρχαιολογικού χώρου είναι ελκυστικά χαρακτηριστικά της μεθόδου για τους αρχαιολόγους, ενώ η τελική ακρίβεια και τα προϊόντα εντυπωσιακά. Κάθε περίπτωση είχε διαφορετικές δυσκολίες, με την περίπτωση του αρχαίου θεάτρου της Λάρισας να είναι η πιο προκλητική, λόγω των υψομετρικών διαφορών. Η περιοχή της Κάρλας ήταν η πιο μεγάλη εφαρμογή με 196 φωτογραφίες, εκ των οποίων οι 121 χρησιμοποιήθηκαν για τον αεροτριγωνισμό. και της συνολικής έκτασης. Κάθετα στοιχεία όπως οι τοίχοι με ύψος μέχρι τρία μέτρα δημιουργούσαν σοβαρά προβλήματα στην ορθοφωτογραφία, λόγω περιοχών χωρίς πληροφορία σε κάθε φωτογραφία. Επιπρόσθετα

προβλήματα αποτελούν ο αεροτριγωνισμός φωτογραφιών ακανόνιστης διάταξης, ο σχηματισμός μοντέλων για στερεοσκοπική απόδοση, η συλλογή ψηφιακού μοντέλου εδάφους και σωστή σύνδεση ανάμεσα σε όλα τα μοντέλα, καθώς και η δημιουργία ισοϋψών.

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1. INTRODUCTION

The fast, accurate, cheap survey and visualization of archaeological sites is a trivial demand, but far from fulfilment.

The necessity of monument surveying is clear. Restoration, recording, reconstruction, or even study of an archaeological site require accurate plots. Traditional method of string grids does not meet the accuracy standards and simple survey of the site can only provide a plan with a few accurate points connected with vectors, without any further information. Both methods have the disadvantage of extra people working within the archaeological site for a prolonged period of time, which increase the possibility of accidental destruction of important findings.

Photogrammetry had a strong case in archaeology, but until now end users were discourage by cost, time needed to develop photographs and the fact that the final result was still a vector plot. Evolution of computers and the passage from analytical stereo plotters to digital ones, re-established photogrammetric procedures and products as well as applications.

Under this new aspect, orthophotographs are a very attractive photogrammetric product that can support documentation, recording as well as restoration purposes (Baratin et al., 2000). It is quite clear that photographic information with surveying accuracy form an unbeaten combination. The only thing better than this is a full 3d rendering of the site providing to the end user the ability to precise measure 3d distances between points himself (Dorffner et. al., 2000). These kinds of applications are excellent provided the end user is computer literate and has access to a powerful portable computer for in site use. Even if he can overcome the aforementioned holdbacks he will still not have in hand a paper copy for overview and communication purposes with workers.

From this aspect orthophotographs are still the best possible solution. What is still a disadvantage in comparison with ground survey is processing time and cost.

Use of low altitude platforms for photography have been reported in many cases (Miyatsuka, 1996, Theodoridou, et. al. 2000, Zischinsky et. al., 2000, Karras et. al. 1999, Ioannidis et. al., 2000). Kites, balloons, cranes, helicopters, radio controlled model helicopters, rope-way, fish rods and well buckets are only some of the ingenious methods photogrammetrists are using for low altitude photography.

In most of these cases, the ideal layout of the photographs is not attained. This is reported in the case of the radio controlled model helicopter (Tokmakidis et. al., 2002) and in the case of the balloon (Karras et. al., 1999), and generally in any case where the photographer cannot fully control the position (kites, balloons) or he is not physically behind the camera (rope-way, fish rods, well buckets). Although the radio-controlled helicopter with a radio link for transmission of the imaged object in the ground does not seems to suffer from the aforementioned problems, this is not the case. Even highly skilled operators cannot fully control the movement of the model helicopter due to random wind blows and the inherent manoeuvrability of the helicopter as a conceptual design.

Therefore the scale is not equal between photographs and overlaps are far from the ideal (fig. 1). Model helicopter though can easily capture an excessive number of photographs and therefore allow for selection among them. Use of a full-scale helicopter with a large format camera (13x18 cm) and the operator on board as reported by Ioannidis et. al. (2000) is the case which simulates the most aerial photography. On the other hand there are some limitations such as:

– the necessity of a large format terrestrial camera in order to keep the number of photographs as low as possible,
– the necessary approval of the flight plan under the proper authorities, especially for such low altitude flights,
– the limited time in conjunction with the cost,
– availability and
– outsourcing

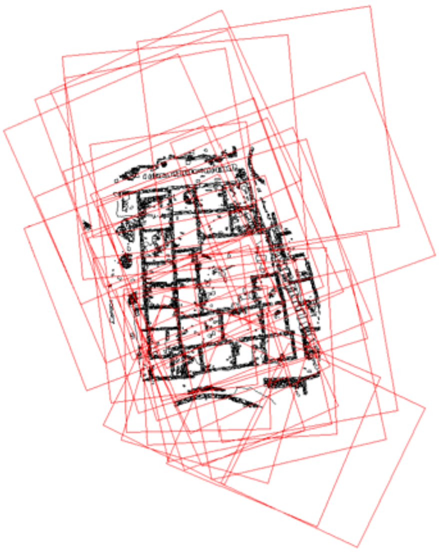

Figure 1: Footprints of aerial photographs on 1st Dilos site

In this paper the experience gathered from four independent projects using photographs from the radio controlled helicopter will be analysed. The method used is described in detail by Tokmakidis and Skarlatos, 2002.

2. ORHTOPHOTOGRAPH PRODUCTION IN ASPROVALTA EXCAVATIONS

This project was concerned with 1:100 colour orthophoto production over a 1400 sq. meters archaeological site of an ancient cottage in Asprovalta (fig. 2). It should be noted that Dr.

Beleni, the archaeologist who was supervising the excavations on the site was not familiar with orthophotographs and this product was a new approach for her.

This was the first commercial project with the radio-controlled helicopter and therefore a number of unexpected problems were confronted. Statistics of this project appear in table 1. The scale of the photography relatively to the final orthophotomaps scale was not very well calculated, although it has been proved afterwards that the achieved quality on the final printout was very good and there were no complaints reported by the end users. Although this project has been planned for 1:100 scale final orthophotograph, it was also printed in 1:50 and it was reported as most satisfying.

The three dimensional plotting was quite uncomfortable because strong tilts and scale differences do not allow for comfortable stereo viewing. This case holds for all projects.

Another result of the lack of experience was the triple visit of the site due to small gaps on coverage, spotted after development of films. The project was completed rather hasty due to lack of time because of these recursive visits.

Figure 2: Final orthophoto on Asprovalta (original 1:100)

3. ORTHOPHOTOGRAPH PRODUCTION AND VECTOR PLOT IN DILOS EXCAVATIONS

The second project was also concerned with colour orthophotograph production of 1:100 scale in Dilos island. In addition, Prof. Chatzidakis, who is the head archaeologist for the excavations on the site, asked for the traditional vector plots as well. Although open to ‘new’ technologies wanted the vector plot for presentations purposes among his colleagues. Problems confronted in this case were raised from the fact that the site was located on an uninhabited island, which operates during work hours as a site museum, without any amenities, electricity or cars. The radio helicopter and all additional hardware (GPS receivers, Rollei Metric etc) had to be carried on foot from harbour to the particular location, a distance of 1 km. The particular day of the photography, the wind was 6 beaufort, and there was a serious consideration whether the helicopter could fly in such contitions. The model helicopter surprised us all by completing the photography without any problems and raising our esteem to it. Statistics can be viewed in table 1.

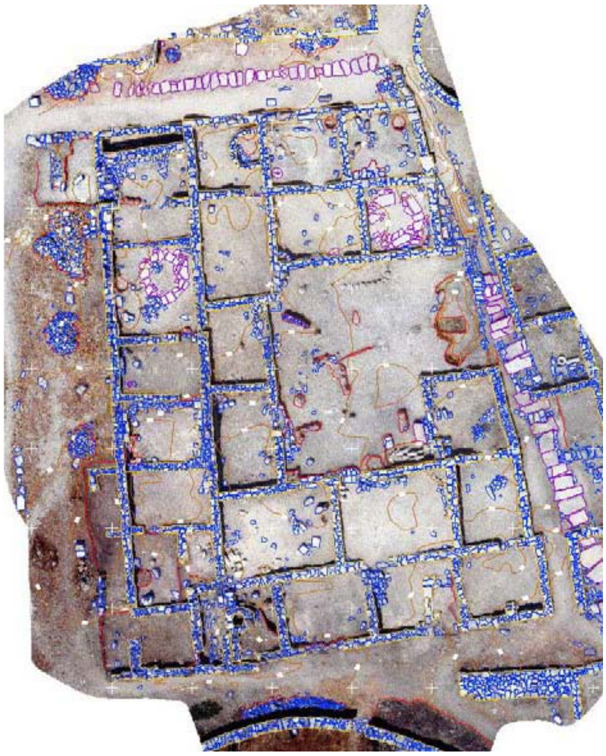

Figure 3: Dilos final mosaic with vector and contours overlaid (original 1:100)

Since processing time was amble, this project has been regarded as a pilot project, done with great detail and rather slowly than what is commercially accepted. The final product can be viewed in fig. 3. The final product was plotted and delivered in 1:50 scale also, without any problems.

The second visit was for a larger area of 5000 square meters, but in order to reduce cost, the scale of the final product was smaller (1:250). The helicopter reached the operational ceilling in order to photograph in 1:1250 scale with the wide 50mm lens.

4. ORTHOPHOTO PRODUCTION IN LARISA'S ANCIENT THEATRE

Larisa's ancient theatre has been discovered a couple of years ago under a street and twelve apartment buildings in the city centre. The buildings have been demolished and the theatre now is under reconstruction.

Detailed plots of 1:50 scale were necessary, showing current state. Mr. Tziafalias, the responsible archaeologist for the restoration and conservation of the theatre, have been informed about orthophotographs and directly asked for such product. The total area of the theatre was 5400 square meters, with a height difference of 13.5. In particular, within the scene there were height differences of 2.5 meters in the walls, which from 22 m which was the selected flying height, develop a 1:9 ratio of object depth against camera-object distance. The expected occlusions were very big and therefore excessive number of photographs was taken over the scene.

In order to correctly orthorectify the photographs a detailed DTM was collected. It was even more intense and detailed than 3d plots of features, since all features had to be double plotted with one line describing the upper edge and another on the lower one. These lines were then divided in 5 cm steps, creating points in these intersections. Additional points were measured in order to describe the surface exactly. The final DTM has been created using only points, without any breakline information. Triangles created were not mixing information from different levels due to their high density in comparison to simple height points. DTM collection was fully manual and time consuming.

In addition, almost all photographs over the scene were rectified and the best ones were selected for mosaicking. A lot of work was necessary in order to connect many orthophotographs so that the final result to be acceptable and the walls vanished from the final product (fig. 4). The final mosaic was retouched for tone balancing and elimination of stretching in some areas with strong relief.

Figure 4: Final mosaic of Larisa's ancient theatre (original mosaic of 1:50 scale)

5. FACADES AND SECTIONS OVER THE SCENE OF THE ANCIENT THEATRE OF LARISA

As part of the theater's recording and restoration, sections and facades of the scene at 1:25 scale were also needed. Since the surfaces were rather flat and in order to cut down cost, simple rectification of photographs was selected as the most appropriate approach. Twentyone independent sections and facades were requested. This project was the most intense in terms of photography. A specialized group of three people was working for twenty hours in order to stick 321 control points in inner and outer surfaces of the scene, measure the network and the control points, and finally take 131 photographs.

Since the control points should be measured with 1.25 cm precision, a traverse with eleven stations was established and measured with reference to a previously established network of four stations. From each station at least four angles and two distances (measured at least twice) were measured to known and unknown stations. Observations were used for least squares solution. The solution had residuals of 0.6, 0.9 and 1.3 cm in X, Y and Z respectively. From these stations the 321 control points were measured using angle intersections or distance and angle measurements. Relative accuracy of the control points is less than 2 cm.

In order to perform projective transformation on the photographs, simple in-house software was created and used to calculate the best fit (using least squares) vertical plane passing through the control points of each section or facade. The new coordinates were calculated, with the Z being the distance from the best-fit surface.

Although special care has been taken in order to view at least four control points in all photographs, where this was impossible a foul triangulation was taking place. Although the photographs were strongly converged, aerial software used had no problem solving the bundle adjustment. The exterior orientation was then used to produce orthophotographs at zero elevation.

Figure 5: Three meters high corridor. The dark part was under shadow and processed with wallis filtering, prior to mosaiking

6. KARLA SITE

Karla archaeological site was revised because archaeologists wanted the progress of the excavations. On the second time they requested a more detail orthophotomap of 1:50 scale over an extened area (fig.6). Photography and ground control measurements lasted 2 days, covering 8800 square meters. The photographs taken and proccesed equal a large aerial photography project. In total 196 photos were exposed and scanned, while 121 were used for aerial triangulation. Due to large overlaps and difficulties in model setup, 43 models were used to cover the area with DTM. The process of DTM was laborious due to the small coverage of the 1:300 photos.

The final product was an orthophotomap with 0.01 m pixel size and was divide in 12 plots.

Figure 6: Karla site during excavations

7. DERVENI SITE

Derveni site was discovered, just as Asprovalta; during the Egnatia natinoal road construction. Photography took place seperately, because initially only half site was exposed and the rest was discovered a couple of days later. The Egnatia SA, constructor of the national road, wanted a very fast recording of the site in order to proceed with the road construction. The helicopter flew the next day and took photographs of the site along with control point mesurement in EGSA 87 (National Greek Geodetic Datum). A couple of days later, during the photography scanning, Egnatia SA asked for a second session of photography because a new part was discovered in the same site. A new photography took place, with new control points and the final map of 1:50 scale was flawless (fig. 7).

Figure 7: Derveni site. Orthophotomap from two different photographic sessions

8. CONLUSIONS AND DISCUSSION

Experience is an expensive and invaluable asset in such projects. Expensive because it is gained the hard way,by the try and failure method. This is mentioned particularly for the first project. Absence of the onboard video camera lead to a triple visit for what today is a four hour job.

The communication between the helicopter operator and the 'navigator' who looks the video and triggers the RolleiMetric still needs a lot of work. Guiding helicopter movement by seeing only the video is difficult, not to mention that the operator can only rarely hover on the point the 'navigator' wants. That's the main reason why the layout of the photographs is almost random. We currently work in

In all cases the aerial bundle software performed well. Large attitudes of up to 75 degrees on phi and omega did not cause any problems at all. The main problem is the uncomfortable viewing of the operator during three-dimensional plotting. A self-levelling mechanism of the photographic camera would be welcomed, along with a lock mechanism of the flying height. Variations in flying height cause scale discrepancies, which deteriorate the situation. These are our next considerations for improvements.

Most of the blocks, with large overlaps and strong convergent geometry, display unusually large RMS error on height, in comparison with horizontal RMS. This phenomenon can be explaned if one considers the small base to height ratio, which leads to poor solution in height estimation.

Another interesting fact is that the scale of the photography and the final plot reaches 1:10 ratio, which is out of the aerial photogrammetric practise.

A very important advantage of orthophotomap is the ability to expose infrastructure and layers of buildings constructed during different eras.

What's common in all cases is the fact that the accuracy implied from the scale of the final product does not meet. It is very expensive, and unviable commercially to try to reach accuracies of 1.25 cm in 1:50 orthophotographs. Archaeologists and architects are not familiar with the relationship between scale and accuracy and therefore consider these terms independent from each other. Therefore they happily accept a really big discount for a product printed at scale 1:50 with accuracy standards of 1:100.

	Aspro-valta	Dilos 1st	Larisa theatre	Larisa scene (sections and facades)
Orthophoto sc.	1:100	1:100	1:50	1:25
Area [sq. m.]	1400	1700	5400	1250
Camera & Lens	50mm	50mm	50mm	50mm and 80mm
Control points	10	30	54	321
Photographs	48	72	144	131
Photography and control [hours/people]	4/3	8/3	9/4	20/3
Av. photo sc.	1:520	1:480	1:450	1:180
Photographs used	8	30	79	86
Scanning [dpi]	1800	1800	1800	1200
Scanning [man days]	1	2	6.5	5
Triangulation model preparation [man days]	3	4	9	22
AT : RMS control X,Y,Z [cm]	2.2 2.7 5.6	1.8 2.2 3.9	1.2 1.3 2.4	Variable < 2.0
Manual DTM [man days]	2	7	15	-
Orthophotos [man days]	1	2	10	8
Mosaics [man days]	1.5	5	17	13

	Aspro-valta	Dilos 1st	Larisa theatre	Larisa scene (sections and facades)
3d plotting [man days]	-	3	-	-
Retouch, preparation printing [man days]	1.5	3	18.5	20
Total time [man days]	10	26	76	68
# of plots	1	1	9	4
Pixel size [m]	0.01	0.01	0.05	0.03

	Karla 1st	Karla 2nd	Derveni	Dilos 2nd
Orthophoto sc.	1:250	1:50	1:50	1:250
Area [sq. m.]	4500	8800	1100	5000
Camera & Lens	50mm	50mm	50mm	50mm and 80mm
Control points	48	70	40	20
Photographs	81	196	111	63
Photography and control [hours/people]	9/3	16/3	16/3	8/3
Av. photo sc.	1:1300	1:300	1:500	1:1250
Photographs used	43	121	48	31
Scanning [dpi]	1800	1800	1800	1800
Scanning [man days]	3	7	2	2
Triangulation model preparation [man days]	6	11	4	3
AT : RMS control X,Y,Z [cm]	3.3 2.8 9.0	0.9 0.8 3.1	1.2 1.3 1.3	0.9 0.8 1.4
Manual DTM [man days]	10	16	7	7
Orthophotos [man days]	5	10	3	3
Mosaics [man days]	5	15	6	2
3d plotting [man days]	-	-	4	-
Retouch, preparation printing [man days]	4	18	10	7
Total time [man days]	34	79	38	25
# of plots	1	12	2	1

	Karla 1st	Karla 2nd	Derveni	Dilos 2nd
Pixel size [m]	0.05	0.01	0.006	0.05

Table 1: Comparison of projects. Man days is the workload for each task. Tasks such as DTM collection, plotting etc, can be done simultaneously or in shifts, hence reducing delivery time. AT: Aerial Triangulation

If we had decided to follow the rull of thumb at scale 1:25, saying that control points should have three times better accuracy than the expected from the final product, meaning that control points should have been measured with ±0.2 cm, the cost of 321 control points would have raised more than the total budget and the customer move to traditional techniques, which are no better.
We shall not forget side products such as the complete DTM of the area. Contours might not be the best possible way to represent the 3rd dimension, especially when man-made features are present. What the end users considered interesting when presented to them, was a red-blue print of orthorectified imagery. This and a photo realistic representation (Ioannidis et. al., 2000) are the best applications of a good DTM.

From Larisas project became apparent that orthophotograph production might not be faster, nor more economic than line plotting but it is much better as a scene representation to the final user.

Time needed for film processing and scanning is considerable when in comparison with the whole project. A digital camera with high resolution might be the answer to this problem. Resolutions are now starting to compete with film and time for downloading the image from the CCD to memory pose two serious holdbacks. Until they reach the same resolution level, in order to keep the same number of processing photographs and models, usage of such camera is not considered.

Another advantage of the model helicopter is the speed of the photographic procedure. The helicopter can shoot a twelve-shoot film in less than 10 minutes. The most competitive platform, the balloon, is much slower. In addition requires three people handling it and they have to walk simultaneously over the site in order to position it. On the other hand height can be better adjusted and layout is similar or better. With a 6 beaufort wind speed though, the balloon is unlikely to be able to complete the task and therefore we still consider the model helicopter as the better platform for fast acquisition of photographs in such cases.

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BIOGRAPHICAL NOTES

Dipl.-Ing, M.Sc. Dimitris Skarlatos, born April 27th, 1972, started his studies on surveying in 1990, at the National Technical University of Athens, having been accepted first in rank. He received his Diploma Degree in June 1995. After receiving award for his diploma thesis from the Technical Chamber of Greece and a scholarship from Athens Academy, he continued his studies in photogrammetry at University of London (U.C.L) and receiving a M.Sc. with distinction in 1996. He was also awarded Hotine Exhibition Award from U.C.L. and the Prize for photogrammetry from the Royal Institute of Chartered Surveyors (R.I.C.S.). Back in Greece he was granted an award by Athens Academy on surveying and a scholarship from Greek Scholarship Institute for a Ph.D. research. Since 1998, he has worked as project manager in a number of consulting companies. Since 1999, he works as photogrammetry manager in GeoAnalysis S.A., supervising production and guiding research. Since 1999, his Ph.D. research is focused in digital image matching techniques. He has been involved in a number of close range and aerial photogrammetric research projects. He is author or co-author in a number of scientific publications and assistant lecturer in National Technical University, at the subject of photogrammetry.

Dipl.-Ing, M.Sc. Sofia Theodoridou, born October 3rd, 1967, started her studies on surveying in 1986 at Aristotle University of Thessaloniki. She received her Diploma Degree in June 1991 and started working as research engineer at Aristotle University of Thessaloniki, participating in G.I.S. research projects, until 1993. In 1993 she continued her studies in Photogrammetry at University of London (U.C.L). Since 1994, when she received her M.Sc. Degree, works as Managing Director in Polyline S.A. During these years she has supervised a number of commercial projects, created and guided the research and development department of the company, co-ordinated numerous research projects, national and international. She is author or co-author in a number of scientific publications.

Dipl.-Ing, Dionisios Glabenas, born January 20nd, 1976, started his studies on surveying in 1993, at Aristotle University of Thessaloniki. He received his Diploma Degree in February 1999 During his last educational year he participated in G.I.S. research projects and creation of educational multimedia tool for Cadastre. He worked as surveyor engineer in construction projects from 1999 up to 2001 when he started working in GeoAnalysis SA as project manager and has been involved in several projects and researches. His current position is photogrammetry manager.

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