

MULTITEMPORAL ARCHAEOLOGICAL IMAGERY TO MODEL THE PROGRESS OF EXCAVATION

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ABSTRACT:

The progress of excavation work has been regularly recorded by taking images during the excavation seasons of Finnish Jabal Haroun Project. This multitemporal archaeological imagery is collected during 1998-2003. Images have been taken daily from the archaeological excavation site, namely the monastic complex of St. Aaron located near Petra, in Jordan. The images have been taken with non-metric digital camera and with non-metric video camera with varying imaging strategies. Large amount of images are convergent panoramic images taken by rotating the camera on the tripod around the projection center. Also separate images and some stereo pairs are available. The aim in the project has been to develop simple documentation methods for archaeologists and therefore minimum preparations are needed during the fieldwork to minimize the disturbance for excavation work. Use of signalised control points is minimized. During excavation season basic geometry of the site has been measured with a tacheometer. In some cases natural control points have been measured with the tacheometer and marked on the printouts. The 3D tacheometer data can be used for solving the orientation parameters. The possibilities to use the collected imagery are presented. The progress of excavation is visualized in one example area – the chapel. The images have been organized by date and their rough orientation relating to the chapel is known. The images are taken from different angles relating to the excavation trenches (the chapel has been excavated in several steps). Therefore a simplified 3D model is used as a visual aid to show the orientation relating to the model. The user can study the available imagery and select the appropriate images for further processing. The original image orientation can be re-fined in case the images are utilized for detailed modelling of the site. The preliminary tests confirm that it is possible to complete the 3D modelling of the excavation site using the collected imagery and basic photogrammetric methods.

1. INTRODUCTION

This paper presents how multitemporal archaeological imagery has been collected during the Finnish Jabal Haroun Project (FJHP). It will describe the image collection process utilized currently and how it has been developed during the project. Utilization possibilities of the collected imagery are presented.

Usually archaeological sites are modelled when fully excavated. However, the progress of excavation is especially interesting, because in many cases the architecture of the site has been modified several times in the past due to various reasons. These various phases of the archaeological site are of special interest for archaeologists. Unfortunately, quite often some of these phases have to be removed during the excavation work.

More generally speaking, the excavation work is non-repeatable and the researcher more or less destroys the research subject. Also some unexpected events, like collapsing of an excavated wall, can reduce the data collection possibilities. Therefore special attention has to be paid to the continuous documentation. The imagery taken during excavation work will be an important data source for the current and future archaeologists. By taking images regularly, it is ensured that also the data, which doesn't seem to be important at the time, can later be measured from the georeferenced images and thus be documented in the same coordinate system.

1.1 Finnish Jabal Haroun Project (FJHP)

The Finnish Jabal Haroun Project (Frösén, et al, 2002) takes care of the archaeological excavations, conservation work and publication of the results at the Monastic complex of St. Aaron and its close environment. The excavation site is located on the upper plateau of Jabal Haroun (Mountain of St. Aaron) near the ancient city of Petra, in Southern Jordan. The director of the multidisciplinary project is Professor Jaakko Frösén, Helsinki University. Beside excavation, an essential part of the project is the archaeological survey conducted in the near environs of the mountain. So far, the FJHP has conducted an archaeological reconnaissance (1997) and six full excavation seasons (1998-2003).

The Institute of Photogrammetry and Remote Sensing at Helsinki University of Technology (HUT) has been taking part into FJHP since 1997. The team of photogrammetric researchers led by Professor Henrik Haggrén has worked both at the excavation site as well as in the archaeological survey. However, this paper concentrates on the terrestrial photogrammetric work at the excavation site where the progress of excavation work has been regularly recorded by taking digital and video images.

1.2 Excavation site

The remains of the monastic complex cover ca 72 m N-S x 48 m E-W. The excavations have proceeded following the stratigraphic principles i.e., through the carefully recorded

removal of distinguishable layers, naturally or humanly deposited. So far, during six excavation seasons, 25 large excavation trenches have been fully excavated. The main techniques to collect data for the 3D modelling have been the use of tacheometer and terrestrial photogrammetry. In addition to this, archaeological notebooks including sketches and photos are important data sources during 3D modelling work.

The isolated location of the excavation site causes its own restrictions. Limitations relating to the electricity and working environment (the team lives in the Bedouin tent beside the site during the excavation work) have affected to the routines. Length of the excavation seasons has varied from 5 weeks to 2 months. The limited time on the excavation site makes the imagery especially valuable. The imagery enables the continuation of the detailed 3D modelling work even after the field season.



Figure 1. The Monastic complex of St. Aaron, Photo by K. Koistinen, 2003.

1.3 Aims of the project

The aim of the project has been to develop simple documentation methods for archaeologists. The disturbance to excavation work has to be minimized. This has been achieved by minimizing the preparations needed before image acquisition, and by adapting the timing of image acquisition to fit the typical working day on the site. The digital images can be utilised immediately during the archaeological field season or afterwards when the demand arises. One major goal has been to record the progress of the excavation site in order to “repeat the excavations virtually”.

1.4 References to related work

In addition to the photogrammetric work at the excavation site (see, e.g. Koistinen, et al, 1999, 2001; Koistinen, 2000, 2002) the research team members of the Institute of Photogrammetry and Remote Sensing have utilized various photogrammetric techniques during the archaeological survey. Especially the use of panoramic imagery in 3D modelling has been tested within the archaeological survey area (Hagrén, et al; 2001, 2004).

Work by Pollefeys, et al (1999) has shown that it is possible to build 3D models even from uncalibrated image sequences taken from an archaeological site. In their case sequence was filmed for TV program. This shows clearly, that even the video sequences collected during early years of FJHP have their own value for future modelling. This has encouraged us to continue

the regular collection of the image data during FJHP. However, the plan is to use different techniques for modelling.

This paper concentrates on the documentation of the excavation work using photogrammetric methods. The emphasis is on how to document and visualize the progress of the excavation work with multitemporal imagery collected during FJHP.

2. MULTITEMPORAL DATA ACQUISITION

The main 3D documentation methods used during excavation seasons of FJHP are tacheometer measurements, and the collection of digital imagery. The collected tacheometer data can be completed using photogrammetric methods. Used camera equipment, adopted imaging strategies, control data for imagery, and possibilities to use the imagery are explained.

2.1 Tacheometer measurements during the excavation season

The FJHP has used tacheometer to collect 3D data from excavation site during the whole project. In the beginning of the first excavation season in 1998, tacheometer network serving the excavation site was measured. The network contained originally 5 points. One point (located in the middle of the site) is no longer reliable due to movement of the underlying structures caused by excavation work. However, the 4 points located around the site are still available. This local network is connected to the GPS-network measured during the 1998 field season.

The tacheometer is used to record the basic 3D geometry of the site. The tacheometer data collected during field season is used to create the basic 3D model of the excavation site. Reliable control points enable the compatibility of the measurements done during different field seasons.

The daily tacheometer measurements are downloaded to the project’s laptop computer. The data is imported to MicroStation program (from Bentley) using TerraSurvey program (from Terrasolid Ltd). The validity of the measured data is checked visually. The collected data can be used to provide up-to-date plans for the use of the excavators.

However, tacheometer measurements can be very time-consuming, especially, if the object is to model complicated ruined structure. The 3D modelling of modern building with regular structures is different from modelling of partly ruined Byzantine walls. Completion of the tacheometer data with other means is obviously attractive solution.

2.2 Terrestrial photogrammetry at the excavation site

Terrestrial photogrammetry is used to complete the data collection during FJHP. This enables the continuation of 3D data collection and modelling work after the field season. Another aspect is, that archaeology destroys the evidence while removing the soil layers. The photographs restore the current situation and enable the measurements afterwards.

2.3 Collection of the multitemporal imagery

The digital imagery is collected systematically during the progress of the excavation work so far (1998-2003). The aim of the photogrammetric team has been to photograph every trench daily in case any changes have occurred due to the excavation

work. Usually the trenches have been photographed as panoramic image sequences taken from several directions. However, stereo pairs have been taken especially for visualization purposes. Camera equipment has varied, including two digital cameras, analogue video camera, and digital video camera. In addition to this especially collected imagery, archaeologists have documented the trenches with film camera following the archaeological convention. Besides, there exist thousands of photographs taken by the personal cameras of the team members.

Next the camera and related computer equipment as well as the different strategies to collect the imagery are explained in more detail.

2.4 Camera and related computer equipment

The idea has been to use non-metric amateur cameras available for reasonable prize. Since the beginning of the project, the focus has moved from analogue video cameras onto digital cameras nowadays widely available.

Two CCD video cameras (Sony Handycam) were in use during 1997-1999. Image data was collected by rotating a video camera on the tripod around its projection centre. This data can be utilised to create panoramic images. The data is still usable although it has to be digitised before use. In 2000 some image data has also been collected using Sony's digital video camera (borrowed from Helsinki University). However, at that time the digital camera had already become the main camera equipment in use.

Since 1998, digital camera - Olympus Camedia C-1400L - has been utilized as the basic photogrammetric recording device. The image size is 1280 x 1024 pixels and primarily the wide end of the zoom optics is in use. This corresponds to a focal length of 1400 pixels. During 2003, a new camera Olympus Camedia C-4000 Zoom was taken into use beside the older one. The image size of the new camera is 2288x1712 pixels. Also here, the wide end of the zoom optics is in use corresponding the focal length of approximately 2161 pixels. Both cameras have been calibrated by Petteri Pöntinen, Helsinki University of Technology.

The technical development relating to storage capacities during the project has been clear. In 1998 the size of the memory units used in our digital camera varied from 4 MB to 8 MB. There was even one 16 MB memory unit available. In 2003 the 256 MB memory unit was available in reasonable prize. Also the possibilities to store large amounts of image data even in field conditions have changed. Previously the backup of the original images was saved into IOMEGA-zips (100 MB per one zip). In 2003, the backup of the original images can be written directly onto CD-R with normal laptop computer. The storage capacity of laptop computers has also risen from 1 GB to 35-40 GB (as an example the laptops used by us). This has to be kept in mind when comparing the image amounts collected during different excavation years.

2.5 Imaging strategies

The images have been taken with non-metric camera with varying settings. Beside the two digital cameras, video cameras have been used during the earlier excavation years. Large amount of images are convergent panoramic images taken by rotating the camera on the tripod around the projection centre.

Also separate images and some stereo pairs are available. Digital images have also been used to record some artefacts and inscriptions relating to the excavation.

2.5.1 Panoramic images

Most of the imagery is collected as concentric image sequences where camera has been rotated around its projective centre. A specific device has been developed to enable this. Panoramic images are created from these image sequences using the algorithms developed by Petteri Pöntinen, Helsinki University of Technology (see, e.g., Pöntinen, 1999). The panoramas can be full circle (360 degrees) or less. The smaller panoramas can be kept in selected image plane and utilised for measurement purposes like they were single images. This reduces the need for control points. Panoramic images have been successfully utilised for measuring purposes within archaeological survey area of FJHP. (Haggrén, et al, 2001; 2004).

2.5.2 Separate convergent images

In some cases separate convergent images have been taken. In 1998 and 1999 this was often done with digital camera while the size of memory units was still restricting factor. At that time CCD video camera was still in more active use when collecting image sequences for creation of panoramic images.

2.5.3 Stereo pairs

Although stereo pairs can be created from slightly convergent images, it is sometimes useful to take them on purpose. The stereo pairs are taken especially when there is an immediate need to visualize specific structures in 3D. (see, e.g. Koistinen, et al, 2001; Haggrén, et al, 2001). The anaglyph images can be easily done already on the field.

2.6 Practical questions relating to the image acquisition

2.6.1 The daily photographing time

The time of photographing has been selected to cause minimal interruption to the excavation work. Therefore the photos are taken before the excavation work is started on the site. In the early morning the lighting conditions are also appropriate. No shadows are caused by strong sunlight, as it would be later when sun has risen above the summit of Jabal Haroun mount. In the evening the strong wind would cause another kind of problems. The similar lighting conditions are also advantage when using images taken at different time.

2.6.2 Documentation of the original imagery

During past six excavation seasons thousands of digital images have been taken. The documentation of imaging is an essential part of the process. Time stamp of the image (date, time of the day) and at least rough georeferencing (orientation) information should be available to able the search for appropriate imagery when needed. Basic information about the camera and the used imaging technique enable the correct processing of the imagery. The camera positions and orientations are not normally measured, but approximate values can be obtained from notes and sketches.

During field seasons so called "photo diary" is written using HTML-language. These HTML-files serve as copy of handwritten notes and enable an easy visual evaluation of collected digital imagery. (Koistinen, et al, 2001). The photo diary can be accessed without special programs and are therefore available for all project participants. Other relating documentation (including control data) can be connected to the diary.

2.7 Control data for more precise georeferencing and image orientation

The use of traditional signalised control points has proven difficult to use without causing disturbance and delays to the actual excavation work.

Therefore, control points have not usually been signalised as well as coordinates of camera stations are not measured. In order to minimize the disturbance for the excavation work the team has preferred the use of natural control points. Signalised control points have been used only in special cases (examples of signal types are shown in figure 2). Due to the excavation work the most of the signals will be removed or they are in danger to destroy during the progress of the work. However, the excavation site and trenches are measured daily with tacheometer. The basic geometry of the site has been recorded and this wire frame model offers features that can be used as control points for the photos. The archaeological notebooks contain sketches drawn during excavation work. These sketches contain also useful references to the tacheometer measurements – namely notes, how the measurements have been taken relating to the specific features.

In some cases the digital photos have been printed out and some clear points have been chosen and measured afterwards with tacheometer. The exact location of the measured points has been marked onto printouts. In many cases the identification on the image is as good as with signalised points. If the points are selected well, the coordinates of these points can be measured as precisely as the signalised points. When measured after image acquisition, it is possible to ensure that the measured natural control points are really visible on the printouts.

It has to be kept in mind, that images can also be oriented relating to the earlier or later images using tie points measured from the images.



Figure 2. Examples of signals used during FJHP.

2.8 Use of the collected imagery during excavation season and afterwards

Compared to traditional film cameras it is possible to verify collected digital imagery immediately on the site. The digital images can be used already during excavation season for various purposes, like collection of notes, documentation of planar objects, etc. After field season, the images can be used to complete the 3D model based on “the modelling-on-the-demand” philosophy (Koistinen, 2000). Naturally it is possible to produce various kinds of image products like photomaps, anaglyph images, etc.

The printouts of digital images can be used already on the field to collect image related notes. As already mentioned, control points for image orientation can be measured afterwards and marked on the printouts. Expert on the subject, like an

archaeologist or a conservator, can mark his or her notes on the image. After georeferencing the images, it is possible to transform these notes into the 3D model – as geometric features or as texture, depending on the content. (Koistinen, et al, 2001).

Documentation of planar objects can be done using basic photogrammetric techniques. For example, during FJHP, 2D projective transformations have been utilized to create photomap of the floor. (Koistinen, et al, 1999). The photomap can be a final product or used as geometric reference for further interpretation by archaeologists.

The further refinement of the 3D model will be done using terrestrial imagery (mostly taken using digital camera). This can be done using photogrammetric software packages. However, the convergent terrestrial imagery taken with non-metric digital camera can cause some problems with the commercial software packages usually optimised for special kind of imaging geometries and objects.

3. EXAMPLE CASE: THE PROGRESS OF EXAVATION IN THE CHAPEL DURING 1998-2003

The progress of the excavation can be visually documented using the regularly collected multitemporal imagery. To visualize the collected imagery and its possibilities, an example area – the chapel of FJHP – is selected. The chapel has been excavated during three field seasons: Trench C in 1998, Trench I in 2000, and Trench Y in 2003. Location of the trenches is shown in figure 3.

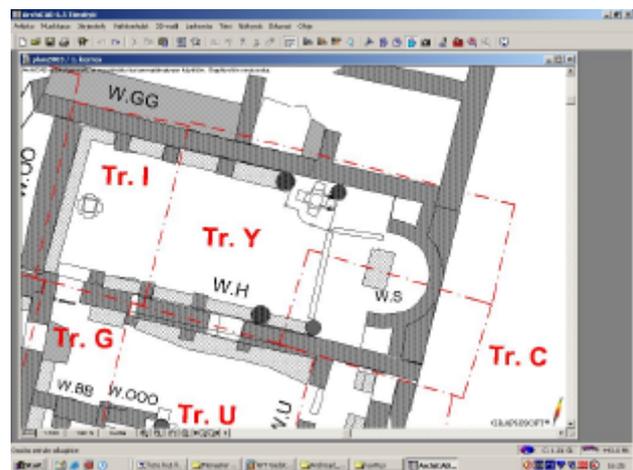


Figure 3. The chapel has been excavated during three field seasons: Trench C in 1998, Trench I in 2000, and Trench Y in 2003.

As already mentioned, the images have been organized by date and their rough georeferencing is available from photo diary. Approximated orientations serve well image management purpose. They enable the selection of the appropriate imagery for further processing.

More precise orientation relating to the chapel can be solved based on the signalised points, natural target points, or other 3D points and features available from tacheometer measurements. One possibility is to use interactive orientation method by Rönholm (2003). In this method digital images are interactively oriented using backprojection of 3D Data. This method suits well for the type of data collected during FJHP. Another possibility is to use photogrammetric software package

and do the orientation processes based on the available 3D-information (either signalised points or natural target points).

The author has tested the orientation of the FJHP images with Pictran software (Pictran, 2000). The photogrammetric processing of image orientations consists of measurement of control and tie points, and of block adjustment. The preliminary results will be discussed later in this paper.

3.1 Progress of the excavation

The regularly collected imagery can be used to visualize the progress of the excavation. Examples of the imagery are shown in figures 3 and 4.



Figure 3. Progress of the excavation in Trench C during 1998

Figure 3 demonstrates the progress of the excavation in Trench C (S-E corner of the chapel) during field season 1998. Images are taken on 2nd August 1998 (from W towards E), 14th August 1998 (from SW towards NE), 23rd August 1998 (from NE towards SW), and 30th August 1998 (from NW towards SE). It has to be kept in mind that during 1998 the CCD video camera was still main camera in use.



Figure 4. Progress of the excavation in 2003

During 2003 two digital cameras (Olympus C-1400L and Olympus Camedia C-4000 Zoom) were used in the excavation site. Small images in figure 4 show the progress during this season. Images are taken on 7th August 2003, 14th August 2003,

16th August 2003 and 25th August 2003. All images are taken from N wall of the chapel towards SE corner of the chapel. This SE corner of the chapel was already excavated in 1998 as Trench C.

3.2 Visual aids to manage the imagery

The images have been taken from different angles relating to the excavation trenches, and the chapel has been excavated in several steps. Therefore the simplified wire frame or 3D model can be used as a visual aid for the viewer. An example of such model is shown in figure 5 where the apse area of the chapel is seen approximately from NE.

The author's idea is to use the image orientation data to control the viewing point for this kind of simplified model. Unfortunately, the final implementation of this is yet not finished while writing this paper. In the examples shown in this paper, the orientation is based on the rough orientation data (see figure 6).

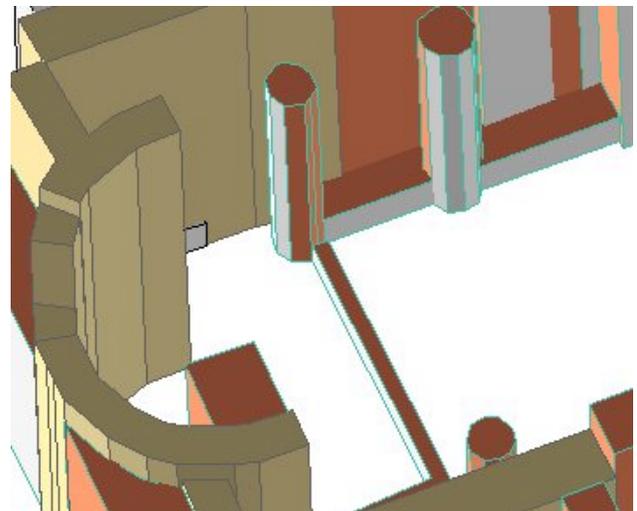


Figure 5. The simplified 3D model of the apse area



Figure 6. The Simplified 3D model can be used as visual aid for the viewer.

The user can study the available imagery based on the date and rough orientations. The appropriate images can be selected for further processing. The original image orientation can be refined in case the images are utilized for detailed modelling of the site.

3.3 Preliminary results from image orientation tests

Preliminary tests have been made to orientate the images from 1998 and 2003. Example images have been oriented using Pictran –software (Pictran, 2000). The minimum number of control points for image pair is four. Either signalised points, or natural target points measured with prism and marked on the printout, were used as control points. In addition to the control

points, several tie points were measured. In test cases, it was possible to do the absolute orientation with sub-pixel level. It is reasonable to say that the 3D modelling based on the tacheometer measurements can be completed using the collected imagery.

This conclusion is supported by the work by Haggrén et al (2004, 2001). They have been testing the use of panoramic images for densification of DTM and tacheometer measured details on the archaeological survey area around the Mount St. Aaron. Compared to the tests on the survey area, the images in the excavation site are usually taken from the distance of 2-10 m. Therefore the identification of the control points (either signalised or natural) can be done more precisely. The identification of the features to be measured is also easier due to scale of the object in the image.

4. DISCUSSION

The long duration of an archaeological project sets special demands on the documentation. When this project started we already know that it will last at least five years. Technical development during the project is evident. However, most of the imagery is unique. The progress of the archaeological excavation cannot be repeated.

The main idea behind the collection of the imagery has been to do it regularly and so that the images can be orientated into the same coordinate system. The tacheometer data provides basic coordinate system on site. How exactly the images can be transformed to the same coordinate system depends on the identification of control points, natural control points, and natural features on the image. The need for control points is clearly reduced by taking the majority of the images as concentric panoramic image sequences.

When documenting already finished excavation, it is possible to use time and effort on the preparations before taking the photos. However, during the excavation work, the documentation process has to be adapted to the archaeological work. The current solution to take the photos regularly before the starting of the excavation day works well in the conditions of FJHP. Natural target points, measured with prism and marked on the printouts, are preferred instead of the signalised points.

5. CONCLUSIONS

The progress of the archaeological excavation is clearly visualized with the multitemporal imagery collected as described. The selection of the appropriate imagery for further refinement of the model is supported with the photo diaries and the use of the simplified 3D model. The viewing angle for the simplified 3D model is based on the available orientation information. The completion of the tacheometer measurements with terrestrial photogrammetric methods is a realistic solution. The next step is to continue the work with the imagery and the available control data. The accuracy achievable in 3D modelling using this kind of imagery will be tested.

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APPENDIX

Homepage of the Finnish Jabal Haroun Project
URL: <http://www.fjhp.info>