

THE USE OF PANORAMIC IMAGES FOR 3-D ARCHAEOLOGICAL SURVEY

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ABSTRACT:

Panoramic images are efficiently used for documenting archaeological sites and objects. In our paper we present a new approach in developing the use of panoramic images for archaeological survey. The work is part of the Finnish Jabal Haroun Project, in Petra, Jordan. The primary motivation has been in developing a procedure for field invention, in which photogrammetric documentation could be used for 3-D measuring of structural remains of barrage systems and terrace walls. Panoramic stereo photography has been applied for wide area documentation, and detailed structures are documented with close up stereo images. Natural features are selected from photographic prints in order to be used as control points. They are identified in field and measured with tacheometer. In addition, archaeologists use prints as photogrammetric notebook when identifying and documenting barrage systems and terrace walls during their field invention. Photogrammetric post processing consists of orientation by bundle block adjustment, and of point wise 3-D measuring of identified structures. The procedure is experimented and the results indicate that the accuracy of applying panoramic imagery for archaeological survey is satisfactory. However, point wise interpretation of detailed structures leads to scattered shapes. We consider that the scattering is mainly caused by stereoscopic imaging geometry. Therefore we propose the use of corresponding features instead of corresponding points when applying photogrammetric documentation for 3-D structural measuring.

1. INTRODUCTION

1.1 Photogrammetric documentation in archaeological survey

Photogrammetry is well-established technology in archaeological survey. Aerial vertical and oblique photography provide both exact and detailed mappings for archaeological analysis. Satellite images are used for landscape analysis and prospecting of archaeological sites. Close-range photogrammetry is applied for documentation of excavations and reconstruction of remains and findings. (Baturayoglu, 2001; Wilson, 2000).

We consider here photogrammetric documentation being the recording of 3-D scenery in the way that the images are geometrically and geographically controlled. The control is maintained for both internal and external references. The internal geometry of the images, i.e. interior orientation, is known by calibration and the external geometry, i.e. exterior orientation, by geodetic control. Once these two references are determined, the image content, i.e. the scenery, can be transformed to any geographical or 3-D information system.

The extraordinary feature of photogrammetric documentation is that the images as such can be used as necessary measuring tool for an archaeologist during his field survey. We hypothesize that the images, or in particular the prints provide not only an instant base for sketches but also the reading and scaling rulers for geographic measuring. All interpretations of the scene and respective field notes become transformed to the same 3-D coordinate system as the images are processed.

In this paper we declare and verify the hypothesis with one example of archaeological survey. The motivation of the work has been to provide the archaeologists an alternative method for field surveys, which are now based on traditional geodetic measuring tools, like on measuring tapes or tacheometers. These are both time consuming and non-reversible, whereas photogrammetric images - being geodetic as well - are fast, timely, and complete, in recording and can be revived as documents.

1.2 Finnish Jabal Haroun Project

This work is part of the Finnish Jabal Haroun Project, in Petra, Jordan. Professor Jaakko Frösén, Helsinki University, leads the project and it takes care of the archaeological excavations, conservation work and publication of the results at the Monastic complex of St. Aaron and its environment (Frösén et al., 2002). An essential part of the project is the archaeological survey conducted in the near environs of the mountain. Institute of Photogrammetry and Remote Sensing at Helsinki University of Technology has participated in the project from the beginning, 1997.

Among the basic archaeological methods like photographing, drawing and recording tracts and sites during the field seasons have been tacheometer measurements and collection of digital imagery. Beside this practical task, the research team has been intensively developing photogrammetric documentation for archaeological survey purposes. (Koistinen, et al., 2002)

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1.3 Survey of barrage systems and terrace walls

The survey aims at understanding settlement and environmental history of Jabal Haroun. According to the latest results, the area has been settled from the late later phases of the Early Palaeolithic to the present. The main objective of the archaeological survey is to investigate the settlement history reflected through sites and finds dating to the different periods.

Hydraulic installations like barrages and terrace systems (Fig. 1 and Fig. 2) are one of the most important indicators of human activity in the area. Because of their large number the geodetic survey methods are extremely important in their documentation. Each structure is measured by tacheometer as 3-D polygon lines, interpreted in field point by point and targeted with prism on stage (Fig. 3).

During the field seasons 2002 and 2003 the Finnish Jabal Haroun Project survey has documented terrace walls by photogrammetric means. This has been made not only because of their large number but also because of the fact that they are more easily visible from certain distance than very close to them (Fig. 1). The team has applied panoramic image sequences instead of single images. In order to facilitate three-dimensional interpretation of both topography and structures, all photography is made as stereo pairs.

A crucial motivation for developing photogrammetric documentation in archaeological survey has been to intensify the

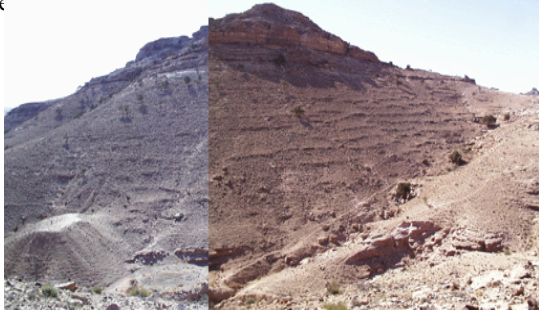


Figure 1. Site 123 on the slope of Jabal Farasha. The remains of terraces to be surveyed in the field become visible in this lighting. This panoramic image sequence is a photogrammetric document and is part of a stereo pair No. 1003-1004 in Fig. 4. The barrages locate in the tributary and are occluded by trees.



Figure 2. The barrages of site 123 in the tributary are documented with close-up photography. In order to ease the structural interpretation the barrages are documents as stereo pairs as well.



Figure 3. The barrage and terrace structures are identified in the field and measured with a tacheometer. In case of large and clear structures the remains are recorded as lower and upper poly lines.

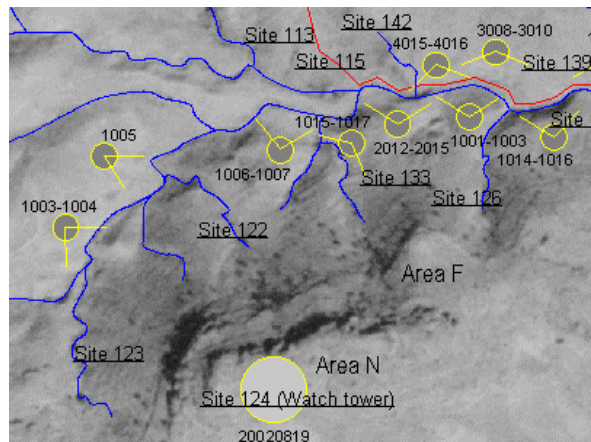


Figure 4. Part of photogrammetric documentation of the FJHP project during the field season 2002. The example used in this paper is based on the panoramic image sequence 1003-1004 and the site 123 on the left. The background is an orthophoto produced from the Russian KVR-1000 space images.

1.4 The use of natural features as control instead of artificial targets

In order to control photogrammetric documents geographically, we have to interpret and locate proper reference objects in the

images, find same objects in the field, and measure them as geodetic references.

In case terrestrial photographs are used for documentation of large areas, the use of targets becomes impractical for various reasons. Since the scale of each photograph will be different with respect to any location on site, the size of each target should be adjusted respectively. Because of varying topography, it is hard to control the visibility between the targets and the images beforehand, whereas natural control points can be selected from images after the photography

The evident payoff caused by the use of natural control points is that they are less accurate than the geodetic and targeted ones. However, improving the photogrammetric block geometry can compensate this deficiency. This can be done by various means, like by increasing the number of control points in image, by increasing the number of images in block, or, by using concentric image sequences, just to name few.

2. METHODS

2.1 Panoramic photography

The survey images are recorded as wide area stereo photography (Fig. 5). The photography is usually performed as panoramic stereo image sequences. The practical location of the camera is the opposite slope of the wadi. Each sequence consists of two to three single images. For panoramic photography, we apply concentric image sequences (Haggrén et al., 2004).

A sequence of three images with an overlap of approximately 30 % corresponds to an approximate horizontal angle of view of 120°. The base has been 15-25 meters and it largely depends on the distance of object area. The photographing distances have been typically 100-200 meters. In general, we aim at base-to-distance ratios between 1:10 or 1:15.

The camera, which we have used for the documentation, is Olympus Camedia C-1400L. The size of a single record is 1280 x 1024 pixels, and we use primarily the wide end of the zoom optics, which corresponds to a focal length of 1400 pixels. The photographing distances of 100-200 meters correspond to 7-14 cm image resolution. On upper parts of the slopes, where the photographing distances may exceed 300 meters, additional closer photography is necessary.

For the sake of occlusions caused by terrain topography, or by bushes and trees, and in order facilitate detailed interpretation of the barrage and terrace structures, we have additionally recorded these by close-up stereo photography. These images are recorded within a distance of some ten to twenty meters with a base of 1-3 meters. The close-up stereo photography consists mainly of single images, not of panoramic sequences.

The survey group has identified barrage systems and terrace walls on marked them on paper prints (Fig. 6 and Fig. 7).

2.2 Control survey

As geodetic control points we have used natural features like corners or edges of large stones. The points are selected on prints. They are then identified in the field and the coordinates are measured with tacheometer (Fig. 8). The exact location of

the control point is simultaneously recorded by photography (Fig. 9 and Fig. 10).



Figure 5. Survey images are based on concentric image sequences. The images are transformed to the normal case of stereoscopy and rectified on planes. The structures are measured from stereo images. The angle of view of this panoramic composition corresponds to 92° x 67° horizontally and vertically.



Figure 6. Archaeologists use photogrammetric documents as their notebook during field invention. The structures to be measured are identified and sketched on prints.



Figure 7. Since no targeted control points are used, recognition of natural features becomes essential part of the fieldwork of photogrammetric documentation. Proper candidates are marked here with triangles. The remains of structures are identified during archaeological survey and marked on prints (here shown in white).



Figure 8. Natural control point No. 22 (Fig. 7) measured with tacheometer. Each pointing of natural control is documented simultaneously by photographing it. These documents are essential in order to identify and relocate control points exactly in survey images.

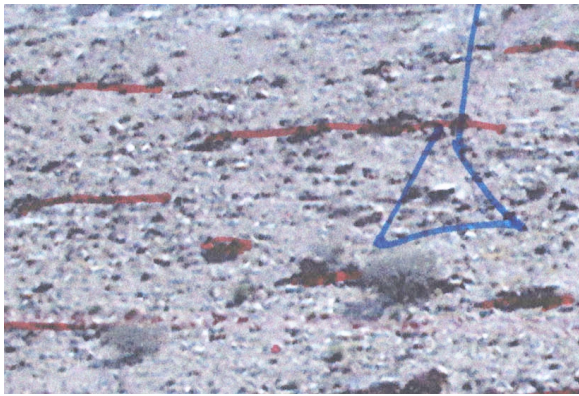


Figure 9. Closer detail of marking of natural control point No. 24 in Figure 7.



Figure 10. Point No. 24 (Fig. 9) photographed for photogrammetric identification. The exact location is shown here by a measuring stake. It is essential that the viewing direction be close to the same than the one of survey images (Fig. 5).

2.3 Orientation of images

The photogrammetric processing of image orientations consists of measurement of control and tie points, and of block adjustment. This has been done with Pictran software (Pictran, 2000). We use some 15 - 20 tie points for orienting one panoramic stereo pair. From these points less than half may be control points, which have been measured with tacheometer (Fig. 11). The minimum number of control points required for one stereo pair is four. The standard error of image observations after block adjustment has varied between 0.5 - 1 pixels.

In case several panoramic sequences are taken from one survey area - but from different distances - we aim to adjust all images in one block. However, this may often cause singularity problems. Similarly, tie points further away cause problems, and in very front of both cameras the stereoscopic area splits to two different views.

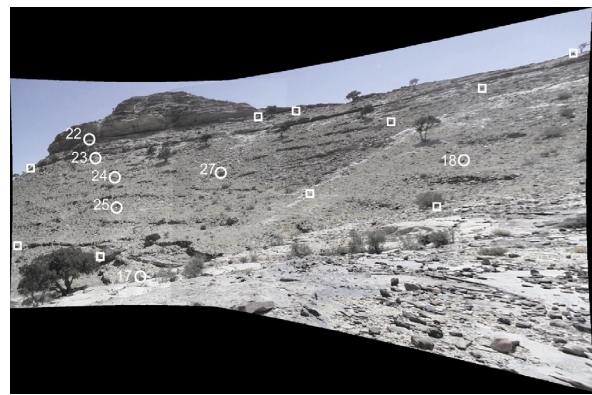


Figure 11. Geodetic control points (numbered squares) and tie points (circles) of the panoramic stereo model. The numbered points are the control points.

2.4 3-D measuring

Once the images are oriented, the remains of structures, which were identified and sketched on prints during archaeological survey, are measured in 3-D. If necessary, the digital elevation model (DEM) will be densified.

The structures will be described and modelled as poly lines. The corresponding points are identified and measured in both images and the 3-D coordinates are determined by intersection in space. The 3-D measuring is performed point wise, since the software we used does not support stereoscopic measuring. However, the images can be at least viewed stereoscopically, which will ease remarkably the interpretation of the structure.

Since a panoramic image sequence is rectified to a plane, geometrically transformed and resampled, the resolution is reduced (Fig. 5 and Fig 11). The stretching of the pixels will reduce the interpretability as well. Therefore, it would be better to use original images for all photogrammetric processing, or project them on cylinder instead of planes, but the software does not support this either.



Figure 12. Barrage structure measured from the panoramic stereo model in Figure 11.

3. RESULTS AND DISCUSSION

In order to verify the procedure, we compared geometries of some structures, which were measured both with tacheometer and from photogrammetric documents. The structures were one barrage system (B1) and two terrace systems (T1 and T2). The measurement geometry is presented in Figure 13. The barrage system and its measured points are shown in Figure 12.

As a kind of rule of thumb one can expect precisions of stereo photogrammetric measurements using following formula:

$$dX = \frac{Z}{c} \cdot dx, \quad (1)$$

$$dY = \frac{Z}{c} \cdot dy, \quad \text{and} \quad (2)$$

$$dZ = \frac{Z}{c} \cdot \frac{Z}{B} \cdot dp_x, \quad (3)$$

in which X and Y are the coordinates parallel to the image plane, Z is the coordinate in viewing direction (i.e. the distance), c is camera constant, B is the effective base of photography.

We consider here roughly that the precision dx or dy of any measured image coordinate is one pixel and the precision of the parallax measurement dp_x is 1.4 pixels. The measurement geometry in our experiment is presented in Table 1 and Figure 13, and the expected precisions in Table 2. In case of our experiment, the camera constant c is 1400 pixels, the base B is 7.5 m and the distances to measured structures varied between 45 – 100 m.

The results indicate that panoramic images can be applied for archaeological survey. With regard to measured locations of structures, the external accuracy meets the expectations: Barrage B1 in Tables 2 and 3, and all structures in Figure 13. The measured bias in case of barrage B1, i.e. the mean of coordinate differences between both measurements are within the range of expected precisions.

With regard to measured points, the internal precision meets the expectations as well: Barrage B1 in Tables 2 and 4, and in Figure 14. Both measured shapes of Barrage B1 appear similar, whereas in case of Terrace T1, the shapes become scattered when measured from images. However, the repeatability is good. This indicates that the interpretation on images becomes

vague or uncertain compared to the interpretation *in situ* with tacheometer.

Table 1. The measurement geometry.

c [pixel]	B [m]	dx [pixel]	dy [pixel]	dp_x [pixel]
1400	7.5	1	1	1.4

Table 2. Expected precisions in the experiment.

	Z [m]	dX [m]	dY [m]	dZ [m]
Barrage B1	45	0.03	0.03	0.27
Terrace T1	60	0.04	0.04	0.49
Terrace T2	100	0.07	0.07	1.35

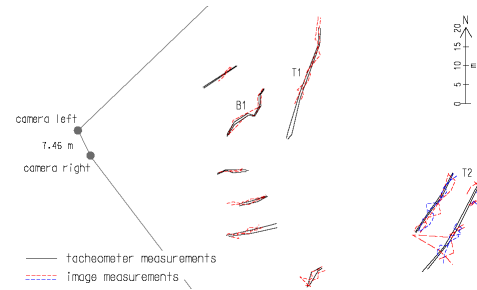


Figure 13. Measurement geometry of presented photogrammetric survey of terrace and barrage structures. For comparison, the structures are measured with tacheometer. The base of the stereo photography is 7.5 m and the distance here to the furthest structure is 100 m.

Table 3. The bias in Barrage B1.

	N ($\sim X$) [m]	Z ($\sim Y$) [m]	E ($\sim Z$) [m]
Bias	-0.01	0.11	-0.17

When imaging distances increase, the uncertainties in measured distances increase. According to the Formula 3 the effect is squared with respect to the distance (Z). This effect becomes clear in case of Terrace T2 (Fig. 15) where the shapes become highly scattered when measured from images.

However, with respect to repeated image measurements 1 and 2, the range of scattering is higher than the expected 1.7 m in Table 2. This increased scattering can be explained by higher uncertainty in finding exactly corresponding points on stereo images when the structure is lineated parallel to the image base. Instead of point wise measuring, the structures should be interpreted on images as linear features, which would lead to less scattered shapes.

In case a DEM is available, these linear features can be measured on single images and the 3-D determination would proceed by intersection with the DEM surface. This alternative method is called mono plotting (Viite). However, mono plotting is inaccurate, since it assumes that the structures lie flat on terrain.

The proper way would be to measure the structures as corresponding linear features on at least two images and then determine the corresponding 3-D structure by intersection in space.

Table 4. Standard deviation between coordinates measured with tacheometer and from photogrammetric documentation.

	dN (~dX) [m]	dZ (~dY) [m]	dE (~dZ) [m]
Precision	0.09	0.06	0.19

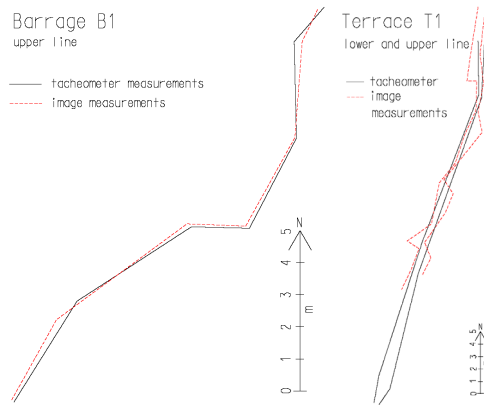


Figure 14. Barrage B1 and Terrace T1 locate at distances of 45 m and 60 m, where the pixel sizes correspond to 4 cm and 6 cm, respectively. The deviation between the image and tacheometer measurements does not seemingly affect the location of the entire structure. In case of Terrace T1, both lower and upper lines of structure are measured. Due to occlusion, the other end of the Terrace T1 could not be measured on images.

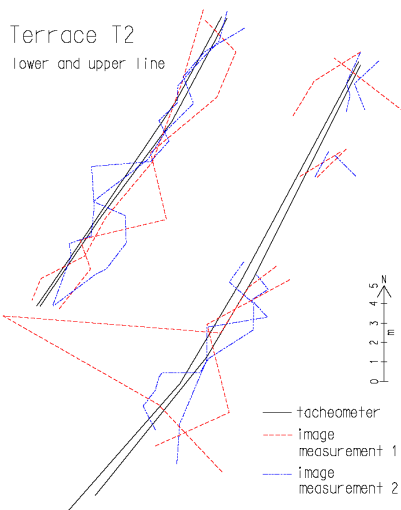


Figure 15. Terrace T2 consists of two terraces, which are both interpreted as lower and upper poly lines. They locate at distances of 100 m from the photography, where the pixel size corresponds to 10 cm. In case of photogrammetry, four poly lines are observed twice. The internal deviation becomes clear. This is due to the point wise interpretation of photogrammetric measuring which becomes uncertain in direction of stereo photography.

4. CONCLUSION

We have presented an approach in which photogrammetric documentation could be used for 3-D measuring of structural remains of barrage systems and terrace walls as part of archaeological survey. The documentation is based on

panoramic stereo photography and natural control points has been used for orientation of the images

New features of the procedure consist of the use of concentric panoramic images in a photogrammetric 3-D reconstruction process, the use of close up photography for exact documentation and identification of the natural control points, and the use of photogrammetric documentation by archaeologists as their notebook during field invention.

The procedure is experimented and the results indicate that the accuracy of applying panoramic imagery for archaeological survey is satisfactory. However, point wise interpretation of detailed structures leads to scattered shapes. We consider that the scattering is mainly caused by stereoscopic imaging geometry. Therefore we propose the use of corresponding features instead of corresponding points when applying photogrammetric documentation for 3-D structural recording.

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