COMBINATION OF PHOTOGRAMMETRY AND EASY-TO-USE NON-METRIC METHODS FOR THE DOCUMENTATION OF ARCHAEOLOGICAL EXCAVATIONS

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ABSTRACT

The geometric documentation of archaeological findings in excavations is expected to fulfil various demands. The work at the archaeological site shall be done in a short time, deliver accurate and impressive results which are easy to use and of high quality. And of course it is desired to be fast and cheap. This paper shows an approach in an excavation project in the PR China. The findings had to be documented geometrically to be able to put them back into the original find position after conservation treatment. First results had to be available quickly after finishing field work. Finally, metrically correct plans are needed later on after the conservation. This is achieved by the combination of non-metric imaging techniques and standard close range photogrammetry. Results are stereo anaglyph images, simple rectified image maps (without using height information) and vector maps of the outlines of the findings with discrete height indices.

KURZFASSUNG

An die geometrische Dokumentation von archäologischen Befunden bei Ausgrabungen werden verschiedene Erwartungen gestellt. Die Arbeiten vor Ort an der Ausgrabungsstelle sollen innerhalb kurzer Zeit abgeschlossen sein sowie Ergebnisse liefern, die von hoher Qualität und gleichzeitig beeindruckend und einfach zu interpretieren sind. Nebenbei wird noch erwartet, dass der Prozess der Dokumentation schnell und finanziell günstig abgeschlossen werden kann. Dieser Artikel beschreibt das Vorgehen bei einem archäologischen Grabungsprojekt in der VR. China. Die Dokumentation der Fundstücke war erforderlich, damit diese nach Abschluss von Konservierungsarbeiten wieder in die originale Fundlage gebracht werden können. Erste Ergebnisse der Dokumentation mussten bereits unmittelbar nach Abschluss der Arbeiten vor Ort vorliegen. Die endgültigen metrisch korrekten Pläne werden erst nach dem Konservierungsprozess benötigt. Diese Anforderungen konnten durch die Kombination von abbildenden nichtmetrischen Verfahren und Verfahren der Nahbereichsphotogrammetrie erreicht werden. Ergebnisse sind 3d Anaglyphenbilder, einfache entzerrte Bildpläne sowie metrisch korrekte Liniendarstellungen der Umrisslinien der Fundstücke mit Höhenangaben einzelner Punkte.

INTRODUCTION

In co-operation with the Museum of Qin Terra Cotta Warriors and Horses and the Shaanxi Archaeological Institute in Xi'an, PR China, parts of the excavation in pit 6 of the ancient burial-site of the first Chinese Emperor Qin Shi Huang had to be documented geometrically. In the pit, among other things nine horse skeletons have been found and laid bare. These bones are intended to be presented to visitors in the future in their original finding position. To do so, they have to be treated by means of conservation to avoid deterioration. For this treatment, the single bones have to be taken out of the pit and put back into the original position afterwards. Thus, a geometrical documentation making this possible was required. The bones are lying in a horizontal plane about 3.5 m below ground level in two locations with areas to record of about 2.5 x 7.5 m² and 1.5 x 3.0 m².

DEMANDS FOR THE DOCUMENTATION

Fig. 1 Pit 6 of the buriel site of Qin Shi Huang

In the conception of the methods to be used and the planning for the field word different demands had to be fulfilled:

- The field work must be completed within a few days.

- The first results, suitable for orientation and the numbering and removal of the findings prior to the conservation have to be provided during the field campaign or shortly after.
- The absolute accuracy of the position of single findings within the excavation field is not of highest importance.
- The final results for the repositioning of the single bones must include 3d-information for the single findings. They can be processed later as the conservation itself needs some time.

APPROACH

The areas to be recorded have a rather small extent in the vertical direction as compared to the horizontal extent. This allows a representation of the situation in horizontally orientated maps without the need to draw up views or maps from different directions respectively with different reference systems. The approach for this project is to use different techniques for the generation of the results needed.
As the first results (or products) will be used for interpretation, orientation and numbering only, there is no need to use high accuracy metric techniques. More important is the easy and reliable identification of the single findings in the find situation and in relation to neighboring objects. This almost automatically leads to the use of image information of the find situation. Together with the need of fast results, the use of digital imaging and processing seems adequate. Using standard hardware (digital camera, laptop, inkjet printer) and easy-to-use software, the results can be completed in a rather short time. Results are simply rectified images and anaglyph images of the findings allowing a 3d impression of the situation in the field during the whole process. These images can be viewed with red-green or red-cyan glasses available for few money. One big advantage of these techniques is that the persons involved can see some results already during the field campaign which improves the trust into the works to be carried out especially when new or unknown techniques are used.
For the precise geometric documentation, the whole location is recorded using standard close range stereo photogrammetry. The analogue stereo models can be processed using an analytical plotter. The ergonomics of stereo viewing and the measurement process especially for irregular shaped objects with low contrast are still better with analytical plotters as compared to digital photogrammetric stations. In the plan the outlines of the single bones and height indices of selected points of the bones give the exact 3-dimensional position of every single piece. If the outline drawing by itself does not allow the unambiguous positioning of the finding, the 3d-images and can support this task.
The two locations were divided into several fields which allowed standardized procedures and reasonable image scales. The connection between these fields was realized by point marks on nails designed for use with different image scales and means of viewing.

FIELD WORK

Equipment. The following equipment was used onsite in this project:

- Digital still camera (6 Mega Pixel)
- Standard laptop computer
- A4 inkjet printer
- Simple construction level, leveling bar and tape measure
- Tripods for level and cameras
- Photogrammetric middle format camera Rollei 6006 metric
- Software for standard image processing tasks (Corel PHOTO-PAINT®)
- Software for generating anaglyph images (CRANAG 3D), anaglyph glasses
- Photogrammetric software (PhotoModeler®)

Preparation. The two locations with findings were divided into two strips of six fields and one strip of tree fields respectively, each field with a size of about 1.2 x 1.5 m² each marked with

point markers. These markers must be usable with analogue and digital images in different image scales, cf. fig. on the left. The position of these points is needed for the later photogrammetric orientation process. The heights of the markers were determined using the level, the x-y-position by measuring distances between the points. The positions were calculated approximately using the simple formulas for arc sections and offset planning in an Excel spreadsheet. The accuracy of these coordinates is sufficient for simple image rectification and as initial values for the later bundle adjustment. The size of these fields was chosen on the one hand with regard to the image scale for the photogrammetric measurements, the resolution of the digital camera, the target scale of the rectified images and on the other hand, of course to the situation in the excavation. The position of the two find locations was measured relative to the covering roof construction using tape measure and level.

Digital Image Capture. The images were captured perpendicular downwards from a simple construction made of boards from a height of about 3.5 m. As the boards were not absolutely stable, it was helpful to control the camera from the laptop especially when the exposure times were long. To enable the generation of stereo images, every field is photographed from two positions. A base to height ratio of about 1 : 8 to 1 : 10 was used, which means in this case a base of about 30 to 40 cm. It is essential that the directions of the exposure axes are approximately parallel and the distance from the camera to the object is the same, otherwise the stereo images cannot be processed with the simple tools as described below. The base must be selected in the same orientation as the final stereo images are to be viewed. One image of every stereo pair can also be used to generate the simply rectified image maps of the situation. Sufficiently parallel exposure axes can easily be achieved using simple tools. A tripod should be used in any case. Simple sliding bars are available as photo equipment which allow the parallel movement of the camera over a small distance. These devices are often limited to about 15 cm, which in many cases is not enough. Another way is to align two of the three legs of the tripod along a board or another line that is parallel to the intended base, mark the position of one leg and then move the tripod along this line for the required distance. The remaining deviations from the parallel axes is usually small enough to be corrected sufficiently when generating the stereo images.
A certain attention should be focussed on the illumination, respectively light conditions in general. For a good stereo impression, the light conditions for the two images should be as identical as possible. Thus, the use of flashes connected to the camera is not recommended, as in this case the position of the light source is different for the two images which deteriorates the 3d impression. Using direct illumination or sunlight can also be problematical, as it often leads to very high differences in light intensity and very hard shadows. This means that darker areas in the stereo model cannot be viewed any more. Even if the images do not look this bright or brilliant, it is

recommended to use ambient light in order to get an image suitable for viewing and interpreting the whole scene. This might be limited under extreme conditions and the options available with the camera used. Using high quality lenses is recommended. The excavation area was covered with a big roof and the locations below ground level were rather dark. One of the them had to be illuminated using lamps, for the other location the ambient sunlight was sufficient. The images were taken in a fixed order along the strips of fields which simplifies and speeds up the process of image capture.

Analogue image capture. The images for the photogrammetric measurements were taken with a Rollei 6006 metric middle format camera on color positive film. The image configuration for the stereo models of the single fields was similar to the one of the digital camera. In Addition to the images for stereo-processing taken with a 120 mm lens, images with a 50 mm lens of the locations have been taken to improve the accuracy of the calculation of the coordinates of the marked points in a bundle adjustment.
Taking the photographs took some time. The exposure time was up to 12 min. for a photo. Reasons are the film material with low light sensitiveness (ASA 50) and the small lens aperture of 32, which was necessary to achieve a sufficient depth of focus for the indexed focusing of the Rollei 6006.

DATA PROCESSING DURING THE FIELD CAMPAIGN

Image Rectification. The rectification of the vertical images is probably not necessary in many cases. If no height information of the object is available (just like in this case) and the object is not really flat, i.e. has some extent in the 3rd dimension, the result of this process can only be a simply rectified image, i.e. not an orthophoto. Nevertheless, there are reasons to do this type of processing. Generating rectified images using the marked points leads to images that are orientated in a unique reference system and which have an approximately identical scale when printed. The rectification can be done using software like PhotoModeler®, which is an easy to use digital photogrammetry software. Otherwise, standard image processing or graphics software can be used to perform a coarse rectification and a resampling to a certain resolution. In this case the influence of the central projection will not be corrected, but dependent on the lens used (if not a fisheye) this can be accepted in many cases. It is important to realize and make understood to all persons involved, that these images are not metric image maps, but only image representations of the situation suitable for orientation, numbering etc.

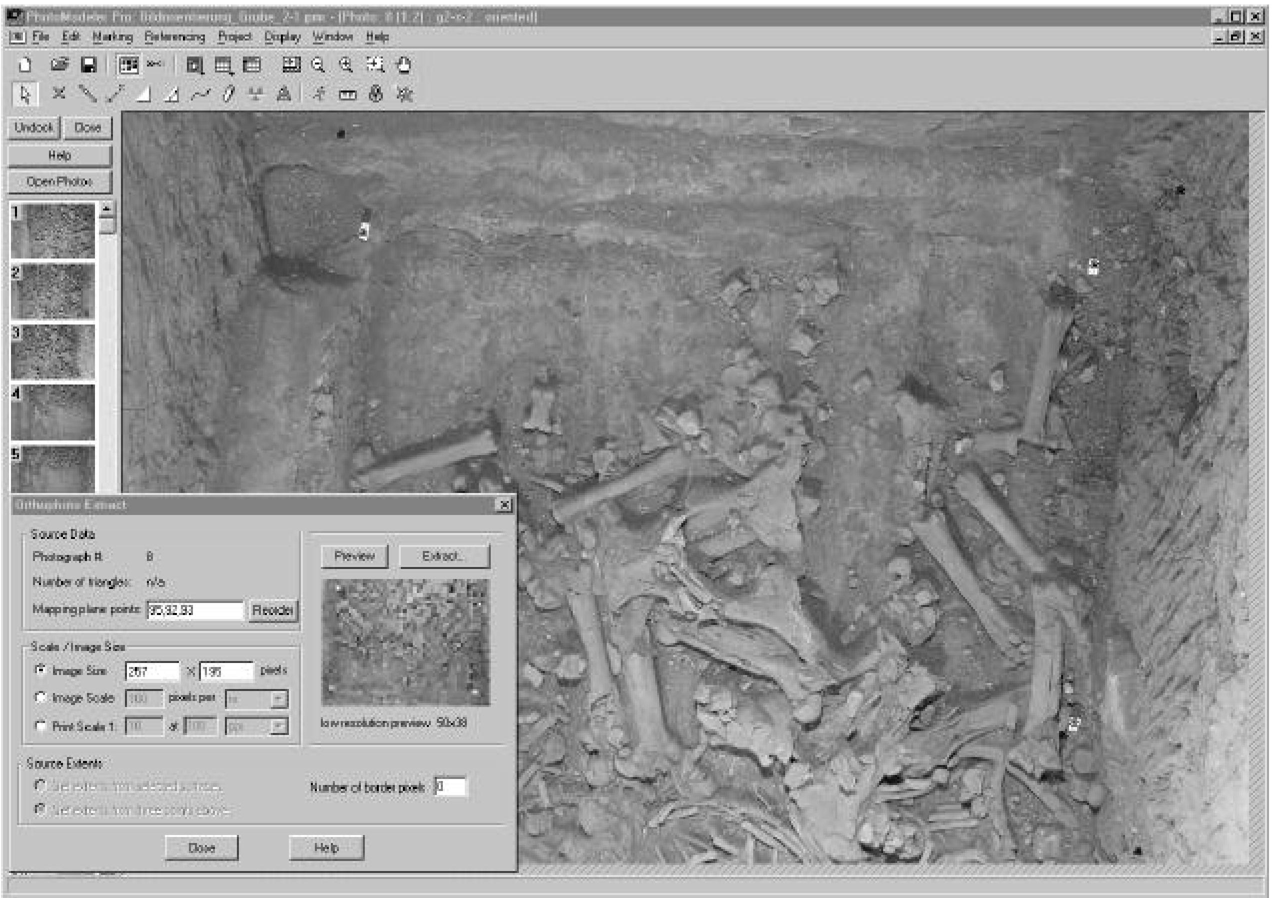

Fig. 2 Generation of a rectified image using PhotoModeler®

In this project, the images were rectified using PhotoModeler® software (cf. fig. 2) and resampled for printing in a scale of 1: 10 on A4 sized paper. The processing of the images was performed in the evenings, so that results on paper and the laptop screen could be presented to the partners the next day. The images are rectified in the plane of the marked control points, displacements remain where height differences occur.

Anaglyph images. An anaglyph image is an image that contains the image information of two single images taken from different positions. If the geometric conditions (parallel axes of exposure, reasonable base to height ratio) are complied with and each eye is provided with the image information of one image, the observer can see the situation in stereo. Where the geometric conditions were fulfilled during the image capture, the separation of the image information can be done using different techniques. A simple method is the separation of the images using different colors for the different images. These colors must be independent form each other. Two color combinations are quite popular for this procedure: red-green and red-cyan images. The red-cyan combination is better for color images, red-green rather for black and white images. With both methods, the color information of the images is strongly reduced. If the color information of the objects is essential even in 3d, these methods are not suitable, others should be taken

Fig. 3 Generation of an anaglyph image using CRANAG 3D

into account like separation using polarization or shutter glasses. The latter have the disadvantage, that they cannot be used as easyly. If the color information is not essential, or black and white images are used, the generation of the images is quite easy. In principle, the intensities of the single images are mapped to the intensity of the appropriate channels in the stereo image. The positions of the different color layers must be adjusted to let the parallaxes disappear for a chosen plane (here defined by the marked points). For objects in front of or behind this plane, the horizontal parallaxes represent height differences of the object. Thus, this simple technique leads to reasonable results only if the height difference from this are not too large. After the adjustment of the images, the new stereo image is cropped and saved as a new image file.

Different tools are available for this task. The one used for this project is CRANAG 3D by Alex Leuthold (cf. fig. 3, www.leual.ch/anaglyph/). It is free for noncommercial use and supports different types of anaglyphs with different color channel combinations. The adjustment of the two images can be achieved by moving and/or rotating the images. The result can always be viewed in a 3D-window. It is recommended to adjust the images in a way that the parallaxes vanish for points or areas that can be observed well in the main plane. If the images are taken according to the statements above, it should be sufficient to first move the images, control the points, do a rotation if necessary, and in a second step refine these adjustments. Another tool (freeware) is Z-Anaglyph by Georges Rosset (z-graphix.com/anaglyph/zanag_en.htm). It supports red-cyan anaglyphs only and has no support for rotating images. The images must be taken quite exactly or rotated with other tools.

The manipulation of the images can also be performed with standard image processing software like e.g. Corel PHOTO-PAINT® that supports rotation of images, the separation and combination of color channels and the manipulation, e.g. copy and past, of images or parts of images. But the above mentioned tools are especially designed for this task and therefore very helpful, as they can speed up the process of generating anaglyph images very much. As mentioned above, it is necessary to keep the geometric conditions for image capture in mind if you want to use these tools successfully and generate impressive and suitable stereo images.

The anaglyph images can be printed on any inkjet color printer. The paper should be of good quality. It is helpful to mark on the prints from which direction this image is to be viewed with which color combination of glasses. Glasses with the corresponding color combinations are requisite for stereo viewing and can be purchased for little money.

DATA PROCESSING AFTER THE FIELD CAMPAIGN

Image mosaicking. Back in the office after the end of the field campaign the rectified images of the single fields were combined using image mosaiking. Mosaicking is the process of

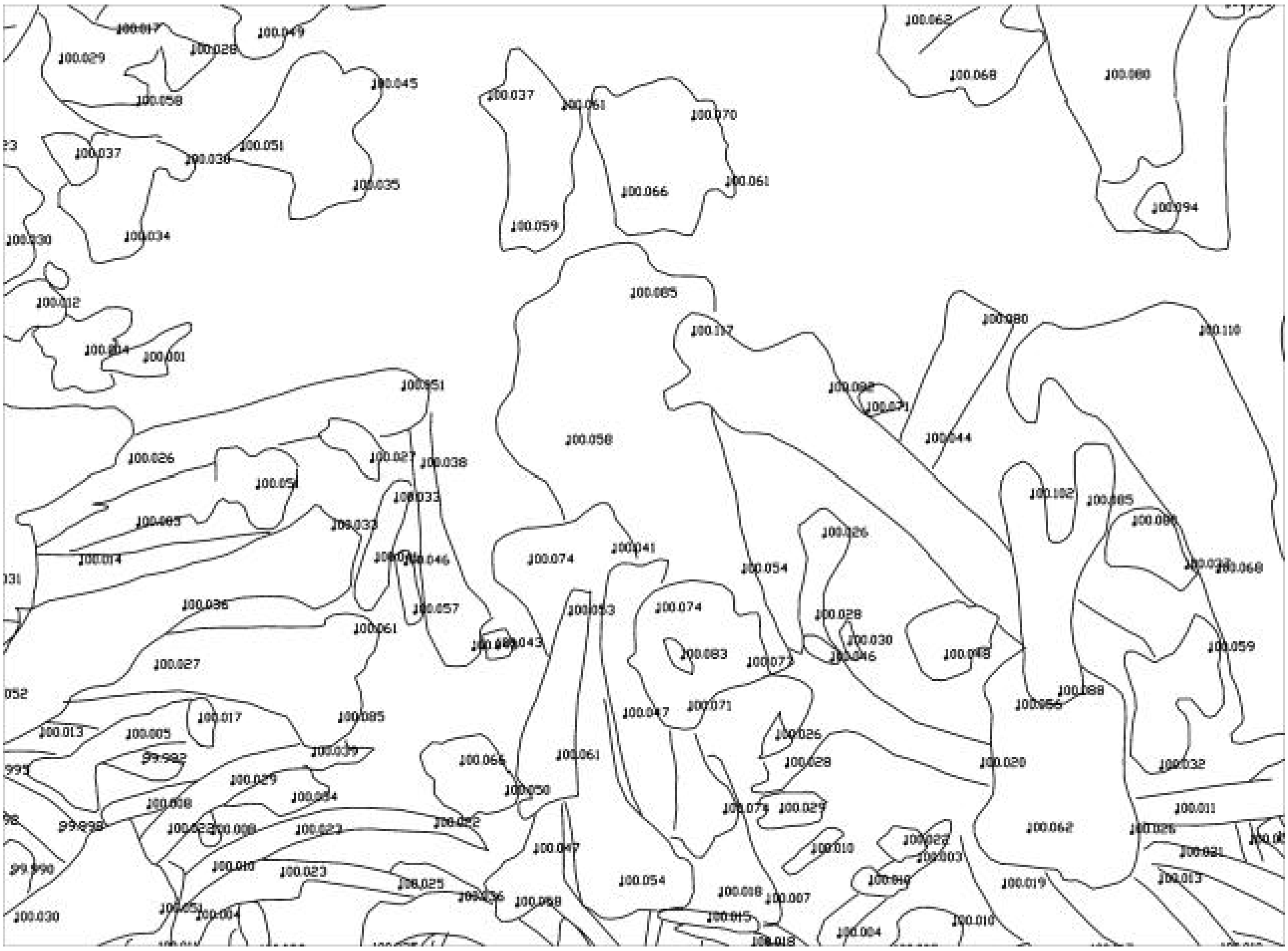

Fig. 4 Part of the vector map. Scale approx. 1 : 5

joining images together to form a larger image. The result is a single image map of each location in a scale of 1 : 5. This map is helpful for overview purposes and because of the larger scale of the images. On the other hand, it is not essential as the information itself has already been provided with the single rectified images.

There are two possible problems in the mosaicking. Firstly there are differences in brightness, contrast and colors of the single images. These can be adjusted approximately selecting one image as reference and proceeding step by step with the surrounding images. Secondly, there will be geometric differences between the different images caused by the fact that the rectified images are no real orthophotos. This cannot easily be corrected and will thus lead to certain cuts or unsharpnesses in the overlapping areas dependent on the procedure used for the mosaicking. There are different methods to perform this mosaicking. The simple one is to combine the single rectified images with standard image processing software. In the overlapping areas, cutlines can be generated which define the image from which the information is used for the final mosaic. Another way is to use special software tools for this purpose that is often used in photogrammetry or remote sensing packages. These packages offer different methods for adjusting radiometry of the images, e.g. hard cutlines or soft transition within the overlapping areas. For this project, ERDAS Imagine® was used to generate the mosaic. Soft transitions were used which led to a certain unsharpness in these areas. The position information which is required to define the geometric position of the image in the common reference system is known from the rectifying process. If unknown yet, the images have to be referenced now.

Photogrammetry. As described above, the locations were completely imaged with stereo models using a photogrammetric camera. Before plotting, exact coordinates of the reference points have to be determined. Image coordinates of all marked points and several tie points were measured using an analytical plotter. Together with the level measurements and the tape measurements, a bundle adjustment was calculated to compute the coordinates. Those could be defined with an accuracy of 3 mm which is a result better than needed in this project. Smaller image scales would probably have been sufficient for the accuracy of the bundle adjustment, but the interpretation of the images was easier and the local conditions during image capture in combination with the existing lenses for the camera led to take the images in the way described.

After these preparations, the stereo plotting could be done. A Zeiss P3 analytical plotter was used in combination with MicroStation® as connected CAD system; the later processing of the maps was performed using AutoCAD®. The outlines of every single bone were plotted with 3d polylines. For every piece, the height of selected points was measured by plotting a small circle to this position. In AutoCAD®, a Lisp program was used to draw small dots at these positions and to place texts with the height of the plotted circles there, allowing to specify the text size in the plot. This procedure resulted in speeding up the time for placing these texts significantly. In the larger location more than 1200 height spots were assigned (cf. fig. 4).

The final maps of the two locations were plotted at a scale of 1 : 5 with height indices accurate to few millimeters, which will allow the repositioning of the single findings with a sufficient accuracy in all tree dimensions.

RESULTS

The results of the documentation process are different types of products. The locations are completely covered with analogue metric stereo models which were the basis for the plotting of the metric plans. These images can be archived for rather long periods of time, whereas in the archiving of digital image data there are still uncertainties concerning the durability of media and the future availability of suitable hard- and software. In combination with the sketches of the situation, the measurements and the coordinates of the marked points, in the worst case the whole geometry of the locations can be reconstructed using these analogue sources.

The derived products are CAD maps, rectified image maps and anaglyph images, both in digital and analogue form. The durability of the analogue versions is limited in comparison to that of the analogue images mainly because of color fading of the plots etc. They are to be used primarily during the process of removal, restoration treatment and the re-location of the findings.

All digital images used, the digital results and intermediate data are stored on CD-ROMs. Analogue versions of maps are stored as well.

PROBLEMS

Concerning the accuracy of the plotting and, of course, of the whole documentation, one problem is the perceptibility of the single findings during plotting and repositioning. Several findings are difficult to differentiate from the surroundings or from pieces of loess differing from the bones only very slightly in color and pattern which complicates the process of plotting. On site, this differentiation should be smooth, whereas a problem during repositioning might be to rotate and move the finding into the position that corresponds to that during the measurements and of course to the outline plotted in the map. The combination of the map with the rectified images and the stereo images of the situation, with the findings in situ should help to solve these possible problems.

CONCLUSIONS

This article describes the combination of different metric and semi-metric techniques for the documentation of archaeological excavations or locations. Especially the non-metric imaging methods are very interesting as the are easy to generate, easy to use, have a high content of information and can be provided very fast. The anaglyph images can give a 3d impression of the location without the need of any expensive hard- or software. Of course, the quality is limited in comparison to other techniques (e.g. because of the lack of colors).

The use of close range photogrammetry delivers metric results and, in case of using analogue images, a very good documentation for archiving. If the high accuracy is necessary for a certain documentation project must be decideded by the project managers. Considering the comparatively short amount of time needed for image capture as compared to processing, it might be sensible in some cases to take the metric images without processing them. If necessary, this can be done later.

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