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3D SCANNING AND PHOTOGRAMMETRY FOR HERITAGE RECORDING: A COMPARISON

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Abstract

There is a high demand in documentation of cultural heritage objects such as artifacts, sculptures or buildings. In the past years, laser scanning, or 3D scanning in general, has been used increasingly for cultural heritage recording and the question arose if this new method can replace traditional methods like close-range photogrammetry. To investigate the advantages and disadvantages of both methods, i3mainz has carried out some case studies for cultural heritage documentation. Different typical objects were chosen and characteristical parts of them were recorded both by photogrammetry and scanning. Documented objects include an archaeological stone wall, baroque relief plates, Stone Age artifacts, ancient statues and the façade of a classical castle. Besides 3D scanning all these examplary objects were also recorded with standard stereophotogrammetry which is the most popular heritage recording method so far. Results are usually line drawings, but the creation of orthophotos or digital surface models is possible, too.

In this paper five case studies are shortly introduced and the results of both measurement techniques are presented and compared. The aim is to give users (especially those who are not surveying experts) recommendations, which method is suited best for what kind of application, or even if a combination of 3D scanning and photogrammetry is advisable. Criteria like quality of the results, amount of cost and time, required equipment and occurring problems are to be considered.

INTRODUCTION

In the past years 3D scanning techniques have gained much interest (also in the cultural heritage sector). Very optimistic people even predicted that traditional surveying methods like tacheometry or close-range photogrammetry might be completely replaced by 3D scanning in the future. But there is still a lot of misunderstanding and ignorance concerning this new method. Many potential users do not know in detail how 3D scanning works, which results can be expected and how much it costs.

Therefore i3mainz, Institute for Spatial Information and Surveying Technology, decided to initiate a project with the aim to compare 3D scanning with the common measurement technique for complex heritage recording tasks: close-range photogrammetry. For this purpose, several typical objects in architecture, archaeology and cultural heritage were documented with both methods and compared regarding quality of results, accuracy, cost and other criteria. As a final result of these investigations, a guidebook was published to give users recommendations which technique is suited best for their applications. The publication (Marbs, 2004) will be handed out to German authorities for historical monuments and other institutions that are involved in heritage recording.

This paper is a condensed version of the guidebook (which amounts to approx. 50 pages) and will give a short overview about the case studies and the measurement technologies used for these projects. In the end, the experiences and insights will be summarized to a final conclusion.

TECHNOLOGY

3D Scanning

3D scanning (often called laser scanning) is a surface-based three-dimensional measurement technique. One scan results in a large quantity of points in a systematic pattern – also called point cloud (Boehler and Marbs, 2002). Final results after processing of the raw data can be line drawings, CAD models, 3D surface models (with artificial or photorealistic textures) or video animations.

Many different systems are on the market for all kinds of object sizes, ranges and accuracies. 3D scanners are already used in industry (e.g. automotive, clothing) for design, development, quality control and rapid prototyping as well as in engineering and construction for the documentation of plants, buildings and landscapes. But 3D scanning offers new possibilities for the recording of objects in archaeology, architecture and cultural heritage as well, which is the main aspect of this paper.

For the case studies, three different scanners were used: The GOM ATOS II is a structured light digitizer for small objects. It captures a maximum scanning volume of 1 m^3 with accuracies of 0.02 mm and better. The MENSI S25 is a triangulation type laser scanner that works best at ranges of 2 to 10 meters with accuracies between 0.5 and 2 mm. Leica's HDS 2500 ranging laser scanner (former Cyrax 2500) is able to scan objects up to 100 m with a single point accuracy of 4 mm.

In addition to a relatively expensive scanner (typically between € 50,000 and € 200,000), a proper software kit is needed to process the raw point data and to achieve satisfactory results. Normally, the scanner manufacturers provide their own software which might be adequate. But often this is not the case and an additional software package has to be purchased. Different stand-alone products are available. Some focus on fitting features and the creation of CAD models, others are primarily specializing in mesh creation. The latter is usually the appropriate method for heritage objects. A detailed list of scanner hardware and software can be found at i3mainz (2004).

Close-range photogrammetry

Analytical stereophotogrammetry is still the predominant method for the geometric documentation of complex heritage objects. Analogue film contains a maximum of information and can be archived for a long time. Analytical plotters for aerial photographs can be used for close-range applications in the same way. Any camera can be used for photogrammetric purposes, from low-cost 35 mm cameras to high-end large format metric cameras. But depending on the accuracy requirements, the camera should meet certain criteria like a stable interior orientation.

A camera like the Rolleiflex 6008 metric middle format camera, which was used for the case studies, is a good compromise. It is equipped with exchangeable metric lenses and a built-in grid (réseau) plate with 11 x 11 reference crosses. The camera is calibrated by the manufacturer for each lens and can therefore be used for any close-range photogrammetric application. With a total cost of about € 10,000 (including lens) it is an affordable investment. The result of photogrammetric plotting is usually a line drawing in 2D or 3D in a CAD system. This can be used as the basis for restoration, visualization or further investigations.

CASE STUDIES

Stone wall with archaeological findings

Nearly 2000 years ago, the Romans started to mine the huge tuff deposit in the Eastern Eifel which originate from the eruption of the Lacher-See volcano 13,000 years ago. Even today, the tuff is mined there, thus most of the ancient quarries were destroyed. But an area of 3,000 m² was roofed and protected against further destruction. Today tourists can visit single mining walls and inspect the underground workplace of the Romans. One of those tuff stone walls (size 4.5 x 3 m²) was documented with laser scanning and photogrammetry. It was demanded that special working traces like wedge holes, cuts and tool marks should be clearly perceptible in the recordings.

A MENSI S25 laser scanner was used to record the wall with an accuracy of 1 to 2 mm. A regular point grid of 5 mm was chosen for the whole wall and 2 mm for interesting areas like the working traces. Since the scanner achieves its highest accuracy at short distances (2 to 3 m) and space in front of the wall was limited, the scanner was not able to capture the whole wall in one shot. Scans from three different observation points had to be carried out and were connected using small spheres which were distributed around the scanning site. The final registered point cloud was used to create a closed surface mesh for visualization purposes (Figure 1).

Figure 1: Screenshots of a video animation of the stone wall.

The photogrammetric work was accomplished simultaneously with a Rolleiflex 6008 metric middle format camera. The use of a 50 mm lens allowed image scales of 1:60 which is by far enough to achieve a final output scale of 1:20. Twelve images were taken for six stereo pairs. For the exterior orientation of the models, 15 reference targets had to be co-ordinated using a total station. The final result after approximately three hours of stereocompilation on a Zeiss P3 Planicomp stereo plotter is a vector map and can be seen in Figure 2.

This project is a typical example for heritage recording, where 3D scanning yields better results than photogrammetric techniques (within a comparable time). A 3D model of the stone wall contains by far more information than a line drawing and conveys the three-dimensional shape of the wall much better. The vector map only shows the most important features and edges and does not provide any information about the areas between the lines.

Figure 2: Vector map of the stone wall.

Façade of a classical castle

Close-range photogrammetry is the typical method for the documentation of façades. Already shortly after the invention of photography in the middle of the 19th century, people started to develop cameras and measurement techniques for the purpose of conservation, restoration and documentation of architecture. But nowadays, laser scanners also measure contact-free and nearly as fast as photogrammetry and thus can be an alternative solution.

The castle 'Schloss Herrnsheim' near Worms, Germany, was used as an exemplary object for the comparison of both methods. This castle was built in the 15th century and got its present shape around 1840. The recorded façade is 34 m wide and 13 m high and was documented with the aim of creating a three-dimensional vector map. Six images were taken with a Rollei 6008 for the stereocompilation. Three to four days of work on the stereo plotter resulted in a line drawing that can be seen in Figure 3.

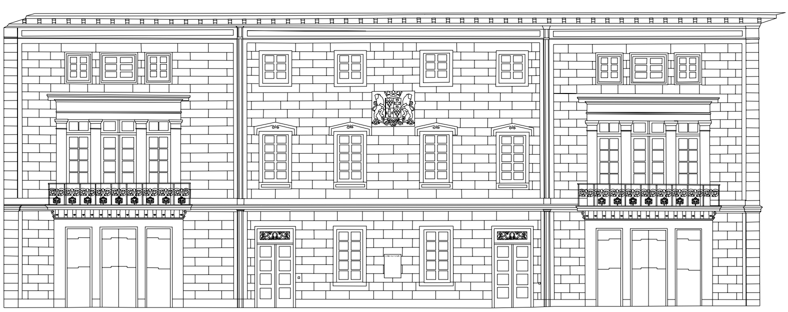


Figure 3: Line drawing of Schloss Herrnsheim.

Scanning was accomplished with a Cyrax 2500 laser scanner. Within two hours of scanning from three observation points, the whole façade was captured using an average point density of 15 mm. After the registration of the three scans, a plugin allowed the loading of the resulting 2.7 million points into AutoCAD. Then a line drawing was created on the basis of the snapped 3D points. This procedure is very time-consuming, because the point cloud has to be rotated permanently to get a 3D impression and to be able to snap the correct points (e.g. on edges). In any case, the resulting lines will have certain deviations from their correct positions due to the point density of the laser scans.

The line drawing originating from this procedure is similar to the stereoplotting results, but contains less information. For instance, it is not possible to detect the joints in the brick-work, which can easily be measured with a stereo plotter. The amount of time for processing the data to a final line drawing is much the same for both methods. But it has to be considered that the scanning results are of lower quality regarding accuracy and level of detail.

But 3D scanning offers other interesting applications, for example a deformation analysis. The result in Figure 4 shows the deviations of the scanned wall from a reference plane.

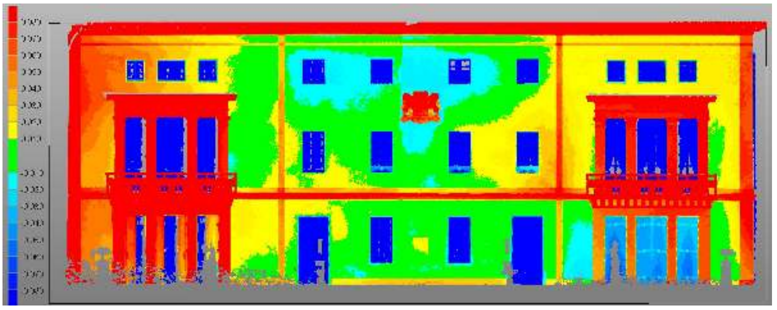


Figure 4: Deformation analysis.

Renaissance relief plate

The Hofkirche at Innsbruck with the tomb of Emperor Maximilian I is probably the most important art-historical monument in the State of Tyrol. The cuboid shaped cenotaph (empty tomb) consists of a frame of black marble in which 24 reliefs of white marble (each approx. 82 cm x 55 cm) are embedded in two horizontal rows around the object. These reliefs show scenes of Emperor Maximilian's life. They have a level of detail within the range of 0.1 mm and had to be documented down to the smallest detail and with the highest precision available. Due to the uniqueness of the object, a combination of surveying methods was applied. Both, close-range photogrammetry and high-accuracy 3D scanning were used.

Due to the complexity of the object, each plate was captured with 12 to 33 scans with a GOM Atos II light projection digitizer. Up to 25 million points were recorded per plate. This amount of data had to be reduced intelligently, because current software products do not allow the handling of more than a few million points. After triangulation of the points, the resulting mesh had to be edited manually to reduce noise and to fill holes in hidden parts of the surface (e.g. behind arms, swords etc.). The whole postprocessing work took about one week for each relief plate.

The photogrammetric work was done with a UMK 1318 large format metric camera. The stereocompilation of two stereo pairs per relief plate also took about one week. In Figure 5 a comparison of photo, line drawing and 3D model is shown, which gives a good impression about the level of detail of these representations of the relief. The photogrammetric vector map is not suited to get a real three-dimensional impression of the object. It only contains the most important contours and feature lines. The 3D model, on the other hand, comprises a virtual copy of the original relief plate with only little loss of information and detail. See also Boehler et al. (2003b).

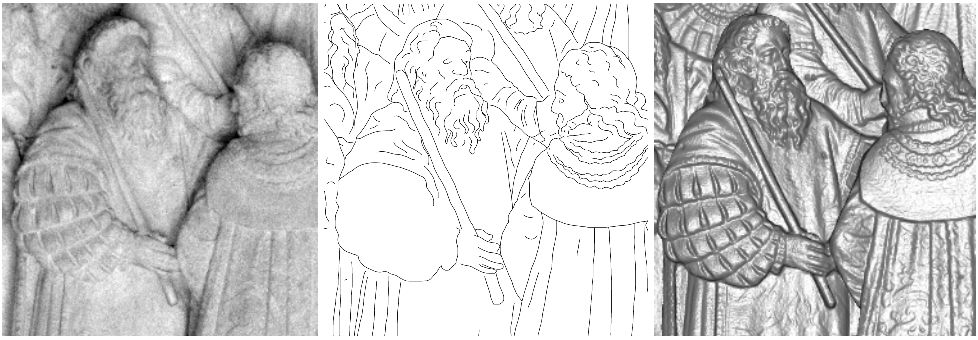


Figure 5: Part of a relief plate (about 10 cm x 10 cm): Photo, line drawing, 3D model.

Archaeological artifacts

Up to now the documentation of Stone Age artifacts is usually confined to manual drawings. Characteristical parts like tool marks or concave and convex faces have to be highlighted by shading. But this method does not contain any true 3D information and is very time-consuming. Innovative solutions are desirable for a more automatic documentation of archaeological artifacts.

For this purpose, a Stone Age hand-axe was recorded with both, a GOM Atos II scanner and a Rollei 6006 camera. A procedure was developed that allows the creation of a closed 3D surface model within 45 minutes, including the scanning time. The stereo plotting of both sides of the artifact using the Rollei imagery took about four hours. Results of both methods can be seen in Figure 6. See Boehler et al. (2003a) for more information on this project.

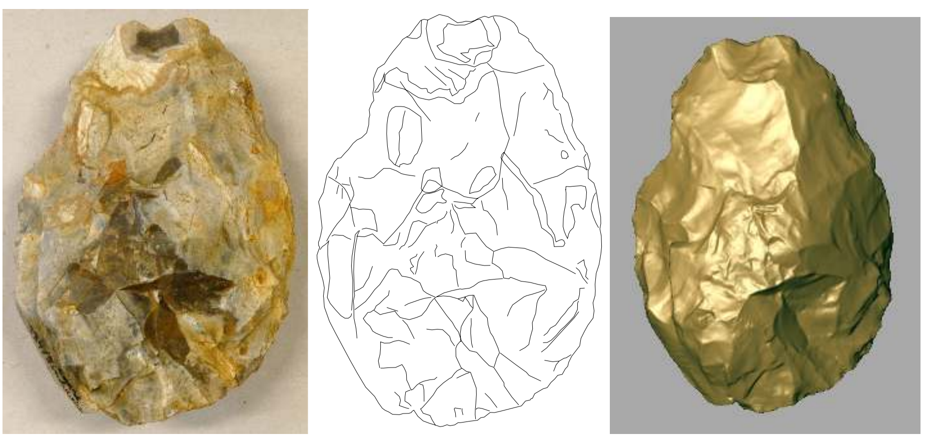
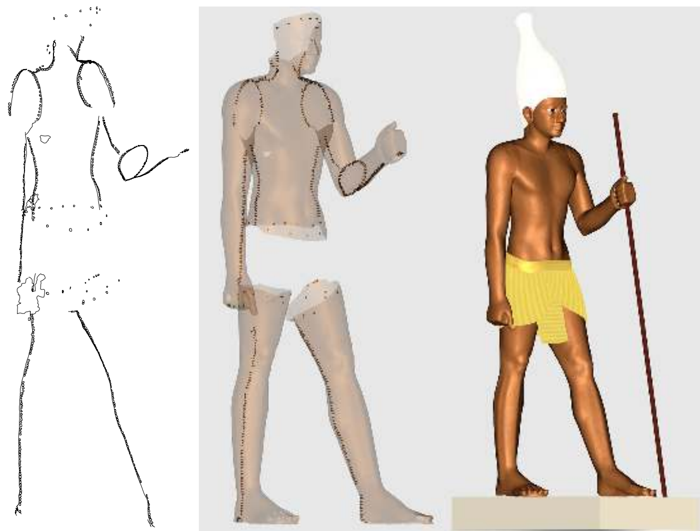


Figure 6: Stone Age artifact (about 11 cm x 4 cm): Photo, line drawing, 3D model.

3D scanning offers new possibilities for analyzing archaeological findings. Once scanned, those findings are available as a digital copy (e.g. via internet) worldwide. At present, algorithms are in development at i3mainz for an automatic extraction of characteristical dimensions (e.g. sizes, volumes) and features like edges, concave and convex surfaces.

Antique statue

The statue of Pharaoh Pepi I is the oldest known life-size metal sculpture in the world. It is dated to about 2300 BC and was excavated in 1897. In 2001, after a several years lasting process of restoration, conservation and technological investigation, the statue was documented geometrically. The shape of the sculpture was recorded using a Mensi S25 laser scanner. Special features like the seams between the copper sheets forming the statue and the rivets connecting them were measured using close-range photogrammetry (Figure 7a). A model was generated from the scanner data (representing the surface) as well as a 3D vector map of the line features (mainly the rivets which cannot be distinguished in the scans) from the stereo images. Besides these single results, both were combined for visualization purposes (Figure 7b) such as video sequences of the rotating sculpture or a combination with reconstructed vanished parts of the statue (Figure 7c).



(a) (b) (c)

Figure 7: Pharaoh Pepi I (178 cm high). (a) Results of stereoplotting. (b) 3D model (semi-transparent) combined with rivet positions. (c) Virtual reconstruction of the original sculpture with crown and loincloth.

In this project, only a combination of 3D scanning and photogrammetry could yield the necessary documentation results. For more information see Heinz (2002).

SUMMARY

The question, which measurement technique is "better" than the other, cannot be answered across the board. Each method has got its advantages at different working fields. In many cases, a combination of different techniques might be a useful solution.

When an object can be described predominantly by point- or line-based structures, close-range photogrammetry will be the perfect solution in most cases. Especially when the object has distinct textures, photogrammetric methods have to be preferred. A vector map as a final result is able to reproduce those objects very accurately, but on the other hand it does not contain any information about the object shape between the recorded lines and points.

Instead of traditional line drawings, orthophotos might be alternative solutions for the documentation of flat, regular shaped objects like architectural façades. Besides geometric accuracy, orthophotos contain radiometric information (gray or color values). But it should be noted that orthophotos are always only two-dimensional.

Further advantages of photogrammetry for heritage recording are the short time needed for the recording on site, particularly when no stable recording platform is available, and the storage qualities of photographic film which can be archived for a long time.

On the other hand, 3D scanning techniques have to be preferred when very complex and irregular objects like sculptures, reliefs or archaeological findings are to be documented. Due to its surface-based working principle, those objects can be captured by 3D scanners very accurately and in full detail. In addition the results of scanning projects can be presented and visualized much better than the results of any other geodetic method. By using artificial illumination and surface textures for the visualization of 3D models, impressive realistic presentations can be achieved which are often more valuable for inspection than the original object itself (see Figure 5 left and right).

In many cases, a combination of scanning and photogrammetric techniques is the best solution. When both, line- and surface-based structures have to be captured, one single method often does not produce satisfactory results.

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REFERENCES

Boehler, W., Boehm, K., Heinz, G., Justus, A., Schwarz, C. and Siebold, M., 2003a: Documentation of Stone Age artifacts. *The ISPRS International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 34, Part 5, 506-510

Boehler, W., Bordas Vicent, M., Hanke, K. and Marbs, A., 2003b: Documentation of the German Emperor Maximilian I's tomb. *The ISPRS International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 34, Part 5, 474-479

Boehler, W. and Marbs, A., 2002: 3D scanning instruments. *CIPA – ISPRS workshop on scanning for cultural heritage recording*, Corfu, Greece. http://www.isprs.org/commission5/workshop/

Heinz, G., 2002: Pharaoh Pepi I.: Documentation of the oldest known life-size metal sculpture using laser scanning and photogrammetry. *CIPA – ISPRS workshop on scanning for cultural heritage recording*, Corfu, Greece. http://www.isprs.org/commission5/workshop/

i3mainz, 2004: WEB site of i3mainz about 3D scanning in cultural heritage. http://scanning.fh-mainz.de/

Marbs, A., 2004: *Vergleich von 3D-Scanning und Photogrammetrie zur geometrischen Dokumentation im Denkmalbereich*. Edited and published by i3mainz. In print.