Surveying of Pharaohs in the 21st Century

Guido HEINZ and Hartmut MÜLLER, Germany

Key words: Laser Scanning, Photogrammetry, Cultural Heritage, Archaeology, Documentation, Visualisation

SUMMARY

The two statues of Pharaoh Pepi I. in the Egyptian Museum in Cairo are the oldest known life-size metal sculptures in the world. They are dated to about 2300 BC and were excavated in 1897. After a several years lasting process of restoration, conservation and technological investigation, the two statues were documented geometrically. The shapes of the sculptures were recorded using a 3D 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. Surface models of the sculptures were generated from the scanner data as well as 3D vector maps of the line features derived from the stereo images. Besides these single results, both were combined for visualisation purposes such as video sequences of the rotating sculptures and a combination with reconstructed vanished parts of the statue like the loincloth or the crown. This paper shows the concepts of the recording, problems and some results.

ZUSAMMENFASSUNG

Die beiden Statuen des Pharaos Pepi I. im Ägyptischen Museum in Kairo sind die ältesten bekannten lebensgroßen Metallskulpturen der Welt. Sie stammen aus dem 23. Jahrhundert vor Christus und wurden 1897 bei Hierakonpolis ausgegraben. Es handelt sich um zwei ca. 1,77 m bzw. 0,65 m große Skulpturen aus Kupferblech. Nach einem mehrere Jahre dauernden Prozess der Restaurierung, Konservierung und technologischen Untersuchung erfolgte die geometrische Dokumentation.

Die Form der Statuen wurde mit einem 3D-Laserscanner aufgenommen, Besonderheiten wie die Nähte zwischen den einzelnen Kupferplatten oder die sie verbindenden Nägel mittels Nahbereichsphotogrammetrie bestimmt. Die Oberflächenmodelle aus den Laserscanningaufnahmen und die Vektordaten aus den Stereomodellen bilden gemeinsam die Datengrundlage für die Erstellung von Nagelplänen, Visualisierungen und Rekonstruktionen der nicht mehr vorhandenen Teile der Skulpturen. Dieser Aufsatz zeigt das Konzept für die Dokumentation, aufgetretene Probleme und Ergebnisse.

Surveying of Pharaohs in the 21st Century

Guido HEINZ and Hartmut MÜLLER, Germany

1. INTRODUCTION

In 1897 two statues of Pharaoh Pepi I. were found in a temple of the ancient city of Hierakonpolis. They are dated to the 23rd century BC and are considered to be the oldest known life-size statues made of metal. In 1996, a joint project between the Egyptian Museum Cairo, the Deutsches Archäologisches Institut, Abteilung Kairo and the Römisch-Germanisches Zentralmuseum Mainz in Germany started with the aim of the restoration, conservation and technological investigation of the statues. The bigger statue is about life-sized (178 cm), the small one about 65 cm high. The statues are made of copper sheets that are connected with a kind of rivets. To conclude the restoration project, the statues had to be documented geometrically. Various measurements between points of the surface of the model are easily possible using a digital model of the statues. Generating a surface model of this kind can reasonably be accomplished using the points measured with a laser scanner. This model can also be used for further visualisation purposes.
As the accuracy of the used scanning hardware was limited, the smooth seams between the single copper sheets and the single rivets connecting them cannot be recognised reliably in the model. To achieve this part of the documentation, the corresponding parts of the statue were also recorded using close range photogrammetry. The results of both methods were combined later for generating various visualisations and animations of the sculpture including the digital reconstruction of vanished parts of the statues like a crown, the loincloths, or the ears. Problems occurred regarding the data capture and processing of the small statue: The statue is mounted onto a base of Plexiglas and is also fixed with a Plexiglas structure at the back which could not be removed for the documentation process. As optical methods for recording are used, the refraction of the light passing through the Plexiglas had to be modelled for the data captured from the back of the statue.

2. SCULPTURE RECORDING

2.1 Laserscanning

The statues were scanned using a MENSI S25 scanner. This scanner can be used in a range between 2 m and 20 m and can reach an accuracy of about 0.6 mm for the closest distance under optimal conditions. It is a triangulation scanner with a base of about 80 cm that sends out the laser beam at the one end of the scanner and records the 3D position of the reflected point using a digital camera at the other end (cf. Fig. 1). The opening angle in this plane is about 45°. Additionally, the scanner can rotate around its horizontal axis and in this way has a vertical opening angle of 320°. The accuracy of a point measurement depends on the distance to the object. The scanner can measure with a rate of 100 points per second at most.

Fig. 1: Recording of the small statue with a laser scanner

One challenge in scanning complex 3D objects like this statues is to cover the complete surface with the scanning process. This is supported by software tools allowing the visualisation of the scanned point clouds, usually supplied by the scanner's manufacturer with the software controlling the scanning process itself. It is highly recommended to do further checking by triangulating the surface to visualise possible holes that are often not easily to recognise by just inspecting the point cloud. The process of scanning the sculptures took several days. The working hours of the single days were short due to the opening hours of the museum and the fact, that the scanner was not allowed to be operated unattended during night time. The big statue was scanned from 29 observing points recording 1.8 million points in 65 frames. For the small statue 16 frames with 500.000 points from 10 observing points were recorded. With regard to the accuracy of the scanner and the time for scanning, an even more dense grid would not result in further improvement. The quality and the processing speed of all following steps of treatment of the measured points are strongly dependent on the software used for

Fig. 2: Point cloud

this purpose. MENSI provides the 3Dipsos software which is designed primarily for the extraction of CAD-features from the point cloud. Additionally Raindrop Geomagic Studio, a software for handling scanner data and triangulated meshes was used for the modelling. The single scans are registered into a common coordinate system using red spheres placed around the sculpture. The accuracy of these registrations is limited to the accuracy of the positioning of the points and thus, especially in close range applications, often not sufficient. The point clouds of the single scans were registered more accurately using the point clouds themselves for the calculation of the transformation parameters. The result of this registration process was an oriented point cloud of each statue. Outliers have to be eliminated and the noise has to be reduced afterwards. Finally the density of the points was reduced using a spatial sampling for the part with overlapping scans. The resulting point clouds consist of about 1.000.000 respectively 440.000 points on the surface of the statues (cf. Fig. 2). After performing a 3D-triangulation, filling holes etc. the final meshes modelling the surfaces consist of 2.0 million respectively 900.000 triangles.

2.2 Photogrammetry

The parts of the statues containing seams between the copper sheets and rivets were recorded with stereo models using an analogue middle format camera Rollei 6008 metric.
For the orientation process of the single stereo models of the big statue, point markers were stuck onto the statue. 16 convergent images were taken in addition to the stereo images. The distances between selected marked points were measured directly to introduce a scale into the following calculations. After measuring the image coordinates of all marked points in all images, a bundle adjustment was calculated to determine the 3D position of the marked points . The coordinates of the points could be determined with an accuracy of about 0.3 mm.
For the small statue the corner points of the Plexiglas structure could be used as reference points, their coordinates could be derived directly from the size of the structure.

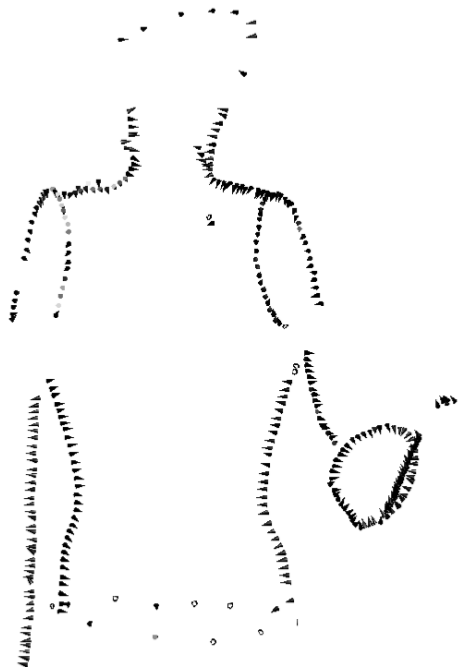

Fig. 3: Photogrammetrically measured features

The features on the statue were plotted using an analytical plotter Zeiss P3 with MicroStation as connected CAD-system. The features to be plotted were attributed very simply using different layers for rivets, rivet holes, the contours of missing parts of the statue, the construction holding up the statue and other details like the remains of the crown or the loincloth. The final 3D vector data set can be viewed and plotted in various projections showing the metric correct position of these features in the plots.
For further visualisation purposes cones and tori were generated from the polyline data of the rivets and holes automatically using AutoCAD LISP (cf. Fig. 3).

3. VISUALISATION

For all further visualisation tasks 3D Studio Max, a 3D visualisation and animation software, was used. The data transfer was realised using Wavefront OBJ and AutoDesk DXF formats.

With the full set of functionalities, different visualisations can be performed. A simple one is to assign a texture to the sculpture that is similar to the current or supposed original appearance of the sculpture and shows it from different directions. The vector data can be emphasised when combined with the surface model. By assigning semitransparency to the model's surface, the position of seams and rivets can be viewed in 3D even though these features are not visible in reality (cf. Fig. 4). Video sequences, e.g. rotating the camera position around the sculpture, have been generated in this way. This kind of animation assist the observer in achieving a good 3D impression of the object and the spatial distribution of the special features.

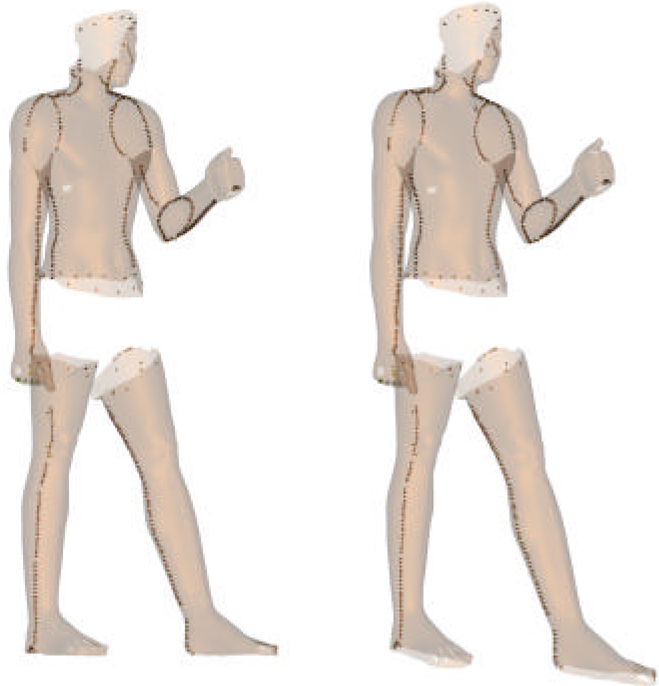

Fig. 4: Visualisations in different projections

Additionally, parts of the sculptures that have vanished in the past have been reconstructed digitally and switched on or off for viewing. Thus, the most probable original impression of the sculpture can be generated without changing the real sculpture itself. The crown of the big and the loincloths of both statues were created using photos of comparable objects from other sculptures (cf. Fig. 5).

4. PROBLEMS

Like mentioned above, part of the data caption was made through Plexiglas. These measurements were taken in that way, that always both rays determining the point to be measured went through the plate. For the correction of the impact of the Plexiglas the following is assumed. The Scanner is a black box system giving coordinates of the surface points. When using standard equipment the vector

Fig. 5: Virtual reconstruction of the small statue

data from the photogrammetric images can be seen similar. So it seems reasonable to apply corrections to the incorrectly measured data on the object's surface. For both measurement techniques the principle is the same: the position of the object point is determined from two positions. In the case of the scanner these are the laser source and the camera recording the laser point. For the photogrammetric recording, the rays run from the object point through the lenses of the cameras. In both cases these positions can be determined relatively towards the Plexiglas plate. The intersection point of these two rays is the position to be measured on the surface of the statue. The displacement of the rays when passing the plate is not considered, the position determined therefore incorrect.
The ray is displaced parallel when passing the coplanar plate, the dimension of the displacement is dependant on the angle of incident, the thickness of the plate and the refraction index of the material. The displacement takes place in a plane perpendicular to the plate through the origin of the ray and the point where the ray hits the plate.

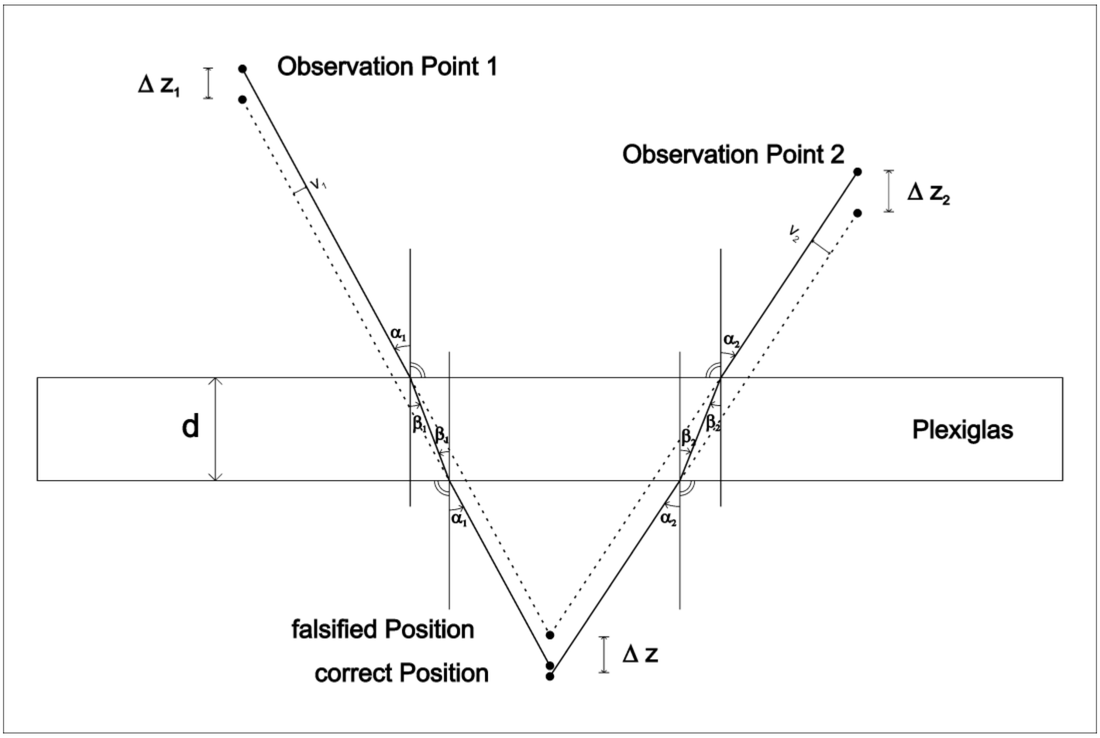

Fig 6: Path of the determining rays trough the plate

Fig. 6 shows a sketch of the rays. The two planes in which the rays are displaced intersect in a straight line perpendicular to the plane. Thus only the distance of the pint to record to the plate changes. During the measurements the falsified position is determined as a straight run of the ray is assumed. Actually the ray was displaced resulting in a different distance to the plate. For the correction the displacement for every single point has to be determined. As the angles of incidence of the two determining rays the determination of one single point are not equal, two distances for the displacement occur. Different values for the displacement are a problem insofar, as the rays used for the calculation did not intersect in reality, whereas this is assumed by the algorithms. A mean value is used for the correction of the point position.

The corrections were applied using a developed routine capable of processing vector data and point clouds. The approach used was verified by making test measurements with a Leica AXYZ, a theodolite-based optical industrial measurement system. The set-up was comparable to the measurements when recording the statues. The differences between direct measurements and corrected measurements through the Plexiglas were between 0.02 and 0.21 mm, the impact of the Plexiglas on the point determination in this set-up was between 4 and 5 mm.
The influence of various sources of errors were estimated by model calculations. Possible factors are the skewness of the rays, the material, the shape and the surface of the Plexiglas plate, the refraction index for different wavelengths, the thickness of the plate and the accuracy of the determination of the positions of cameras / scanner. Using a mean configuration as compared to the real conditions the impact of these factors was modelled.
The result was that the differences in the corrections values was below the accuracy of the measurements and at most one fortieth of the correction itself.

5. ACKNOWLEDGEMENTS

Funds for the acquisition of laser scanning equipment were provided by the German Federal Ministry of Education and Research within its zip initiative (Zukunftsinvestitionsprogramm) to i3mainz.
The documentation was carried out within the co-operation between the Römisch-Germanisches Zentralmuseum Mainz, Germany and i3mainz, Institute for Spatial Information and Surveying Technology of Mainz University of Applied Sciences, Germany.

zip
Ein Projekt im
Zukunfts-
investitions-
programm
der Bundesregierung

REFERENCES

Böhler, W.; Heinz, G.; Marbs, A.: The potential of non-contact close range laser scanners for cultural heritage recording - CIPA International Symposium, Proceedings, pp. 430 – 436, Potsdam, Germany – 2001

Eckmann, C., Shafik, S.: Die beiden Kupferstatuen des Pepi I. aus dem Tempel von Hierakonpolis in Ägypten. Mainz 2002.

Heinz, G.: Geometrische Dokumentation und Visualisierung zweier antiker Statuen. Master Thesis, 2004, Mainz University of Applied Sciences. Unpublished.

Marbs, A.: Experiences with laser scanning at i3mainz - CIPA, Heritage Documentation - International Workshop on Scanning for Cultural Heritage Recording, pp. 110 – 114, Corfu, Greece - 2002

BIOGRAPHICAL NOTES

Hartmut Müller gained his diploma and doctoral degree in Geodesy at Karlsruhe Technical University. After several years of professional experience outside of universities he has been working as academic teachers at sub-department Geoinformatics and Surveying of Mainz University of Applied Sciences. He has been members of board of the research and development institute i3mainz since 1998. Guido Heinz holds a diploma degree in Geoinformatics and Surveying and a master degree in Geoinformatics. He is currently working as scientific coworkers at the Römisch-Germanisches Zentralmuseum Mainz, Research Institute for Pre- and Early History.

CONTACTS

Prof. Dr. Hartmut Müller
i3mainz – Institute for Spatial Information and Surveying Technology
Fachhochschule Mainz – University of Applied Sciences

Holzstrasse 36
55116 Mainz
GERMANY

Tel. +49 6131 2859 674
Fax +49 6131 2859 699
mueller@geoinform.fh-mainz.de
http://www.i3mainz.fh-mainz.de