

PHARAOH PEPI I.: DOCUMENTATION OF THE OLDEST KNOWN LIFE-SIZE METAL SCULPTURE USING LASER SCANNING AND PHOTOGRAMMETRY

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ABSTRACT

Two statues of Pharaoh Pepi I. are the oldest known life-size metal sculptures in the world. They are dated to about 2300 BC and were excavated in 1897. In 2001, after a several years lasting process of restoration, conservation and technological investigation, the 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. A model was generated from the scanner data as well as a 3D vector map of the line features from the stereo images. Besides these single results, both were combined for visualization purposes such as video sequences of the rotating sculpture or a combination with reconstructed vanished parts of the statue like the loincloth and the crown.

INTRODUCTION

In 1897, amongst numerous other things 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. After a first restoration around 1900 AD, the statues were in the exhibition of the Egyptian Museum in Cairo. 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 (fig 1) statue is about life-sized (178 cm), the small one about 78 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.

Different demands were to be fulfilled: The shape and size of the copper sheets and the rivets had to be documented and to be plotted in maps from different views respective reference planes. Measurements, e.g. distances between certain surface points, shall be possible, even if not directly accessible. The documentation of the bigger sculpture was of higher importance as compared to the small one.

OBJECTIVES

Measurements of any kind between points of the surface of the model are easily possible using a digital model of the statue. 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 visualization purposes.

As the accuracy of the used scanning hardware was limited to about 0.7 mm, the smooth seams between the single copper sheets and the single rivets connecting them cannot be recognized 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 resulting 3D



Figur 1. Statue of Pharaoh Pepi I.

vectors can be plotted in different projections (e.g. parallel projections from different sides of the sculpture).

The results of both methods can later be combined for generating various visualizations of the sculpture including the digital reconstruction of vanished parts of the statues like the crown or the loincloth, which originally were made of wood covered with a layer of gypsum colored in gold.

The small statue was recorded using the same techniques and procedures as with the bigger one. Problems occurred regarding the recording process: The statue is mounted onto a base of plexiglas and also it is fixed at the back with a plexiglas structure 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 should be modeled for the data captured from the back of the statue, which seems to be anywhere between difficult and impossible. Thus, these data sets have not been processed until now.

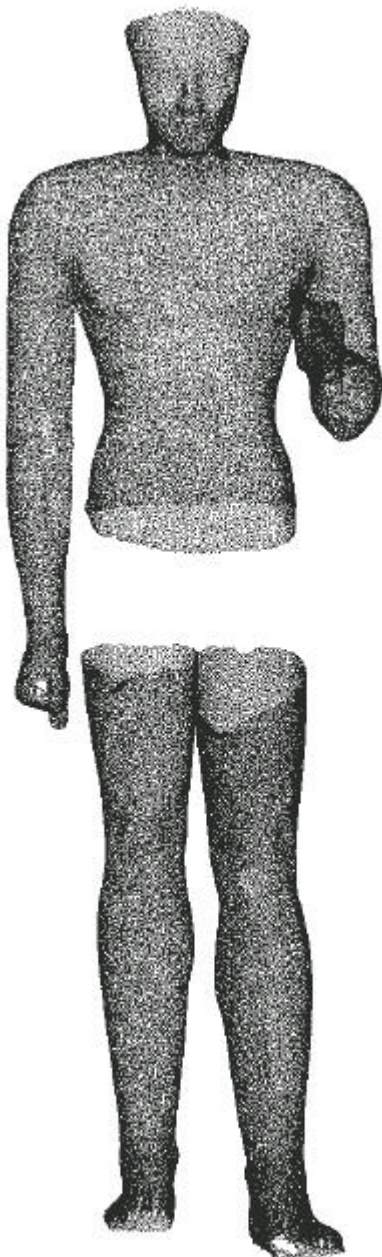


Figure 2. Registered point cloud from laser scanner.

LASER SCANNING

The statues were scanned using a MENSIS S25 scanner. This scanner can be used in a range between 2 m and 20 m and can reach an accuracy of about 0.3 mm for the closest distance under optimal conditions. It is a triangulation scanner that sends out the laser beam at the one end of the scanner base and records the 3D position of the reflected point using a digital camera at the other end. The base for this scanner is about 80 cm. 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 is dependent on the distance to the object due to the triangulation concept of the scanner. The scanner can measure with a rate of 100 points per second at most.

As the calibration of the scanner was not optimal for closest distances at the time of recording the sculpture, the accuracy of the derived surface model can be expected to be about 0.5 mm. This should be sufficient for measurements to be taken at the model, e.g. the distance between certain points on the statue, but this model does not allow an accurate reconstruction of the sculpture, which was not intended in this case, anyhow.

One challenge in scanning complex 3D objects like this statue is to cover the complete surface with the scanning process. This is supported by software tools allowing the visualization 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 visualize possible holes that are often not easily to recognize by just inspecting the point cloud.

The process of scanning the bigger sculpture took about 6 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. In this time, altogether about 1.8 million points on the surface of the statue were scanned from 29 different observing points. The scans were performed with a mean point grid on the surface of the statue of about 1.0 mm for every single scan. This point grid is densified considerably as the surface is usually covered in multiple scans from different directions. With regard to the accuracy of the scanner and the time for scanning, an even more

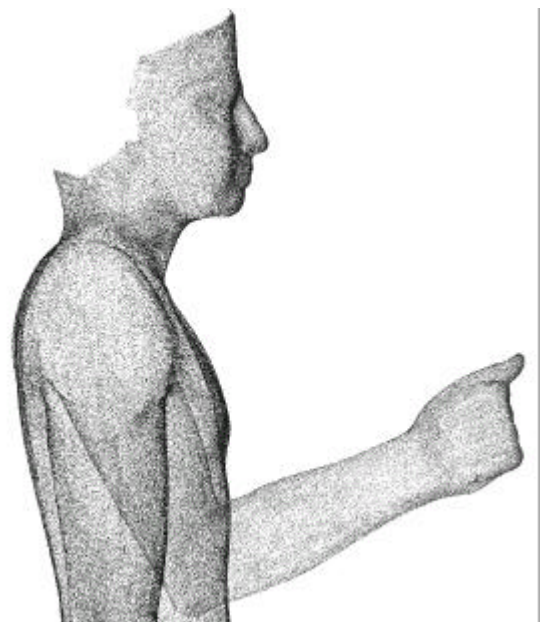


Figure 3. Detailed view of point cloud.

dense grid would not result in any 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 this purpose. MENSİ provides the 3Dipsos software which is designed primarily for engineering projects with the extraction of CAD-features from the point cloud. The treatment of irregularly shaped surfaces including triangulation and model generation is possible but is not always very effective.

The single scans are registered into a common coordinate system using red spheres placed around the sculpture. The center of each single sphere is modeled in the software and the points of the scans are transformed using these positions of the spheres as common tie points. At least three spheres are needed for every observing point. The accuracy of these transformations is limited to the accuracy of the positioning of the points and thus, especially in close range applications, often not sufficient, therefore. The point clouds of the single scans were registered more accurately using the point clouds themselves for the calculation of the transformation parameters, as provided by the 3Dipsos software. The result of this registration process was an oriented point cloud of the statue. Because of the overlapping scans of parts of the surface, the density of the points had to be reduced using a spatial sampling resulting in a point spacing of 1mm. The resulting model consists of about 1.000.000 points on the surface of the statue (fig 2, 3). The following steps are the elimination of wrong points, e.g. occurring at edges, and the smoothing of the point cloud.

3Dipsos provides two different approaches for the triangulation of the point clouds. Firstly, a true 3D triangulation which requires a regularly spaced point cloud. The second method uses projection surfaces like planes, cylinders or spheres, and performs a 2.5 D triangulation on this reference surface. This can be useful for building the mesh, e.g. for a part of an arm, but on the other hand leads to single mesh arrangements that must be stitched together to achieve a complete model of the statue.

The time needed for the generation of the complete model was a multiple as compared to the time needed for scanning. Reasons for this are firstly the poor calibration of the scanner which led to a higher noise in the recorded points and secondly the software that provides only basic support for the generation of triangulated surface models and thus is not optimal for this task. The noise in the data itself also led to a higher effort in time for the model generation, as a higher effort is necessary in the preliminary treatment of the point cloud (cleaning, filtering) prior to the modeling of the surface.

PHOTOGRAMMETRY

The parts of the statue 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, 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.

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

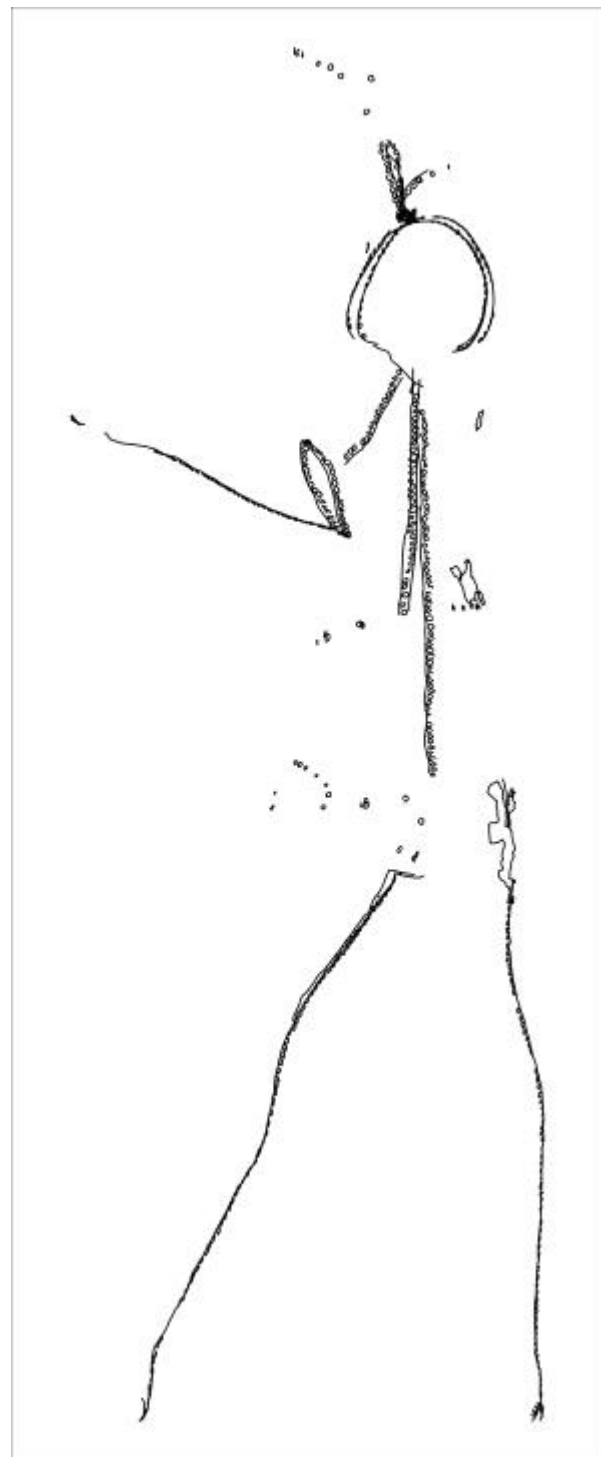


Figure 4. Vector plot.

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 (fig 4).

VISUALIZATION

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



Figure 5. Left: Shaded view of the sculpture's model. Right: Combined with vector features.

With the full set of functionalities, many different visualizations 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 show it from different directions. Video sequences, e.g. rotating the camera position around the sculpture, can easily be generated in this way. Such an animation assists the observer in achieving a good 3D impression of the object.

The vector data can be emphasized when combined with the surface model. By assigning semi-transparency 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 (fig 5).

Additionally, parts of the sculptures that have vanished in the past can be reconstructed digitally and switched on and off for viewing. Thus, the most probable original impression of the sculpture can be generated without changing the real sculpture itself. The crown and the loincloth of the sculpture were created using photos of comparable objects from other sculptures.

MEASUREMENTS

Using the model of the sculpture, measurements can be performed that are not possible with the sculpture itself. Using rather simple software tools, point coordinates or distances

between points can be measured as 3D distances or differences parallel to selected coordinate axes. Points without direct connection in between can be used easily.

Thus, measurements can now be done without the need to use the real sculpture itself with sufficient accuracy. This will be an advantage when the sculpture will be in the exhibition of the museum again, or not accessible at all to scientists interested in further investigations.

CONCLUSIONS

The used approach for the geometric documentation of the statue of Pepi combines the prospects of the two methods used. The documentation of the seams and rivets with close range photogrammetry represents established standard technologies. The digital surface model of the sculpture generated from laser scanner points allows measurements on the one hand and is suitable for various kinds of visualizations, in addition. The digital reconstruction of perished parts as well as animations can be made

using these data.

The accuracy of the digital model is not sufficient for an exact reconstruction of the sculpture, which was not an objective of this project. In such a case, another scanner with higher accuracy using different techniques (e.g. structured light projection) should be used. The size of the sculpture and the accuracy needed is near the limits of the used scanning hardware.

Comparing the simple line drawing of the seams and rivet features only (fig 4) with the combination of 3D model and line drawing (fig 5) shows the much higher information content of the latter. It is much easier for the observer to relate the line features with the corresponding areas of the sculpture and at the same time see all features, even those actually hidden by the sculpture itself.

The digital representation of the sculpture can additionally be used for measurements and visualizations distant from the sculpture itself which can only be accomplished with such a virtual 3D model.

Further results and visualizations of the sculpture will be published in a separate report covering the whole process of its restoration, conservation, technological investigation and documentation.

PROBLEMS

Various problems occurred, respectively had to be solved during this project. Beginning with the on-site work the temperature during the scans was at the limit of the hardware specifications. The scanner can be operated at temperatures up to 40° C; the actual temperature inside the scanner was 39° C sometimes. In the worst case external cooling is possible using a ventilator.

The limited opening hours of the museum lead to an extension of the recording time, but were not a problem in general. An important factor for the recording time is the scanning rate of about 100 points per second at best. This is quite slow as compared to ranging scanners or light projecting systems. The most important advantage is the accuracy in the range between 2 m and 10 m, which is unrivaled at present.

The fact, that the calibration of the scanner was not optimal for close range applications in spite of a manufacturer's calibration immediately before the project, led to a reduced accuracy of the scanned points and a higher expense for the generation of the model.

The software used is workable for generating irregular object models, but far from optimal. The current situation is that optimal packages are not available at present (cf. Böhler et. al., 2002).

The whole equipment including the scanner itself, tripod, power transformer, etc. in a transportation box has a complete weight of about 150 kg. It was shipped from Germany to Egypt by airfreight. The time for transportation and possible delays must be considered as a period when the scanner cannot be used for other projects.

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REFERENCES

Boehler, W. Heinz, G., Marbs, A., 2001: The potential of non-contact close range laser scanners for cultural heritage recording. XVIII CIPA Symposium, proceedings (in print). (Also available at <http://www.i3mainz.fh-mainz.de>).

Böhler, W., Siebold, M.: 3D Scanning Software: An Introduction. Published in this volume.

Heinz, G., 1998 : Comparison of Different Methods for Sculpture Recording. - ISPRS Commission V, Symposium, Hakodate, Japan, 1998. International Archives of Photogrammetry and Remote Sensing, Vol. XXXII, Part 5, pp. 557-563.

Marbs, A.: Experiences with Laser Scanning at i3mainz. Published in this volume.

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

