High Quality Scanning and Modeling of Monuments and Artifacts

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SUMMARY

3D scanning is a new technology which has proven to be well suited for a more efficient documentation in architecture, cultural heritage and archaeology by using 3D scanners. However, to obtain high quality results it is indispensable to control the whole data acquisition and data processing chain very much in detail. The paper will show how to apply laser scanning technology to objects of different kind and will include the demonstration of the achieved results.

ZUSAMMENFASSUNG

3D Scanning hat sich als neue Technologie für die effiziente Dokumentation in Architektur und Archäologie sowie des Kulturerbes bewährt. Wenn Ergebnisse hoher Qualität erzielt werden sollen, muss die gesamte Prozesskette der Datenerfassung und -verarbeitung sehr detailliert kontrolliert werden. Der Beitrag zeigt die Anwendung der Laserscanner-Technologie an Hand unterschiedlicher Objekte einschließlich der erzielten Ergebnisse.

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1. INTRODUCTION

Three projects will serve for the demonstration of 3D scanning capabilities.

- Maximilian's cenotaph is the largest and most significant mausoleum of the Western World. It consists of an (empty) sarcophagus which has 24 delicate white marble reliefs around its sides and 5 statues on top. Two different scanners were used to capture the whole object in 3D with high accuracy.
- Two statues of Pharaoh Pepi I. are the oldest known life-size metal sculptures in the world. The shapes of the sculptures were recorded using a 3D laser scanner. Special features 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.
- Stone age findings of the Middle Rhine Region in the South West of Germany are documented with 3D scanning technology. For this purpose, they are borrowed from the private collectors for a short period of time and scanned with a GOM ATOS 3D scanner. As an average, about one hour is necessary for an artifact to be recorded from all sides and to be turned into a 3D mesh model representation.

2. 3D RECORDING AND VIZUALIZATION OF THE CENOTAPH OF MAXIMILIAN I. IN THE HOFKIRCHE, INNSBRUCK

2.1 Background

Fig. 1: Total view of the cenotaph during the measurement work

The Hofkirche at Innsbruck with the tomb of Emperor Maximilian I. is probably the most important art-historical monument, which is possessed by the state of Tyrol. It contains the most important German emperor grave of Maximilian I.. The cenotaph (i.e. technical term for an empty tomb) with the statue of the kneeling Emperor is located in the center of the church's nave. The cenotaph comprises about 3 m x 5 m. The top of the Emperor's statue is 4,5 m above the base. The cenotaph consists of a frame of black marble in which the 24 reliefs of white marble (each approx. 82 cm x 55 cm) are embedded in two horizontal rows. These reliefs show scenes from the life of the Emperor Maximilian I. They have a level of detail within the range of 0.1 mm and had to be documented in particular and with highest available precision. On the cover of the tomb the kneeling figure of the Emperor is central, surrounded by representations of the four basic virtues, which are arranged at the four corners. All mentioned figures consist of dark bronze.

The cenotaph was separated for centuries by a wrought-iron lattice from the visitors. Additionally the white reliefs were hidden by glass plates. On the occasion of the preservation and restoration of the tomb a complete art-historical and geometrical documentation was initiated for the first time since the completion around the year 1568. Thus, for ten days for the first time since its establishment, the cenotaph was accessible from all sides and unwrapped both from lattices and from window panes. This time slot was used for the complete documentation and the measurement work described here.

2.2 Data Acquisition

The setting of tasks was not clearly defined and had to be developed in cooperation with the responsible authorities. Because of the preciousness of the object - and the uniqueness of the opportunity for data collection - accordingly a combination of geodetic measuring methods was suggested and carried out in May 2002. On the one hand classical close range photogrammetry was used for the complete measurement of the cenotaph and on the other hand - due to the high detail of the reliefs – the 3D documentation should be carried out by use of 3D scanning techniques. The geometrical survey of the object by the 3D scanners also would be combinable in the future with the radiometric information from the photos when both methods were used in one operation. The measurements were accomplished by three independent teams. In order to avoid interference during the short time available, all measurements had to be coordinated exactly and scheduled accurately in advance. Since the surveying methods for the geometric documentation of the cenotaph have been described in earlier publications, only a brief outline is given in the following sections.

A general requirement for all surveys was a common coordinate reference. A precise network of eight observation points around the cenotaph was established and vertical and horizontal angles were observed to the reference targets for the scans and the photogrammetric images (spheres and self-adhesive flat targets). An accuracy of better than 0.5 mm (standard deviation of spatial location) could be achieved. Additional targets which were necessary for the detail scans of the reliefs were stuck onto transparent adhesive tape which was fixed in front of the reliefs without touching them. The coordinates for those targets were derived from photo triangulation using GOM’s widely automatic TRITOP system.

A complete scan of the cenotaph was achieved with a MENSI S25 triangulation type laser scanner (Mensi, 2003). A point density of about 2 mm was chosen. This resulted in 20 observation locations from where a total of about 10 million points were recorded in about 60 hours of scanning time. As long as a scanning range of 5 m is not exceeded, the MENSI S25 will achieve a point accuracy of better than 1 mm.

Because the marble reliefs show very fine details, it was necessary to use a high precision scanner for their documentation. A GOM ATOS II scannner was chosen. This scanner projects fringe patterns onto the object and uses two cameras to analyze the resulting images. Since high resolution was important, the version with a 400 mm base and 35 mm cameras was selected. In this configuration, the scanner yields about 1.3 million points in a field of view of 175 mm x 140 mm. Thus, twelve scans would cover one relief (not counting numerous additional scans which were needed to reduce the hidden areas due to occlusions). The raw data for one single relief amounted to about 450 – 700 Mbytes (GOM, 2003).

A photogrammetric documentation of the whole object was carried out by a private surveying company experienced in the documentation of cultural heritage. A Zeiss UMK metric camera was used. In addition, stereo images were acquired for each relief on high resolution b/w film. Also, orthogonal images were exposed on color film for later rectification and/or texturing.

2.3 Hard- and Software for Processing

Since very large amounts of data have to be handled and visualized, a 2.667 GHz PC with 1.5 Gbyte RAM, including a GeForce4 4600 video board with 128 MB RAM, was acquired for data processing. Software requirements for large 3D models consisting of irregular meshed surfaces are very demanding. From all programs tested for this task, Raindrop Geomagic Studio (which was used in the latest Versions 4.1 and 5) proved to be the most versatile (Geomagic, 2003). Nevertheless, even with this software it is not possible to run all processing steps when a complete model for one of the 82 cm x 55 cm reliefs is loaded. Thus, the following proceeding had to be chosen for the 3D representation of the whole cenotaph:

- one coarse model with 2 mm sampling for the whole object using Mensi S25 data
- one fine model based on GOM ATOS data with 0.3 mm basic sampling (further reduced by about 40% using a curvature based algorithm)
- five to six fine partial models for every one of the 24 reliefs with 0.1 mm sampling using the full resolution available from the GOM ATOS II data

2.4 Data Processing

2.4.1 High resolution model (one model per relief)

Merging. In a first step, all (up to 35) scans available for one relief are imported into Geomagic Studio. After all points outside the relief area are deleted, the various scans are merged into one single data set. This does not include any transformations since the registration was already completed earlier in the GOM software using the targets which were determined in the photogrammetric densification process described in section 2.2.

Thinning. Point density in the object varies considerably. Areas in the foreground may be registered in many scans taken from different viewing angles whereas areas in the background may have been scanned only once (or even been missed completely). The aim of the thinning procedure is to delete surplus points in repeatedly scanned areas. At the same time, the total number of points has to be reduced below 4 million points which is a critical value for some of the following procedures, especially the reunion procedure following the hole filling (‘Merge Polygon Objects’, see below). After some experiments, the best solutions could be achieved when the points were first thinned to a uniform sample width of 0.3 mm and subsequently the sampling rate of a curvature based algorithm was changed until the required threshold of 4 million points was reached. This could be accomplished by deleting about 35 to 45 % of the 0.3 mm sample.

Meshing. The automatic meshing procedure creates about 8 million triangles from of the 4 million points. With the hard- and software used, this will take about 10 to 15 minutes of processing time.

*Checking manifold meshes***.** At the end of modeling, the object should be covered by one continuous mesh only. After the first meshing, several isolated meshed surfaces can result, however. For example, the surface of a shield held by a hidden knight’s arm may result in such a separate surface. If the surface is significant (as in the case of the shield) it has to be connected manually to the main mesh by introducing suitable triangles. The result should be checked again for manifold surfaces. Accordingly, the examination for manifold meshes should be repeated after any manipulation of the data as described in the following steps.

Cleaning. The cleaning procedure of Geomagic Studio readjusts neighboring triangles which show large orientation differences. It applies a sophisticated shape-cleaning algorithm that alters the triangulation of the point data and results in a certain extent of relaxation of the mesh. The cleaning procedure can handle 6 million triangles only. Therefore the relief has to be split in two parts which are processed separately.

*Hole filling***.** Even with many scans from different angles, some parts of the reliefs remain unrecorded. This is due to the very detailed structure of the reliefs which contain very sharp edges and even free standing figures and objects whose rear sides cannot be inspected from any observation point. The recording method of the scanner requires any surface area to be visible from the light projector as well as from the two cameras at the end of the instrument’s base. This fact results in additional inevitable holes in the object. Before the holes are filled, the relief is divided into six parts because the filling procedure may prove problematic if more than 2 million triangles are loaded. Geomagic Studio offers an automatic hole filling procedure which interpolates new points based on the curvature of the surrounding area. This works well when the area is flat and curvature is changing smoothly. Often the last points recorded at the edge of a hole show large deviations, however, because they have already been partially occluded by the object parts that in the end caused the adjacent hole. These holes remain after the automatic filling. In these cases, the last row of triangles around the holes is removed and the automatic filling procedure, when applied again, will be successful for further holes. If the object structure is very complex, which is not unusual in the neighborhood of holes, the hole filling has to be accomplished in an interactive manual process which is very time-consuming. The hole filling treatment for one single relief may require up to four working days!

2.4.2 Very high resolution model (5 to 6 models per relief)

A point distance of 0.1 mm is aimed at for the very high resolution model. All scanned points as merged for the fine model plus all points resulting from the hole filling process are introduced. Then the points are thinned to a uniform 0.1 mm point width. In order to make data handling possible, the relief is now divided into 5 to 6 sub-models which should contain not more than 3 million points each. The following procedures are much the same as described above for the fine model: The points are meshed and cleaned. Manifold checks are applied after every procedure that results in data changes. New holes appearing in the model because of the more sensible meshing parameters must be filled. This has to be done in subsets which have to be merged again afterwards.

2.4.3 Coarse resolution model (one model for the cenotaph)

Because of the processing limitations caused by the hard- and software which have been mentioned above, the 3D model of the whole cenotaph structure will remain relatively coarse as compared to the relief models. The 2 mm sampling as well as the poorer accuracy of the 3D points result in a good geometric model for the whole structure; detail resolution and neighborhood accuracy are not satisfactory, however. The procedures to be carried out are much the same as described for the high resolution model. A combination of all scanned and meshed information is not possible presently. There is little doubt that this can be accomplished in the near future.

2.5 Results and Conclusions

The full value of the data can only be judged when evaluated in 3D on a computer monitor, however. 3D scanning yields results that have not been possible in the past for objects with extensive and complicated 3D surfaces as in the case of the cenotaph and the associated reliefs. Photogrammetric matching methods to achieve a digital object model do not work in this case as the white marble reliefs do not show enough texture. Orthophotos or line drawings from stereo pairs can be useful for some purposes but do not contain the information for the creation of a complete virtual (or real) model. The processing of the laser scanner data is very timeconsuming, however, when high model quality is aimed at. Presently, it also suffers from many restrictions. Even with the latest computers and software products, certain processing steps are only possible when the number of meshed triangles is less than some millions. If the development in hard- and software continues as rapidly as in the past, these problems should be overcome in a few years. Even a combination of laser scanner (geometric) and photogrammetric (texture) data may become available for such large and complicated objects. Since all the original cenotaph data are archived, improved results may be created in the future.

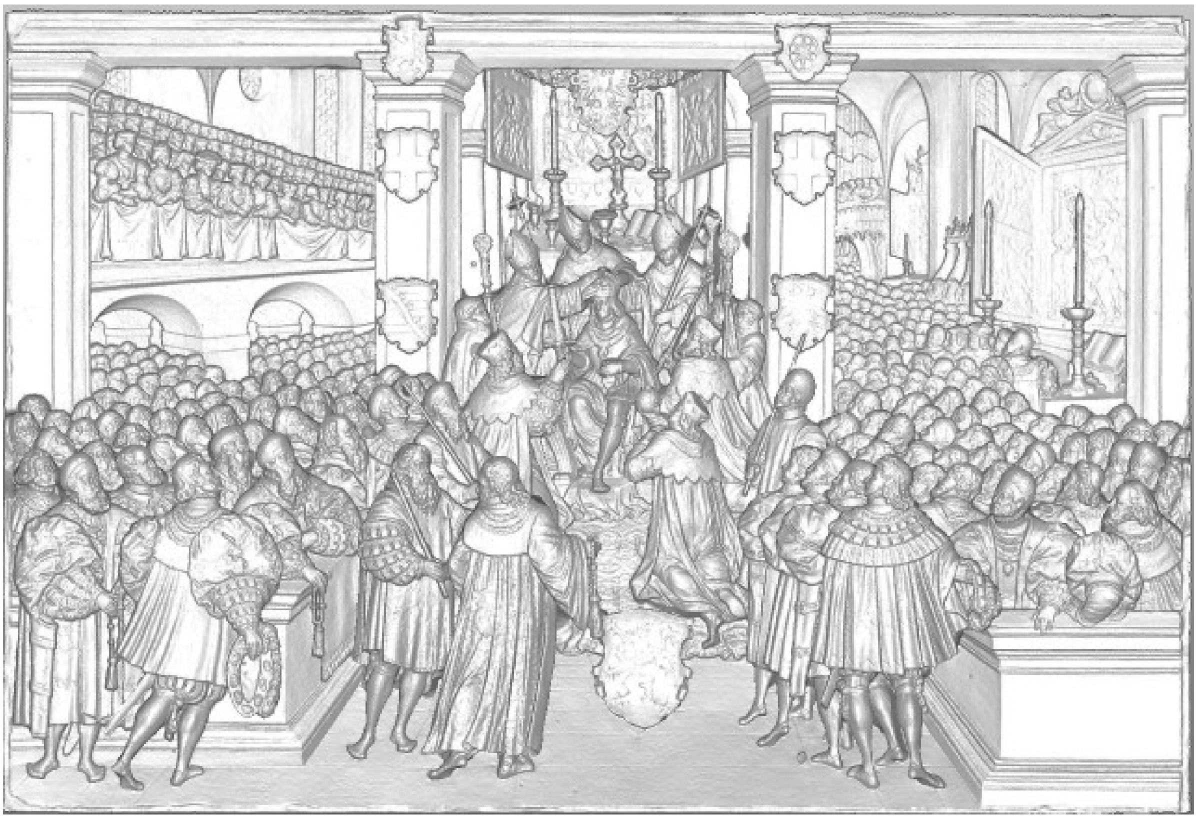

Fig. 3: Shaded view of relief plate from high resolution scanning data. Screenshot, scale about 1:5

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

3.1 Objectives

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, fig. 4), 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.

Measurements of any kind 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 visualization purposes.

As the accuracy of the used scanning hardware was limited to about 0.6 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 results of both methods were combined later for generating various visualizations and animations of the sculpture including the digital reconstruction of vanished parts of the statues like a crown, the loincloths, or the ears.
The small statue was recorded using the same techniques and procedures as with the bigger one. Problems occurred regarding the data capture and processing: 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 modeled for the data captured from the back of the statue.

Fig. 4: Big statue with reference spheres

3.2 Laser Scanning

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. 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.
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 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.

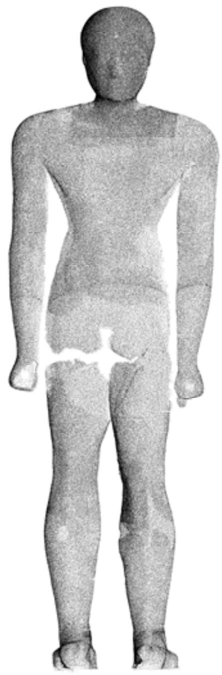

Fig. 5: Scanned point cloud of small statue

The process of scanning the sculptures took about 8 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. 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 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 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 modeling.

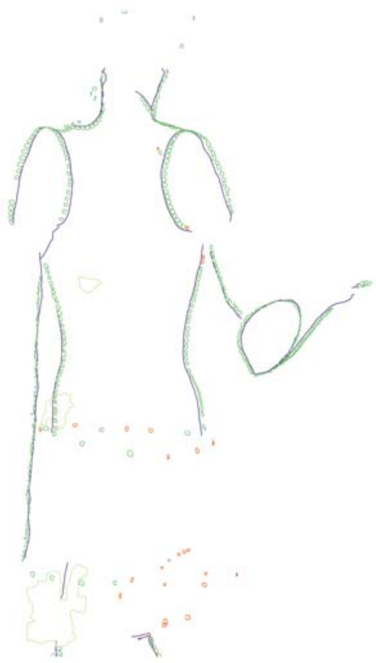

Fig. 6: Vector plan of features from photogrammetric plotting

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. 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. 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. After performing a 3D-triangulation, filling holes etc. the final meshes modeling the surfaces consist of 2.0 million respectively 900.000 triangles (fig. 5).

3.3 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 of the models of the small statue the corners of the Plexiglas structure could be used as reference points. On the big statue, point markers were stuck onto it. 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. A bundle adjustment was performed 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 statues were plotted using an analytical plotter Zeiss P3 with MicroStation as connected CAD-system. The features to be plotted were attributed simply using different layers for rivets, rivet holes, the outlines 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 dataset can be viewed and plotted in various projections showing the metric correct position of these features in the plots (fig. 6). For further visualization purposes the polylines of the rivets and holes were replaced by volume objects of cones and tori.

3.4 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.
With the full set of functionalities, different visualizations can be performed (fig. 7). 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 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. Video sequences, e.g. rotating the camera position around the sculpture, have been generated in this way. This kind of animations assist the observer in achieving a good 3D impression of the object and the spatial distribution of the special features.

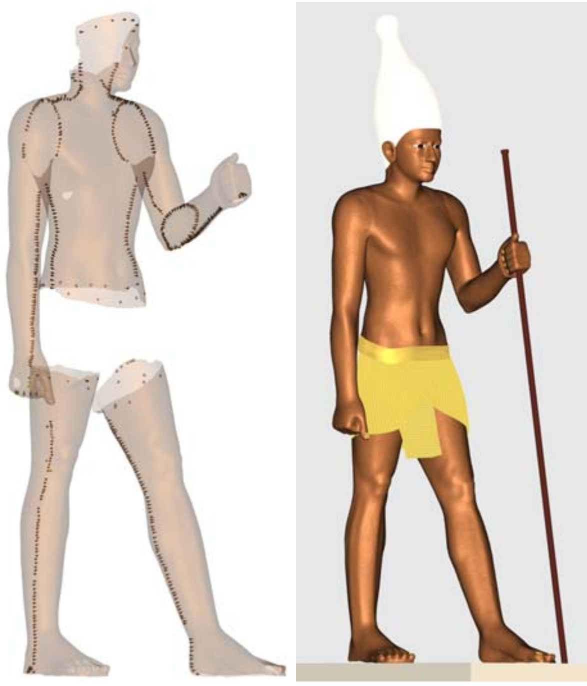

Fig. 7: Visualizations: Plan with rivets and semitrans-parent surface model (left) and

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.

3.5 Conclusions

The used approach for the geometric documentation of the statues 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.

Comparing the simple line drawing of the seams and rivet features only with the combination of 3D model and line drawing shows the much higher information content of the latter. It is 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 visualizations distant from the sculpture itself which can only be accomplished with such a virtual 3D model.

3.6 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. Limitations of the equipment of this kind must be taken into account.
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 still unrivaled at present.
The influence of the Plexiglas plate for the recordings of the back of the small statue could be modeled and corrected (Heinz, 2004).
The quality of the surface models is dependent on the software used. Improvements have been made in the past years in this area. Further developments have to be observed and checked for the use in cultural heritage recording.

3.7 Acknowledgements

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zip
Ein Projekt im Zukunfts-investitions-programm der Bundesregierung

4. DOCUMENTATION OF STONE AGE ARTIFACTS

4.1 Motivation

The Middle Rhine Valley between Bingen and Koblenz has recently been added to UNESCO’s World Heritage List of cultural landscapes. The Neuwied Basin north of Koblenz is a rich archaeological area. Since the 1960s systematic excavations have been undertaken here on different sites.

Besides artifacts that are recovered by systematic excavations, many objects can be found scattered over large areas. For more than 40 years amateur collectors, in cooperation with the Bodendenkmalpflege (curators for archaeological monuments) in Mainz, are working on this surface sites. A scientific evaluation of these objects has not been possible yet, because archaeologists do not have the resources to collect and examine all these findings. For that reason the research project “Paleolithic Land Use in Rheinhessen” was initiated. The principle aim of this project is to get an overview over these, in some cases, huge private collections.

Archaeologists and engineers started a joint project to develop a method to make these artifacts available to scientific evaluation without removing them from the private collections. The developed documentation procedure relies on 3D scanning. The methods, described below, proved very promising and can be used for any archaeological artifacts and localities.

4.2 3D Scanning

4.2.1 General Remarks

As the objects themselves cannot be examined by all interested parties, very good digital representations have to be made available. In the case of the complicated stone artifacts concerned, this demands a high resolution 3D documentation which comprises the complete surface which consists of sharp edges and larger areas which are relatively flat. Since enormous quantities of objects have to be documented, the method will only be acceptable if it works fast and efficiently.

4.2.2 Selection of an appropriate scanner

The ATOS II system, produced by GOM mbH (GOM, 2003), was chosen from a large list of possible candidates with similar features for sub-meter object spaces (i3mainz, 2003). A main advantage of the system is its modular design which allows various fields of view between about 1 dm³ and 1 m³ when certain components (base, lenses) are exchanged. For the stone age tools, the ATOS II is used in a version that allows to scan a measuring volume of 250 x 250 x 200 mm³. The software computes 3D coordinates for up to 1.3 million object points from the camera images with an accuracy of about 0.02 mm.

Fig. 8: The ATOS II on a heavy

4.2.3 Scanning Procedure

*First object position***.** The ATOS sensor head mounted on a tripod can easily be positioned relative to the stone age artifact which is fixed in

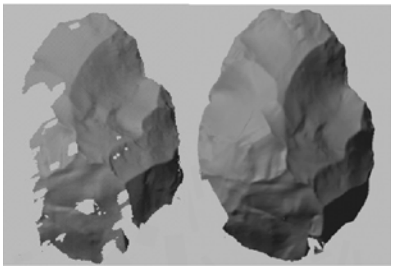
special plasticine on a wooden block, where the adhesive ATOS reference points are attached (fig. 9b). Different fringe patterns are projected onto the artifact (fig. 9b) and are captured by two integrated CCD cameras on either side of the 600 mm sensor base (fig. 8).
The result of the measurement is directly displayed (fig. 10, left). By rotating the object, further scans can be acquired without changing the relative position of object and reference points. Usually, 5 to 7 individual views are needed to record the complete visible surface in the first object position.

For a complete representation the individual views are merged into a single data set. With an automatic determination of the current sensor position, the system can transform the individual measurements into a common object coordinate system using the detected ATOS reference points. The result is the 3D mesh for the first object position. The part of the artifact covered by the plasticine must be measured subsequently in a second object position.

Fig. 9a. Fig. 9b.

*Second object position***.** The object is turned around and the other side is now held in the plasticine. Again, several single scans are acquired and combined to the mesh for the second position. The two meshes have to be merged into one. Since there are no common ATOS reference marks available in this case, four or more common points have to be identified interactively on the meshed surface. In most cases, this is a very time consuming process; often it is impossible at all. After many experiments, including the construction of swiveling clamps, it was decided to mark four very small three-dimensional targets on flat parts of the object.

After this pre-registration which merges the two meshes together, an automatic 'Best Fit' registration improves the result and provides the final set of data for the whole artifact as an ASCII point cloud or in a polygon mesh according to the STL format. If there are some small holes, these can easily be filled by the software. This completes the scanning procedure, and a virtual 3D model of the object is now available (fig. 11). The whole procedure which includes scanning, registration, meshing and hole filling can be accomplished with the hard- and software supplied by GOM and takes less than 45 minutes per artifact.



Using the ATOS software itself or other software products like Geomagic Studio or qslim the mesh can be thinned intelligently. For the storage of the results the common STL file format is used.

Fig. 10 left: Result of a single scan.
Fig. 10 right: Combination of different scans.

4.3 Visualization

4.3.1 3D viewers for 3D inspection

With a viewer program (such as SolidView which is freeware in its 'lite' version), the virtual model can easily be inspected from all sides (fig. 11), much in the same way as the original stone object would be examined.

4.3.2 Edge based visualization

In a diploma thesis at FH Mainz (Tschoepe, 2003) an attempt was made to classify and visualize local curvature on the object. The developed computer program computes the differences between a triangle's normal and the angles of the normals of neighboring triangles and uses it to classify the local curvature (fig. 12).

4.3.3 Object outlines in 2D visualizations

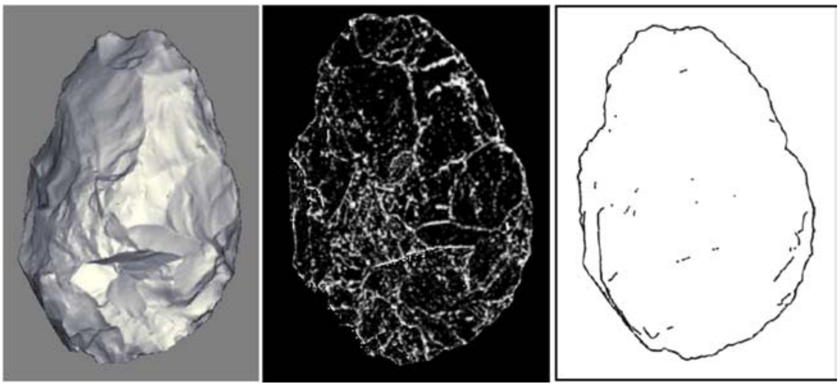


Fig. 11: Virtual 3D copy of a stone age artifact.

Fig. 12: Object shaded depending on local curvature. Colors cannot be distinguished in this gray tone printing.

Fig. 13: Automatically generated contour lines (silhoutte).

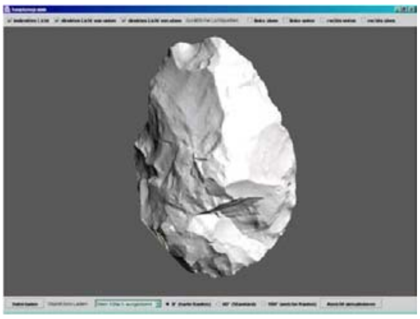
Since manually capturing outlines for a 2D view is very tedious, an automatic procedure was developed at i3mainz. It detects all lines on a digital 3D model where the observation vector and the object normals are perpendicular (fig. 13). For a convex body they can also be called silhouette or contour.

Thus, finding contour lines consists of the following steps:
- Choosing the desired 2D (parallel) projection.

- Reading front-facing triangles.
- Finding edges belonging to one single triangle only.

4.3.4 3D viewer for interactive inspection in the Internet

The data should be available in the Internet. For this purpose an interactive visualization tool was developed. Various alternatives were considered for the technology and an approach based on Java3D was finally chosen. This provided the necessary options for the integration of database access. In addition, the tool can be used as a standalone application as well as an applet running in the Internet.



At the current stage, the tool allows Internet based visualization with standard means. For a thorough inspection, the complete set of data is necessary, however. Thus, the Internet may serve to inspect the collection and select those pieces for which a complete set of data will be ordered.

Fig. 14: Java3D visualization tool for the Internet using a flat shading approach.

4.4 Database design and GIS concept

In addition to the scanning data describing the geometry of the artifacts, further information concerning the artifacts are stored in a database.

The items can be classified into different categories:
- Items of identification like the identification number.
- Person keeping the artifact, place where it is kept, and inventory number.
- Basic description (type of artifact, material, weight).
- Link to the scanning data and derived graphical products like sections, views, etc.
- Geometric quantities derived from the scanning data like volume, surface, unit weight, etc.
- Information about the place where it was found (easting, northing, height, accuracy of position and height).
- Information on the actual condition (recent damages, traces of fire, etc.).
- Further textual information.

The main table keeps all major information describing the single artifact and links to further information like the 3D model and views.

The availability of information concerning the place of finding the artifacts allows using basic GIS functionality. Using further external information like e.g. DEMs, geological or hydrological maps in combination with the distribution of the artifacts and the functionality of a GIS allow further conclusions about the history of the findings and their usage by man.

4.5 Conclusions

Considerable numbers of artifacts can be documented with high accuracy and resolution when the methods described are used. Virtual artifact collections can be documented completely, even if the artifacts are stored at different places, including objects that were considered as being unretouched pieces. The virtual collection thus achieved can be distributed easily on storage media such as CD-ROMs or even through the Internet. It can be examined by anybody and compared to any real or virtual artifacts of similar origin.

All visualization products are results of automatic and objective procedures, thus avoiding the individual subjective interpretation which is inevitably part of hand drawn figures.

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BIOGRAPHICAL NOTES

Wolfgang Böhler and **Hartmut Müller** both gained their diploma and doctoral degree in Geodesy. After several years of professional experience outside of universities they have been working as academic teachers at sub-department Geoinformatics and Surveying of Mainz University of Applied Sciences. Both have been members of board of the research and development institute i3mainz since 1998. Andreas Marbs and Guido Heinz hold a diploma degree in Geoinformatics and Surveying and a master degree in Geoinformatics, Monica Bordas holds an engineering degree granted by the Polytechnical University of Valencia, Spain. All three persons are currently working as scientific coworkers at the i3mainz institute.

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