

3D MODELING OF HERITAGE OBJECTS BY FRINGE PROJECTION AND LASER SCANNING SYSTEMS

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ABSTRACT:

The treasure of the Essen cathedral in Germany is one of the few collections of medieval art completely preserved in the course of history, including approximately 250 objects such as crosses, crowns, swords, statues, manuscripts, and reliquaries. These precious works of art show a great variety in size, shape, material, and complexity. In the paper, ideas and concepts for recording the manifold objects of the treasure by optical methods such as photogrammetry, fringe projection and laser technique are reported on. The measurement systems used are described as well as calibration aspects, difficulties of data acquisition and processing are mentioned, and virtual models of the treasure are presented.

1. INTRODUCTION

The recording and modeling of cultural heritage objects for the purpose of conservation, structural investigation, restoration, visualization, documentation, and archiving is, by common consent, an important task. Mobile and flexible optical 3D measuring systems based on techniques such as photogrammetry, fringe projection, laser scanning, and combinations of these image-based or range-based systems can successfully be applied to the measurement and virtual reconstruction of objects in art and cultural heritage.

Recently, it was decided to establish a digital archive of the treasure of the Essen cathedral by means of optical 3D measurement methods. The treasure of the Essen cathedral is one of the most significant collections of ecclesiastical art in Germany. It originates from the former canoness convent's treasure which passed into the property of the parish after the secularisation in 1803. Since 1957 the diocese of Essen has been responsible for the treasure. Because only a few pieces have got lost in the course of history, the collection is exemplary due to its completeness. However, the treasure includes approximately 250 objects comprising some outstanding works, in particular from the Ottonian epoch (Figs. 1 & 2). A great number of significant works of art varying in size, shape, material, and complexity are to be measured. The artifacts provide more or less co-operative surfaces: a challenge for any measurement system. The 3D reconstruction is to be performed with high accuracy (0.1 to 1.0 mm, depending on the size of the object) at large scales (1:1 to 1:5).

The paper overviews both the main objects of interest being among the treasure and the measurement systems or techniques, respectively, to be used for the recording. A chapter dealing with difficulties and drawbacks when digitizing artefacts is included. Finally, the state of the project as up to now is reported on.



Figure 1. Otto-Mathilden-Cross, 10th century, different materials, 44.5 cm high, 29.5 cm wide (© Martin Engelbrecht)



Figure 2. Child's Crown, made for Otto III., 10th century, different materials, e.g. gold sheets, jewels, and pearls (© Martin Engelbrecht)

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2. MEASUREMENT SYSTEMS

“We can safely say that at the moment, for all types of objects and sites, there is no single modeling technique able to satisfy all requirements, like high geometric accuracy, portability, full automation, photo-realism, low costs as well as flexibility and efficiency.” (Remondino & El-Hakim, 2006)

The authors of this paper entirely confirm the above statement from their own practical experience. Therefore, several measurement techniques are proposed for the project

- photogrammetry
- fringe projection technique
- laser scanning.

Active sensors using fringe projection or laser technique accomplish the very fast and precise digitization of an object surface resulting in a dense 3D point cloud. The combination of image-based and range-based methods is appropriate to all tasks where a single technique by itself fails. So the structure of an object can be measured by photogrammetry, complex details of the object surface with a range sensor. Texture information for generating a realistic 3D model is provided by high resolution digital colour images.

Subsequent to the point cloud generation, software is used for a topologically correct surface reconstruction, for texturing and visualization, in this case by means of the RapidForm and Geomagic software packages (Inus, 2007; Geomagic, 2007).

2.1 Fringe Projection Systems

For the data acquisition of the treasure of the Essen cathedral mainly fringe projection systems have been applied so far. At the beginning of the project, a Breuckmann optoTOP HE-600 was used to digitize the *Golden Madonna*, the oldest known statue of Virgin Mary dating from around the year 990 A.D. (Peipe & Przybilla, 2005). Since then a Breuckmann triTOS has been employed (Fig. 3; Breuckmann, 2007). The system consists of a mechanically stable base connecting a 1.3 megapixel camera and the fringe projection unit, and a high-end PC or notebook with the operating and object reconstruction software. The triangulation angle of the system amounts to 20 degree leading to a medium accuracy of about 0.2 mm when digitizing object surfaces. Base length and lenses can be changed to capture different fields of view. Calibration data and accuracy figures of the triTOS system were determined by test measurements published in a previous paper (Bange et al., 2007).



Figure 3. triTOS fringe projection system

A series of scans has to be generated to cover the complex artefacts, including a lot of detailed views to acquire more or less hidden regions, too. The single views can be combined within the triTOS software by a best fit approach based on iterative closest point algorithm (ICP). Moreover, a network of reference points precisely determined by photogrammetric means may serve to merge all the scans of the object captured with the range-based system. Furthermore, a Nikon D2Xs digital SLR camera was used to take colour images for texturing the 3D model.

2.2 Laserscanning

In addition to the fringe projection system, a laserscanner will be applied for point cloud generation. Laserscanners have been very expensive, but newly developed devices may change this situation. For example, the MicroScan laser sensor is a powerful but affordable measuring tool (RSI, 2007; Fig. 4).

The scanner is connected to the MicroScribe measuring arm, i.e. it is attached to the stylus of the 6DOF MicroScribe. The portable MicroScribe + MicroScan combination provides an accuracy of approx. 0.2 mm within a reach of about 1.5 m. 28.000 3D points per second are registered while the laser line is navigated over the object. The camera of the MicroScan records the deformations of the scanning line caused by shape variations of the object surface. Point clouds originating from different scans can be merged by the system software.

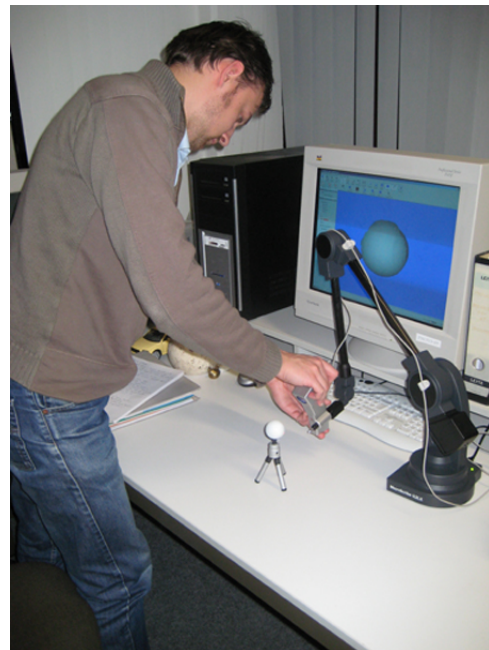


Figure 4. MicroScan + MicroScribe during calibration

In addition to the laserscanning, the MicroScribe measuring arm can also be utilized as a touch probe device for digitizing single 3D point positions.

First results of laserscanner calibrations (by means of tools included in the system) and measurements show a good accordance with the specifications given by the manufacturer of the system. Further investigations have to be performed concerning calibration procedures, especially those defined by the German VDI/VDE guideline 2634 (VDI/VDE, 2002). An example of object scanning with MicroScan in comparison to an image taken with the Nikon camera is shown in Fig. 5.

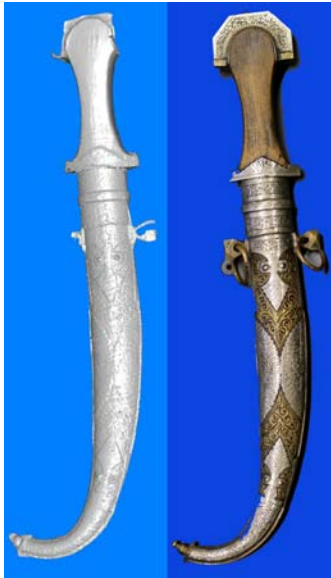


Figure 5. Scan (left) and digital image (right)



Figure 7. Digitizing the ceremonial sword

3. STATE OF THE PROJECT

As mentioned in chapter 2, the *Golden Madonna* of the cathedral's treasure was digitized and modeled at first. In the meantime, some more works of art have been surveyed (Figs. 6 & 7):

- the so-called *Elfenbeinpyxis*, an elliptical box (10.4 cm and 12.5 cm in diameter, 8.8 cm high), made of ivory, originating from the 5th/6th century
- the *Ludgeruskelch*, i.e. a ceremonial cup (12.2 cm high, 7 cm diameter at the top), made of copper and gold, originating from the 10th century
- the scabbard of a ceremonial sword (94 cm in length), made from wood and covered by golden plates, originating from the 10th century.



Figure 6. Digitizing the *Elfenbeinpyxis*

These objects are very different in size, structure and material. Therefore, the digitizing is complicated and time-consuming. Some difficulties appear in case of

- reflections, especially when capturing glittering material (gold etc.)
- more or less transparent materials (gems etc.)
- complex surfaces providing hidden parts.

Specifications of the data acquisition can be found in Tab. 1.

	Elfenbeinpyxis	Ludgeruskelch	Ceremonial sword
base length	50 mm	50 mm	300 mm
measuring distance	400 mm	400 mm	1000 mm
survey depth	90 mm	90 mm	180 mm
fixed sensor, object on turn-table	yes	yes	no
number of scans	36	85	83
measuring time	8 h	5 h	7 h
fitting by ICP	during measurement	additional 5 h	additional 4 h

Table 1. Specifications of data acquisition

4. DATA PROCESSING AND VISUALIZATION

Visualization of complex object structures cannot be done by common computer aided design programs. Tools like those used for reverse engineering and rapid prototyping have to be applied to transform scan data into accurate digital models. Favourable results could be achieved with Geomagic Studio (Geomagic, 2007). This software package includes features such as

- point processing (data filtering, noise reduction)
- polygon building
- curvature-based hole filling
- automatic edge sharpening
- surface smoothing
- texture mapping
- etc.

A serious problem when digitizing and processing complex objects is the large amount of data, especially if the modeled artefact should be posted on the internet. Data reduction is an

important issue. Fig. 8 presents a detail of the *Elfenbeinpyxis*, beginning (left) with the original resolution and, then, after reducing to 25% and 3% of the primary data volume. Fig. 9 shows the same detail overlaid with photographic texture. Even a significant reduction of 3D data is partly compensated by the overlaid texture.

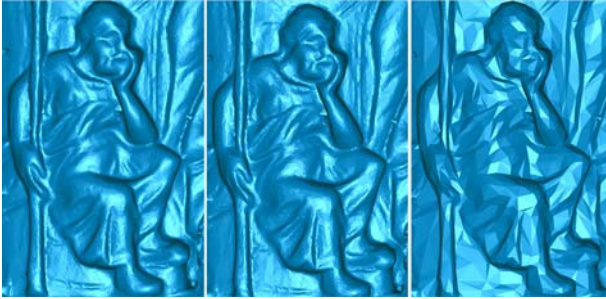


Figure 8. Detail of the *Elfenbeinpyxis* after reducing polygons



Figure 9. Textured detail of the *Elfenbeinpyxis* (left: 25%, right: 1.5% of original polygons)

These experiences can be confirmed with the results of other artefacts (Fig. 10). Data processing using reverse engineering software seems to be suitable for modeling complex cultural objects (see Remondino & El-Hakim, 2006).

5. CONCLUDING REMARKS

3D data from different sources are suitable to establish a digital archive of the treasure of the Essen cathedral. Fringe projection systems have been successfully applied to generate 3D models of several important and valuable works of medieval art. In addition, the combination of a touch probe digitizer and a laserscanner provides an adequate accuracy and a favourable price/performance ratio, and seems very promising for quick data collection of complex objects.

Based on the geometrical reconstruction of the artefacts and additional information, multimedia processing is planned. In the near future, the data will be included in a 3D information system supporting any kind of art-historical activities and research, but also useful for the non-professional museum visitor interested in medieval art.

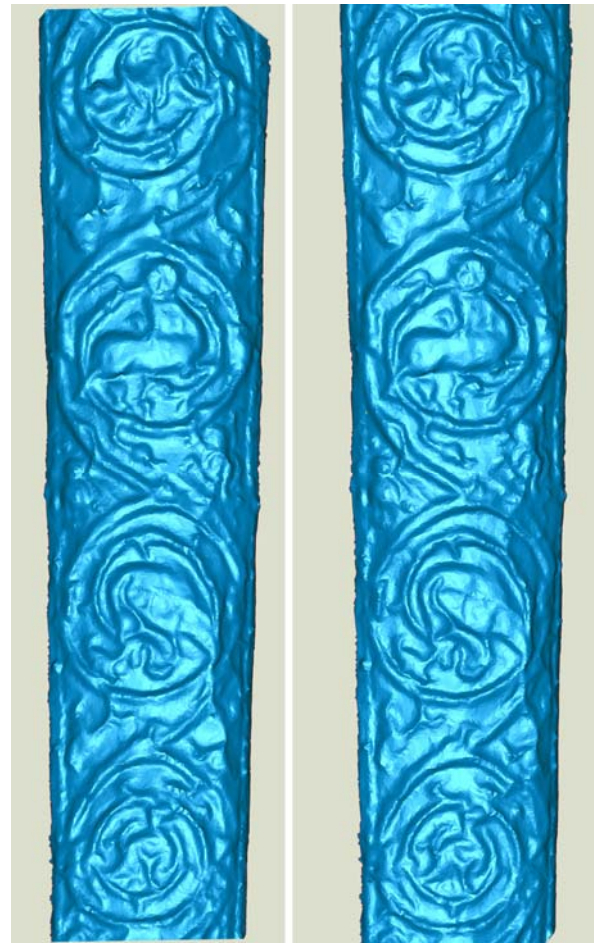


Figure 10. Detail of the ceremonial sword (left: 100%, right: 50% of original polygons)

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