RECORDING AND VISUALIZATION OF THE CENOTAPH OF GERMAN EMPEROR MAXIMILIAN I

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ABSTRACT:

The Hofkirche in Innsbruck, Austria, with its tomb of German Emperor Maximilian I is one of the most famous and outstanding historical monuments in Central Europe. For centuries the Cenotaph (i.e. empty tomb) was separated from the visitors by a black iron lattice. In addition, the fine caved marble plates were covered by glass. Because of a basic restoration of the tomb, lattice and glass plates were removed for the first time ever since its construction in the 16th century. For a short period in May 2002 all sides were accessible after the temporary housing of the restoration technicians had been removed from one side and not yet been moved to the other side for the second restoration period. This could be used for a complete metric documentation of the object.

Both, close-range photogrammetry and 3D scanning techniques were used. Photogrammetric images consisted of stereo pairs and separate color images. 3D scanning was accomplished with a MENSI S25 laser scanner for the overall structures and a GOM ATOS II structured light scanner at high resolution for the relief plates.

Fig. 1: Overview model of the cenotaph derived from scanned data

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Different methods can be used to visualize the meshed surface model. Line plots from the photogrammetric stereo models do not really give an adequate representation of this object. 3D visualization using the scanning results can achieve a much better impression of the complicated geometry after data modeling, error correction, and filling in remaining 'holes'. In order to model the complex geometry, it is necessary to use huge amounts of data. The model in its highest resolution consists of more than 1.000.000.000 triangles. Because of restrictions in the hard- and software presently available, the high resolution model has to be processed and stored in more than 140 separate virtual models. The project proves the enormous potential of these new technologies, but shows as well that more progress is needed in hardware and software development to accomplish such demanding tasks.
An attempt was made to convert the meshed 3D models to 2D vector drawings, similar to those resulting from traditional plotting using photogrammetric stereo models. Solutions could be found to select all object outlines and all edge areas where curvature shows high absolute values. On the other hand, for other "lines" (e.g. the details of a human face) where a stereo plotter operator will draw lines on his own intuition, no obvious mathematical definitions could be found.

1. INTRODUCTION

1.1 Background

Between 1420 and 1665, Innsbruck was the residence of one of Europe's most known imperial families, the "Habsburger". The Hofkirche at Innsbruck with the tomb of Emperor Maximilian I probably is the most important art-historical monument, which is possessed by the country of Tyrol. It was built between 1555 and 1565 under Emperor Ferdinand I who was the grandson of Maximilian and the brother of famous German Emperor Karl V. The cenotaph (i.e. technical term for an empty tomb) with the statue of the kneeling Emperor is in the center of the church's nave. The tomb was created by artists from various countries, who cooperated in the production. It is a unique certification of European court art, which was influenced by the personality of the Emperor and its successor as clients. The sarcophagus is surrounded by 28 more than life-sized bronze figures, embodying ancestors and relatives of Maximilian, the so-called "Schwarze Mander" (i.e. black men).

The cenotaph itself (fig. 1) has an extent of 6,4 m x 4,5 m x 3,3 m and consists of a frame of black marble in which the 24 reliefs of white marble (each approx. 80 cm x 45 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 precision available. 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 are made of dark bronze.

1.2 Restoration

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. In order to allow a continuous access for tourists, only one half at a time was concerned by the measures of restoration and covered in a boarding. The other part remained accessible for the public. The cenotaph was separated for centuries by a wrought-iron lattice from the visitors. Additionally the white reliefs were hidden by glass plates. In May 2002 the right half was completely restored and it became necessary to dismantle and transfer the temporary housing set up by the restoration technicians to the other side. 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 windowpanes. This time slot was used for the complete documentation and the measurement work described here.

2. DATA ACQUSITION

2.1 General remarks

The setting of tasks was not clearly defined – as it is often the case in comparable projects, and had to be developed in co-operation with the responsible authorities. It stood firmly that the rare chance of accessibility from all sides should be used for documentation by all means. Of course, neither detailed plans nor art-historical documentations of this tomb were available at this time. 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 complex 3D details of the reliefs – the documentation should be carried out by use of 3D scanning devices. The appropriate scanners were chosen from a list of available instruments (i3mainz, updated 2004). The geometrical survey of the object by the scanners also later would be combinable 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 (Marbs 2002, Hanke 2003), only a brief outline is given in the following sections.

2.2 Geodetic survey and photogrammetric densification

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 on the object for the scans and for 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 those. The coordinates for those targets were derived by photo triangulation using GOM's widely automatic TRITOP system.

2.3 3D Scanning

A complete scan of the cenotaph was achieved with a MENSI S25 triangulation type laser scanner. 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 (standard deviation of spatial location) of better than 1 mm if correctly calibrated.

Because the marble reliefs show very fine details, it was necessary to use a high precision scanner for their documentation. A GOM ATOS II scanner 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 camera lenses 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.

The GOM ATOS II was also used to document the five statues on top of the cenotaph since their surfaces show very fine detail (fig. 2)..

2.4 Photogrammetric imaging

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.

Fig. 2: Kneeling Maximilian I. Virtual model from scanned data.

3. DATA PROCESSING FOR SCANNED DATA

3.1 Merging and thinning

Data processing which kept one person busy for nearly one year was a very delicate task. The procedure which was accomplished using Raindrop Geomagic Studio software has been described earlier (Boehler et al. 2003). Before the objects can be treated, neighboring point clouds have to be merged into one data set. The following point thinning process has to reduce the data for easier handling without a degradation of object resolution. In smooth surface areas, a considerable reduction can be achieved, whereas detailed object parts (as they are typical for the reliefs) should not be thinned out at all. Even with the most advanced hardware and software, one complete relief plate could not be treated at the same time without loss of detail. Consequently, several partial models had to be created.

3.2 Meshing, checking manifold meshes, cleaning and hole filling

The following data processing steps include a check for manifold meshes which are unavoidable where hidden parts of the surface cannot be observed from any point, and a cleaning procedure which readjusts neighboring triangles which show large orientation differences. A hole filling process completes the data processing.

4. RESULTS

Presently, the results of our cenotaph documentation belong to the most detailed virtual models of art worldwide. The model in its highest resolution consists of more than 1.000.000.000 triangles. It should be noted that this number does not express the amount of data collected (which is much larger) but the necessary data to describe the object with the desired resolution. Because of restrictions in the hard- and software presently available, the high resolution model has to be processed and stored in more than 140 separate virtual models. Various other models with a reduced number of triangles are available for visualization and publication (e.g. figs. 1, 2 and 3 of this publication).

Fig. 3: One of the relief plates.
Top: Virtual model from scanned data. Bottom: Result of stereo plotting

Fig. 4: Detail from relief plate above (fig. 3), about 10 cm x 10 cm in reality.
Left: Photograph. Center: Result of stereo plotting. Right: Virtual model from scanned data.

5. VISUALIZATION

5.1 3D model versus photography

Virtual images from meshed 3D models can give a much better perception of the object than photographic images of the real object (see fig. 4, left and right image). This is especially true when there is hardly any texture to the object as is the case with sculptures from stone or bronze. Since the virtual model is illuminated by virtual light sources which can be arranged according to the desired effects, the resulting images show details much clearer. If the lights (or the object itself) are gently moved in an animation, the resulting changes and movements allow a good 3D perception, even though the monitor image itself is still 2D. If the whole object definition relies on texture only, photographic images have to be used. The written text in figure 3 could not be modeled from the scans, for example. In such a case, photographs have to replace or complement 3D scanning.

5.2 3D model versus line drawing

It has often been discussed whether metric line drawings are an adequate means of documentation of sculptural works of art. Nevertheless, this form of documentation is often asked for and the considerable cost caused by the line drawing process which is usually accomplished using stereo photographs is accepted. Undoubtedly, this form of documentation can result in remarkable interpretations of the art works (fig. 3 bottom, fig. 4 center). The selection of the lines to be drawn is a subjective process carried out by the operators on their own ideas. Complex surfaces are reduced to a set of lines. Metric quality is present but cannot really be used if a complete reconstruction should become necessary. The virtual 3D model from scanning data, on the other hand, is a complete metric representation of all surfaces involved and has a considerable visualization potential at the same time (as can be seen in figs. 1, 2, 3 top and 4 right).

5.3 Outlines from 3D models

Outlines describe a 3D object's furthest extent in a specific 2D projection. In stereo photogrammetry, these silhouette lines are often very difficult to measure. If the images have been taken at an angle to the selected projection and the object has no defined edges (as is often the case with sculptures) it is nearly impossible to find these lines correctly. Meshed 3D models can be used to find the correct outlines. After the rotation into the desired projection is accomplished, a program developed at i3mainz selects all those lines that are common to a pair of triangles where one triangle has a normal pointing towards the observer and the other triangle has a normal pointing away from the observer. After all hidden lines are removed, the resulting line pattern will give a good description of the object if it has a definite 3D structure (as in fig. 5). In the case of relief type object parts, only few lines have an outline character (as in fig. 6 center).

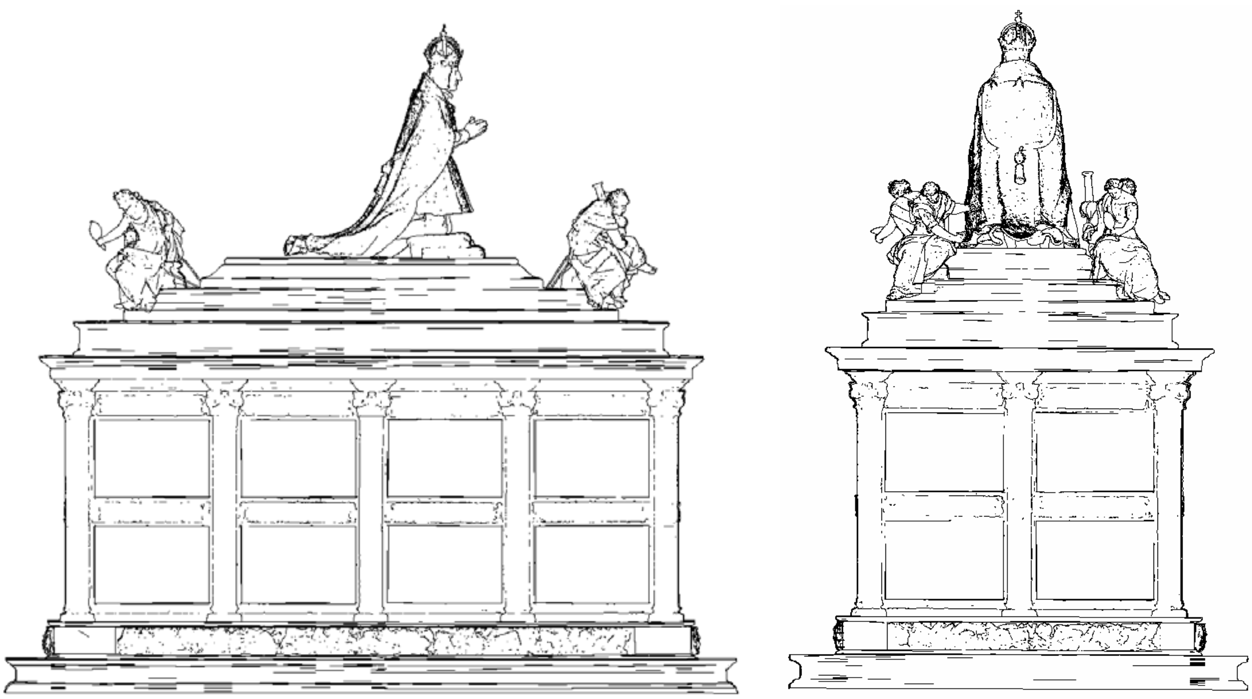

Fig. 5: Outlines of the cenotaph, automatically derived from the meshed 3D model.

5.4 Complete line drawings from 3D models

Additional lines are needed to complement the outlines if a line representation is needed. If a drawing similar to a stereo plot is desired, the rules a stereo plotter operator uses to select and draw lines have to be analyzed. If these rules are known, a mathematical model can be created which selects the proper lines from the 3D surface model accordingly. Trying to find those rules is possible only to a certain extent since every operator will select different lines intuitively and without a fixed set of rules. In addition to the outlines, all sharp edges are significant for the object and will undoubtedly be selected. Other features (e.g. eyes and other parts of faces) are important to understand the drawing. Therefore, an operator will add lines to show such elements although there is not enough geometrical evidence in the 3D model to justify those lines.

If a procedure is to be developed to select meaningful lines from a meshed 3D model, it has to detect edges (in addition to the outlines). Edges in meshed models can be described as local curvature which can be quantified by the angles included between neighboring triangles. It cannot be expected that the resulting plan will have the quality of a plan produced by an operator with artistic skills, but if this product can be derived automatically, it can serve as a template which can be used as a background for drawing a meaningful and expressive 2D line drawing with metric qualities.

The software developed at i3mainz computes the normals for all triangles of a mesh. For every triangle, the spatial angles to the three neighboring triangle normals are identified and a weighted mean value is computed. Positive (convex) and negative (concave) values can occur. Then, a histogram of all values is produced. Based on this, the user can define a number of classes for local curvature and select intensity values (green for convex, red for concave) which are used to shade the triangles concerned. This can easily be accomplished if the OBJ format is used for the mesh. Since shaded triangles are used, the result is not a true vector plan. This is not a real problem since – for the reasons mentioned above - the result cannot be used as a final drawing anyhow. Instead, it is used together with the plan of the outlines as a background for the creation of the final vector product.

Fig. 6: Left: Part of a virtual relief model. Center: Automatically detected outlines. Right: Automatically detected edges; unfortunately, the red and green colors (for concave and convex edges) cannot be shown in this black-and-white print.

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