LASERSCANNING AND PHOTOGRAMMETRY FOR THE MODELLING OF THE STATUE MARC ANTON

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ABSTRACT:

Photogrammetry is a well-established method for the use of heritage recording and documentation, whereas terrestrial laserscanning is a rather new technique for 3D object modelling. Both sensor systems have their individual advantages. This paper describes the combined use of both techniques for the modelling of the statue Marc Anton. This statue, located in the city center of Vienna, has an approximate size of 2.5m by 5m and has a height of 3m. The statue represents Marc Anton sitting on a chariot pulled by three lions. The aim is to determine a 3D model of the whole sculpture for documentation purposes (e.g.: showing differences in the used material, decomposition and offering the possibility of adding further information to certain parts of the statue). First, we describe our experiences during data capture and focus on a description of the acquired data sets. The following work can be split into two parts. The first part deals with the registration of the different sensor positions and the orientation of the digital photos into one statue co-ordinate system using hybrid adjustment techniques, whereas the second part concentrates on the 3D surface modelling. The surface modelling is performed with the software package GeomagicStudio. After a 3D-triangulation the surface is simplified using NURBS (Non-Uniform Rational B-Splines) in order to generate a CAD model. Finally, our experiences with the combined use of both data capture methods and the modelling are presented.

1 INTRODUCTION

For a detailed heritage recording a lot of different attributes have to be captured and stored to certain parts of the object. For this aim a sufficient accurate geometric representation of the object is necessary. For the generation of such an object model different surveying methods do exist. Depending on the necessary accuracy, the complexity of the object and other limitations (e.g. time for data acquisition) the most suitable measurement system has to be selected. After the data capturing a geometric representation of the object has to be defined on the basis of the acquired data. This object representation has to offer the possibility to decompose the object into smaller parts in order to add local object attributes.

Photogrammetry offering - additionally to the possibility of accurate 3D point or line/curve measurements - texture information, being very important for the purpose of interpretation, is a widely used technique for 3D object modelling. However, the measurement capabilities are limited by the fact that point identification is only possible in textured areas and that a high degree of automatization can not be achieved on complex surfaces.

In contrast to photogrammetry laserscanning provides a very high point density on the object surface, within a more or less automatic recording procedure ([Pfeifer and Rottensteiner, 2001]). This allows a very detailed surface description. Additionally laserscanning is independent of texture information. In the moment the disadvantages of this measurement method lie in the measurement resolution and in the fact that laser scanner systems do not provide high quality RGB-texture information.

This paper deals with the combined use of both methods in order to use the individual advantages of both mentioned measuring techniques for the recording of the statue Marc Anton (see Fig. 1). The statue located in the city center of Vienna has an approximate size of 2.5m by 5m and has a height of 3m. The statue represents Marc Anton sitting on a chariot pulled by three lions. A fourth lion can be found on the backside of the statue. The data capturing is described in Sec. 2, whereas Sec. 3 describes the registration of the different data sets, including also an accuracy analysis.

Challenging is the modelling of the detailed structured surface (cf. Sec. 4). Details with extensions less than 1cm can be found on the object, e.g. in the face of the lions or Marc Anton. From the geometrical point of view no parametrization over a plane or another simple surface (e.g. a sphere or cylinder) of the whole statue is possible. Furthermore, small holes (e.g. between the spokes of the wheels) increase the complexity of the object. Due to the overall complex structure occlusions cannot be avoided and some areas cannot be digitized without tremendous effort (e.g. underside of the lions bodies). To reduce the time for data acquisition we accepted some data gaps and some loss of detail. The following final section is devoted to the discussion of the results.

2 DATA CAPTURING

For the data capturing we used the digital camera Kodak Professional DCS460c and the Riegl LMS-Z360 (cf. [Riegl, 2003]) laser scanner. The camera based on a Nikon N90 uses a CCD-array with 2036 x 3060 elements (6.2 million pixels) in the image plane with a pixel size of $9\mu m$. 50% of the pixels record the intensity of green radiation, whereas 25% of the pixels are used to store the red and the blue, resp. color information. With the help of an interpolation method digital pictures with 2036 x 3060 pixels are computed. To capture the object and the surrounding tie points we used a 28mm lens with an average distance

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Figure 1: Photo of the statue Marc Anton which shows the complexity of the sensed object.

to the sensed object of 5m, the average pixel size on the object is 3mm. The laser scanner LMS-Z360 allows to capture 360 ° scans with a vertical scanning range of max. 90 ° . The measurement rate of this system is 12000pts/sec. For the range measurements a pulsed laser beam with a beam divergence of 2mrad is used. The sensor provides a single shot accuracy of ±12mm. For natural targets range measurements up to 200m are possible. The minimum angle step width of this laser scanner is 0.01 ° offering an angular resolution of 0.002 ° . Additionally to the high frequent range and angular measurements true color of the target's surface can be recorded by a one pixel camera. The time of exposure for this one-pixel-camera is quite short due to the high point measuring frequency resulting in an instable radiometric quality.

With the help of these sensors 22 digital photos and scans from 10 scanner positions (at every scanner position two scans were acquired: one coarse panorama scan (360 ° with an angle step width of 0.2 °) and one fine scan (angle step width of 0.05 °) of the object) were captured (see Fig. 2). For the collection of the image data approximately one hour was necessary, whereas for the 20 scans the data acquisition time was approximately 2.5 hours. For the observation of the higher object surfaces 5 photos were taken from a ladder and two scanner positions were taken using a higher scanner mounting.

For the identification of homologous points in the photo and scanner data 29 signalized tie points were used (see Fig. 2). 18 of these points were located on the statue (quadratic retro-reflective foil with a size of 2cm by 2cm). For the other tie points (11) retro-reflecting cylinders (with a hight of approx. 7cm and a diameter of approx. 5cm) located around the statue were used. 10 minutes per signal group were necessary to fix the retro-reflecting tie points. For the selection of the most appropriate position no complicated analysis is necessary. The aim was to place the targets in a way that 4 of them can be sensed from every sensor position in order to reduce the amount of work for manual identification of un-signalized tie points.

3 HYBRID ADJUSTMENT

For the generation of a surface model of the whole sculpture it is necessary to transform all different sensor observations into one global statue co-ordinate system.

All observations in the scan data (distance measurements, horizontal and vertical angles) and in the image data (pixel co-ordinates) can be described in a local

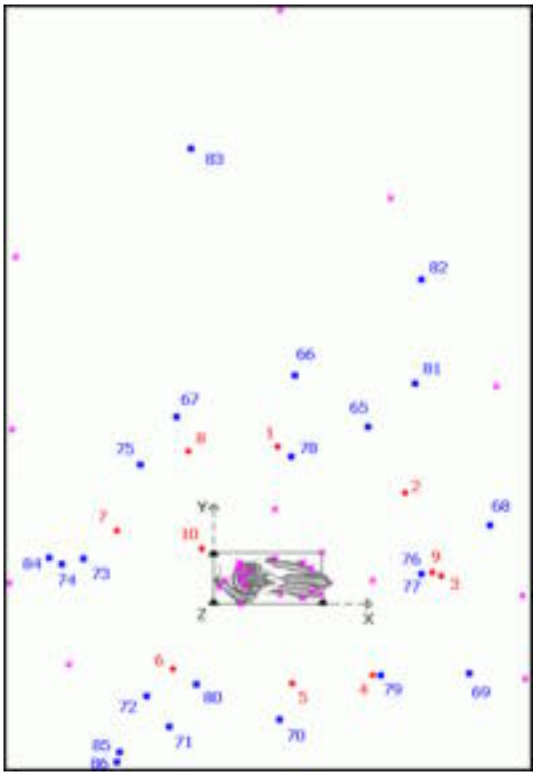

Figure 2: Scanner positions (red circles), photo positions (blue rectangles) and signalized tie points (magenta crosses). The three black triangles on the statue are used to define the global statue co-ordinate system.

sensor xyz-co-ordinate system. For the description of the observations in the global co-ordinate system the transformation parameters of a spatial similarity transformation of each sensor position must be derived in a hybrid adjustment procedure considering individual weights for certain observation types (cf. [Ullrich et al., 2003]).

Such a hybrid chained spatial similarity transformation considering image as well as laser scanner data can be performed with the photogrammetric software-package ORPHEUS/Orient ([ORPHEUS/Orient, 2003]) on the basis of homologous points. For this aim the measurement of tie points in the image as well as in the scanner data is necessary. For the adjustment of the data of the statue Marc Anton the global co-ordinate system was defined with the help of three control points in the horizontal plane of the socket (cf. Fig. 2). To achieve an unconstrained definition only 6 (defining the translation and rotation of the global system) of the 9 co-ordinates were fixed. For the definition of the scale of the global system the range measurements provided by the laser scanner were used.

The measurement of homologous points was performed manually in the digital photos as well as in the intensity images provided by the laser scanner (see Fig. 3). All in all 33 tie points (29 signalized) were used. The measurement of these tie points in the image data as well in the coarse panorama and fine scans lead to 1300 observations for the adjustment. With the help of robust estimation and data snooping 62 of these observations (mainly from the measurements in the coarse panorama scans) were eliminated so that in the final adjustment 1238 observations participated. The accuracies after the adjustment were very satisfying: It was possible to determine the position of the laser scanner with an average accuracy of 16mm in X-direction, 19mm in Y-direction and 28mm in Z-direction (the definition of the coordinate

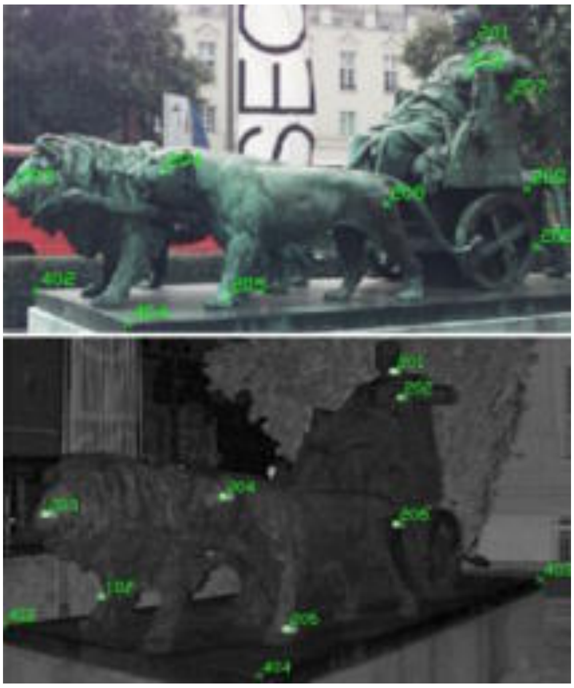

Figure 3: Measurement of tie points (Upper image: photo data, Lower image: Intensity image of the laser scanner).

system can be seen in Fig. 2). The rotations of the local sensor co-ordinate systems of the laser sensor in respect to the global co-ordinate system could be computed with an accuracy of 0.38gon for ω (rotation around the x-axis), 0.18gon for ϕ (rotation around the y-axis) and 0.17gon for κ (rotation around the z-axis). The photo positions have an accuracy of 22mm in X-direction, 21mm in Y-direction and 46mm in Z-direction with an accuracy of the rotations of 0.18gon for ω, 0.29gon for ϕ and 0.27gon for κ. The average accuracy of the tie points is 17mm in X-direction, 16mm in Y-direction and 28mm in Z-direction. Separating the tie points on the statue, which are in general much closer to the sensor position, from those around the object shows that the accuracy of the points on the sculpture is much higher (XYZ: 11mm, 11mm, 9mm vs. 28mm, 26mm and 61mm).

Finally, a variance component analysis was performed. The following observation groups were examined:

- image co-ordinates in photos: 0.37pixel
- fine scan polar co-ordinates:
  horizontal angle: 48mgon; vertical angle: 31mgon; distance: 12mm
- panorama scan polar co-ordinates:
  horizontal angle: 74mgon; vertical angle: 42mgon; distance: 16mm

4 SURFACE MODELLING

The goal of surface modelling is to get a geometric representation of the object's surface such as a triangulation or even a - more or less - continuous surface described by NURBS. NURBS (Non Uniform Rational B-Splines) are B-Splines, which are (rational) polynomials of usually low degree. The (rectangular) NURBS patches are fitted to the measured points, minimizing the residual vectors from the measurements to the idealized surface. As mentioned above, this surface is smooth, which is also the case for the original (i.e. the statue), with possible exceptions at certain lines and points. A surface composed of NURBS

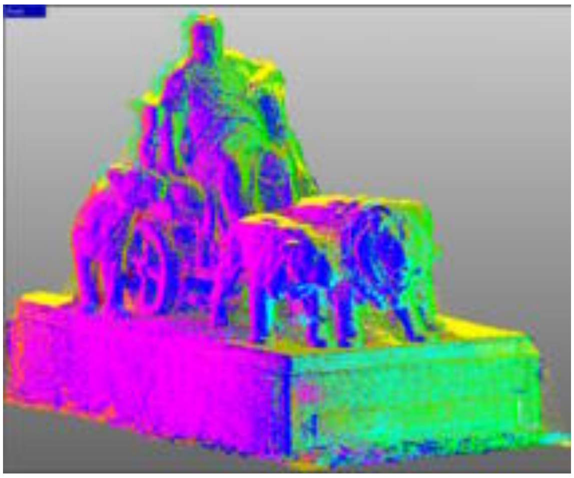

Figure 4: Point cloud from 10 fine scans (points with the same color belong to the same scan position).

patches has therefore similar properties to the original surface, which makes renderings and texture projections - in order to name two applications - more appealing. There is another rational for using surface patches, which is the data reduction. A patch has typically only few parameters and needs therefore less storage capacity than the original points, e.g. in a triangulation.

In this example, surface modelling was performed by the use of the software package GeomagicStudio 5.0. (cf. [Geomagic, 2003]).

Only the data of the 10 fine scans (see Fig. 4) were eventually used for the modelling process, whereas the 10 coarse panorama scans and the 22 photos served to stabilize the adjustment and increase its redundancy. Of course, it would be a promising idea to include the photos for the geometric reconstruction of the object, especially when thinking of sharp edges, which could be measured directly in the photos with a higher reliability.

Using the parameters of outer orientation obtained by the adjustment, each of the fine scans was exported to a xyz-file (ASCII). Afterwards, those 10 point files were imported to the modelling software. It supports "ordered point clouds", achieved by directly importing the format of the original scanner data. Unfortunately, Riegl's format *.3dd is not supported for I/O by GeomagicStudio. So, for each scan, the topological information given by the raw data matrix was lost, the point cloud was not ordered anymore.

With regard to ordered point clouds, some advantages compared to unordered point clouds arise: Due to the implicitly stored topology, nearly all operations on the point cloud can be performed much faster, and the quality of the results improve (e.g. noise reduction or triangulation). Furthermore, GeomagicStudio provides a "select best data" operation, which selects the points from the "best" scan in overlapping areas, based on the angle between laser beam and (estimated) surface normal. However, this example - as mentioned above - is restricted to unordered point clouds.

Within GeomagicStudio the modelling process is subdivided into 3 main phases: point phase (editing of the point cloud), polygon phase (computing and editing of the triangulation), shape phase (creating and editing of the patches used to generate NURBS). Each one will be treated in the following.

In the first step (the Point Phase) a manual preprocessing was necessary. Since each scan was exported completely, manual editing (deleting of extraneous points, e.g. those on the ground around the statue) was necessary to confine the point clouds to the area of interest. This step reduced the number of points from about 7.4 Mio. to about 4.0 Mio. points. The next step was to eliminate points that were erroneous due to distance errors occurring along the contour (distance measured too long because of averaging with the background due to beam divergence). The wrong points occurred in conspicuous structures and could be easily detected by displaying the scans in different colors (cf. Fig. 4). Nevertheless, this step was tiresome and time-intensive. It should be avoided by recognizing data errors already in the raw data.

It turned out to be advisable to subdivide the whole point cloud (or rather the object) into two separate areas, namely the socket and the actual statue, each of them having about 2 Mio. points. This was done because of the following reason: The two parts show different surface characteristics: The socket can be approximated by planes, it has a prismatic shape, whereas the actual statue is rather complex and its surface can be best characterized by free-form shapes. This seemed to be important when using the "reduce noise" operation, because the user can choose between "prismatic shapes", which preserves better edges and corners, and "free-form", which is optimized for free-form shaped surfaces. The (horizontal) separation-plane was chosen about 2cm above the socket's top surface because the noise around the latter was about 2cm.

The point cloud representing the socket was thinned out as well as the one representing the sculpture, using a uniform sampling of 1cm-cubes: This means that space is subdivided into equally sized cubical cells, and afterwards, all but one point from each cell are deleted. Thus, the sculpture's point cloud was reduced to about 1.4 Mio. points.

Because of their simplicity, it is appropriate to describe the socket by a set of planes. Therefore, GeomagicStudio provides a tool called "detect planes", which searches the point cloud for planes using thresholds/tolerances that can be quantified by the user. Due to noise, this tool did not work properly. So, the function "capture plane" was used instead several times: It determines a set of points "belonging" to the plane based upon a manual selection of points, which are supposed to lie on a plane. Finally, for each plane's detected point set, the parameters of the best fitting plane were calculated. The intersection of the mathematically defined planes was done with a simple program. The point cloud representing the sculpture had to be filtered strongly because the noise was so high that the calculation of the triangulation did not make sense yet (see Fig. 5). So, the point cloud had to be filtered three times (maximum filter setting, unfortunately this is delivered as black box only). Step by step, outlying points were eliminated and the roughness of the data was reduced, too. As result, the noise was largely reduced (of course, some details were lost and features were smoothed), and a curvature-based sampling had become reasonable. Thus, the point cloud was reduced to 25% (about 320,000 points). The transition to polygon phase followed.

The point cloud was triangulated. The triangulation was quite satisfying at the most parts of the object's surface. Nevertheless, especially near the data holes, there were gross errors in the triangulation, which had to be repaired. For example, the lions at the front part of the statue "grew together". This caused the following problem: The program supposed the three lions to be one single surface and flipped the surface normal at one whole lion because the surface normal got twisted between two lions.

After coarse editing, the triangles were reduced (50%)

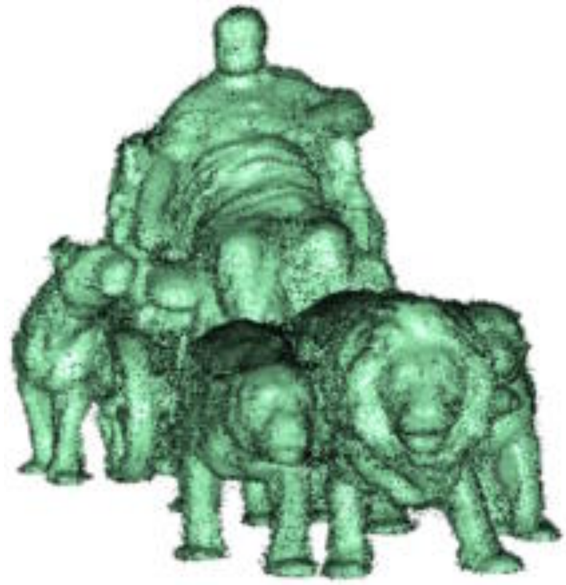

Figure 5: Triangulation of the unfiltered point cloud. Measurement noise leads to a rough surface representation.

from about 615,000 to about 307,000 in order to make manual editing easier, almost without losing surface details. This can be achieved, because the triangles already represent a surface, and triangles in (approximately) the same plane can be combined.

Then, a very time-intensive manual editing of the triangulation followed: Holes and partial holes had to be filled, spikes had to be removed, local smoothing was performed, eliminating "wrong" features, local reduction of triangles in hardly curved regions, refining the triangulation by more triangles in strongly curved regions, and other operations like that. One must say that this manual editing was necessary because of the shortcomings of the triangulation due to using the merge of unordered point clouds. The quality of triangulation can be expected to be better when having a topology already in the point phase.

After that, the number of triangles was once more reduced to 50% and some fine edits were done. Finally, the statue's surface was represented by 79,634 points and 155,762 triangles.

The next step was to enter shape phase in order to generate a NURBS representation of the object. Since Version 5.0, GeomagicStudio provides a function called "AutoSurface", which automatically produces a patch layout necessary to generate NURBS (see Fig. 6). The user can decide how much surface detail shall be preserved. In this case, the detail should be preserved as good as possible.

The result of the NURBS surface was very satisfying but the number of patches was 3,293 causing a file of about 205 MB (compared to 26 MB for triangulation). Creating the patch layout manually would certainly result in fewer patches. Of course, a manual patch layout might be a little better in certain areas, but the effort would be enormous.

Finally, it must be said that the most time of the modelling was necessary to find out which steps had to be done and in which order they had to be performed. Certainly, this steps applied on this complex statue are other ones than when modelling a relatively simple facade. The relative high noise required much editing already at

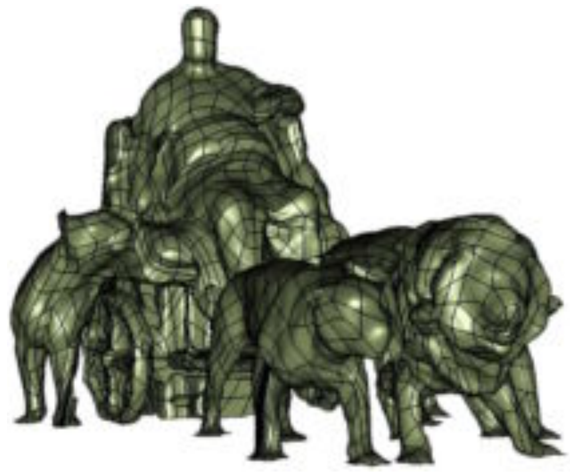

Figure 6: Smoothed surface with automatic generated NURBS patches. The black lines show the patch boundaries.

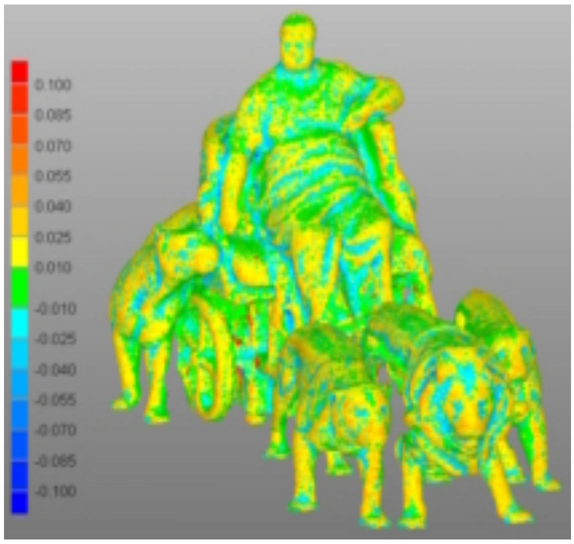

Figure 7: Color coded difference model between the final triangulated surface and the original laser point cloud data (units: m).

point phase. It seems to be reasonable to invest that time into point phase because triangulation needs a well-edited point cloud, otherwise it is hardly possible to overcome the difficulties arising at polygon phase.

5 DISCUSSION AND SUMMARY

With the help of hybrid adjustment techniques a simultaneous transformation of the image and laser scanner data into a global co-ordinate system on the basis of homologous points is possible (cf. Sec. 3). Additionally, we used variance component analysis for the determination of the individual accuracies of the different observation types within the adjustment procedure. These accuracies can be compared with the nominal accuracy of the measurement sensors (e.g.: The computed variance of the range measurements to the signalized tie points of the fine scans is the same than the nominal accuracy of the laser scanner Riegl LMS-Z360.). Furthermore, the analysis shows that the accuracy of the coarse panorama scans is lower than the one of the fine scans and that the manual measurements in the digital images of the signalized tie points have sub-pixel accuracy.

The generation of the object model of the statue Marc Anton was performed with the software package GeomagicStudio on the basis of the laser scanner point cloud. During the modelling process we have recognized that the laser scanner has obviously problems with measurements close to the contour of the objects (cf. Fig. 4). This can be explained by the beam diameter and the fact, that only a part of the energy is reflected from the object surface, the other part is lost, or reflected further behind. As the intersection angle between the surface and the laser beam comes closer and closer to 180°, the reflection area on the surface becomes bigger, too. This may also explain the deterioration of the measurement quality.

In general the triangulation of the data did work quite well, but there occurred problems in occlusion areas. In these regions time consuming manual editing was necessary. Additionally problems were caused by random measurement errors (approx. $\pm$2cm dispersion of the point cloud around the averaging surface). Due to this noise local curvature based re-sampling methods did fail. Therefore smoothing operations were necessary. As a result, the final surface model is a compromise between smoothness and detail preservation. The difference between the final triangulated surface and the original laser scanner point cloud can be seen in the Fig. 7. The average distance of the points to the model is 12mm and the standard deviation of these differences is 13mm. Finally, a NURBS surface is automatically computed on the basis of the triangulation. This final CAD-model (cf. Fig. 6) describes the statue by a continuous surface (in the case of our statue it has holes due to missing data). This model is differentiable within the boundaries of one NURBS-patch, whereas on the patch boundaries this differentiability is only approximatively given (epsilon tolerance).

On the basis of our experiences gained during the modelling step, we can say that it would be very useful to integrate additional image measurements into the modelling process. Especially the accurate representation of edges on the statue would be much easier with the help of additional image data. As mentioned above, the distance measuring unit of the laser scanner has difficulties with measurements close to the contour of the object. It would be possible to eliminate this lack by the digitalisation of these line features in the image data. This capability is demonstrated in Fig. 8. For this visualization the contours of two lions were digitized in one image. Then for the determination of the 3D co-ordinates these contour points are projected into a vertical plane. Finally, these points are connected to the projection center of the digital image. This leads to a general cone which is displayed with the help of a VRML-visualization. Additionally to the possibility of accurate 3D point or line/curve measurements the image data provides texture information, which can be very important for interpretation and documentation. Therefore the next aim for the documentation of such an object will be the task to project the texture information onto the final surface model in order to generate a photo-realistic 3D model of the statue.

Summing up our experiences in the combined use of laserscanning and photogrammetry for heritage recording and documentation it turned out that both techniques are necessary for the determination of a high quality 3D model. With the help of hybrid adjustment techniques all observations can be simultaneously transformed into one global co-ordinate system ([ORPHEUS/Orient, 2003]). As mentioned at the beginning, the modelling of the statue Marc Anton is - due to its complexity - a very difficult task. During data capturing we had to accept data holes in occlusion areas to reduce the time for

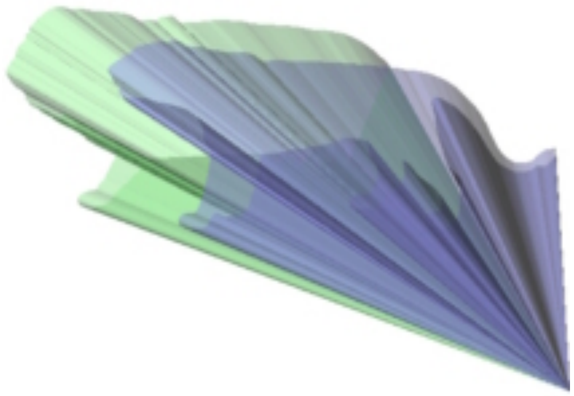

Figure 8: Visualization of the contour of two lions (digitized in one image). The points on the contour are connected with the projection center of the digital image. This results in a general cone.

data acquisition. Therefore the model of the statue has holes, which cannot be closed without any further measurements. These holes and additionally random and gross errors in the laser scanner data generate problems during the automatic modelling process (cf. Sec. 4). Nevertheless we were able to determine a smooth surface model of the statue. Improvements of this model would be possible with the help of additional image information. With the help of this additional data further geometric details of the sensed object can be modelled. The goal for further research work in the area of 3D-modelling will be the development of adequate methods for the combined surface determination of laserscanner data and image data.

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