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Photogrammetric measurement and visualisation of blood vessel branching casting: A tool for quantitative accuracy tests of MR-, CT- and DS- angiography

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ABSTRACT

Currently three different angiographic techniques are used to measure and visualize major blood vessels in the human body: magnetic resonance (MR), computer tomography (CT) and digital subtraction (DS) angiography. Although these imaging systems have been already qualitatively compared, a quantitative assessment is still missing.

The goal of this work is to provide a tool enabling a quantitative comparison of the three imaging techniques to an unbiased reference. MR-, CT- and DS- agiographies are first performed on a corpse. Then, a casting of the abdominal aorta and its main branches (iliaca communis, iliaca externa) is prepared, removed from the body and measured with photogrammetric methods. The elongated (40 cm long) and thin (0.5-1.5 cm) cast is fixed in a three-dimensional frame with 16 signalized small spheres used for calibration and orientation purposes. Three fixed CCD cameras acquire triplets of images of the casting, which is turned in 8 positions. In order to perform multi-image matching, an artificial random texture is projected onto the object. For each triplet of images, a semi-automated matching process based on least squares matching determines a dense set of corresponding points. Their 3-D coordinates are then computed by forward intersection, with a mean standard deviation of about 0.2 mm. The results from the 8 positions are merged together into a 3-D point cloud and an adequate filter is applied to remove the noise and the redundancy in the overlapping regions.

The paper depicts the basic design of the system and the measurement methods. Furthermore some preliminary results are presented.

Key words: Medical, Modelling, Photogrammetry, CCD

1. INTRODUCTION

A pilot project was started in cooperation with the department of radiology of the university hospital Zurich. The aim was to evaluate the accuracy levels of the currently techniques used for the visualization and measurement of major blood vessels in the human body. Magnetic resonance (MR), computer tomography (CT) and digital subtraction (DS) angiographies were considered in this work. In the radiology literature, comparison of different methods can be found. The scientific publications treat the detection of diseases using visualisation tools[6,7,8,9] or describe methods for the measurement of blood vessels with CT techniques[10], but a quantitative assessment is still missing. The goal of this pilot project was to establish if it was possible to determine a potential accuracy of the three techniques (CTA, MRA, DSA) for the measurement of blood vessels and compare them using unbiased data as reference. The abdominal aorta and its main branches (iliaca communis and iliaca externa) were chosen for this test (see figure1).

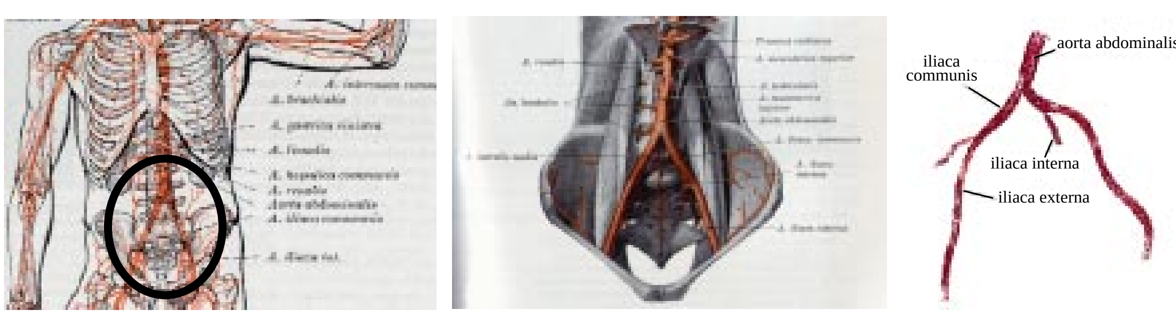

Fig. 1: Aorta abdominalis and its main branches (iliaca communis, iliaca externa, iliaca interna)[15]

MR-, CT-, and DS- angiographies were first performed on a corpse. Then, a casting of the aorta abdominalis and its main branches (iliaca communis, iliaca externa) was prepared. The idea of the project was to measure the casting with optical methods and use the results as unbiased reference for a quantitative comparison between the three techniques.
Four different optical methods can be used for the measurement of the casting: laser scanning, silhouette extraction, coded light and photogrammetric approaches. Laser scanning methods are widely used to model objects in macro scale. Their advantage is the simplicity in use and the wide range of software package available for the modeling process. The elongated and thin shape of the arterial cast would however pose problems in the registration phase of the data processing and the use of control points would probably be required. In the case of silhouette extraction based methods[11,12], images acquired around the object are processed to extract the silhouettes, which are then combined to result in a 3-D surface model. This method can however generate ambiguities in the regions of overlap and occlusion, leaving the surface model with uncovered areas. Structured light methods[13,14] are well known and used in industrial applications to measure the shape of objects with high accuracy. Like laser scanning, these methods could meet some problems in the registration phase, leading to non-standard procedures. Finally, the photogrammetry solution[1,2] consists in the acquisition of images of the object from different directions, determination of the camera positions and internal parameters, establishment of correspondences between the images and computation of their 3-D coordinates. The result is a 3-D point cloud. Although the relatively complex and long processing, the photogrammetric approach was chosen for its versatility. This paper describes the basic design of the system and the techniques used to measure the blood vessel casting. Some problems occurred during the process are discussed and the preliminary results presented.

2. SURFACE MEASUREMENT

The main characteristics of the aortal cast are: (1) the thin (0.5-1.5 cm), elongated (40 cm long) and branched shape; (2) its flexibility and (3) the complete lack of natural texture. For these characteristics the measurement task was rather difficult.
At first an adequate frame was constructed to immobilise the casting and sixteen white spheres were fixed on metal lines for the determination of the external orientation. The rotation of the entire frame containing the blood vessel branching was possible without moving the signalized spheres. The design of the frame allowed an easy replacement of the casting with a new one. Figure 2 shows an image of the blood vessel branching casting fixed in the frame.

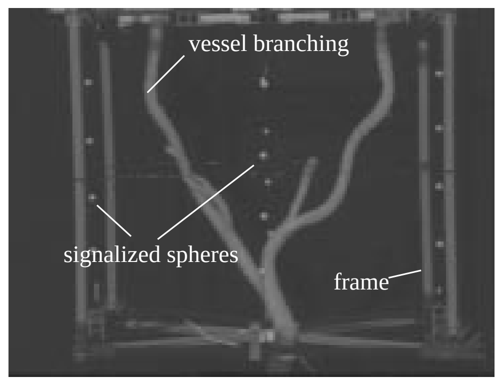

Fig. 2: Configuration of the frame

2.1. Setup

Three CCD cameras with 768x576 pixel resolution were used for the image acquisition. Two slide projectors placed at both sides of the cameras projected a random pattern texture. To achieve a complete 360˚ imaging of the object, the frame was turned in 8 positions. At each position, a triplet of images was acquired, resulting a total of 24 images (figure 3).

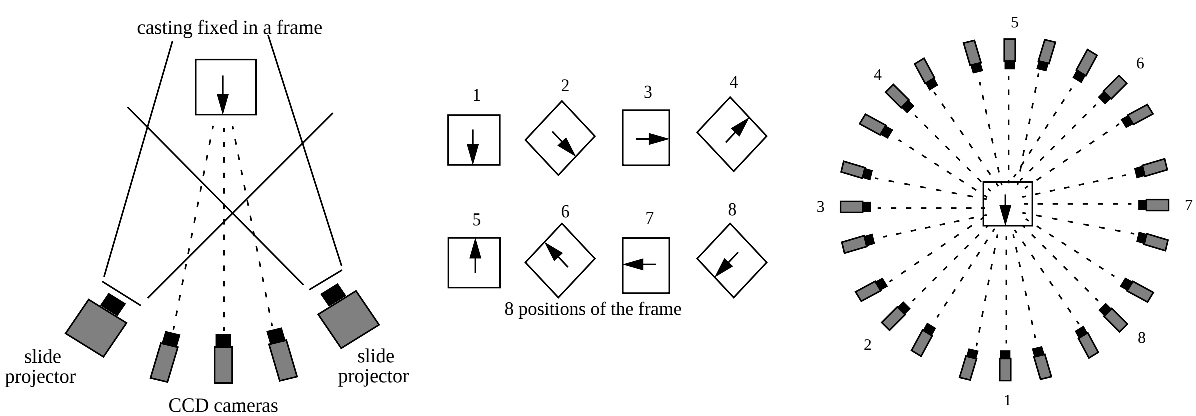

Fig. 3: Setup of the acquisition system: 3 CCD cameras and 2 slide projectors (left).
The frame is turned in 8 positions (centre), this results in 8 triplets of images around the object (right).

Figure 4 shows a triplet of images for the first position and the images taken by the central camera at the 8 positions of the frame. As it can be seen, the shape of the casting was very thin and elongated. Its branched form, together with the frame construction, caused relatively wide occlusions (i.e. in the turns number 3 or 7). A large number of images was therefore required to assure the complete coverage of the object.

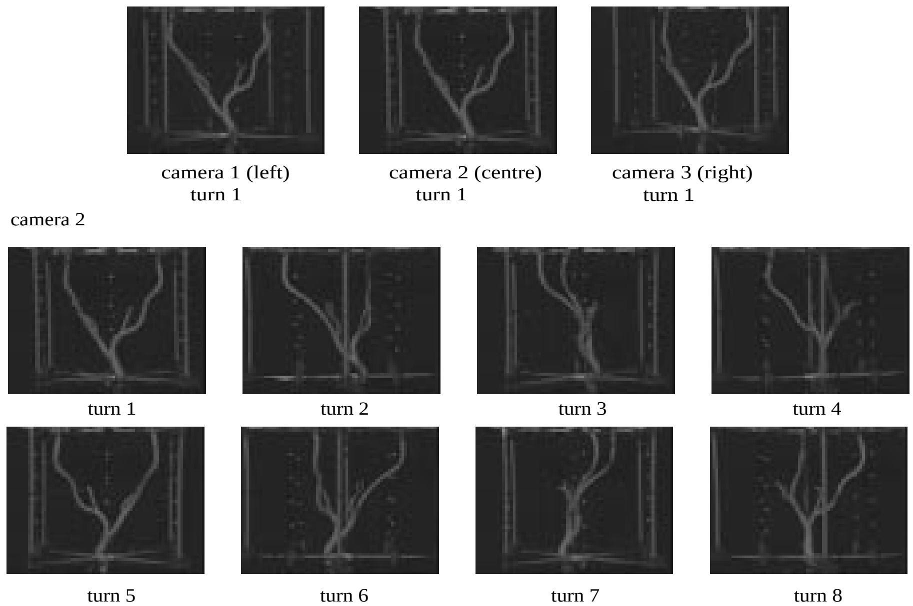

Fig. 4: One triplet of images (top) and images from the central camera for the 8 turns (bottom)

2.2. Calibration

To calibrate the 3 CCD cameras, a 3-D reference field with coded target points was used (figure 5). The target points were automatically recognised and measured in the images[5]. The internal orientation and the additional parameters[3] modeling the different distortions were determined with the bundle adjustment method. The 3D-coordinates of the points have been previously photogrammetrically determined with a mean standard deviation of 20 µm.

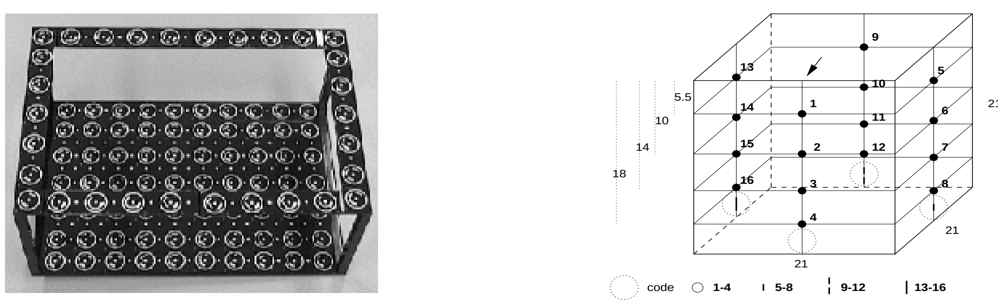

Fig. 5: Reference field with coded targets for the calibration of the 3 cameras system (left), control points on the frame for external orientation (right)

The reference field was placed in the object space and the 3 CCD cameras acquired a triplet of images. The images were used to perform the calibration (internal orientation and determination of the lens distortion of the 3 CCD cameras) and to determine the external orientation for the first position. Once the calibration process was concluded, the reference field was replaced by the frame containing the blood vessel branching casting. The frame was turned 8 times of about 45 degrees around its axis. This rotation can be considered like a displacement of the 3 cameras around the object (figure 3). To determine the external orientation at the different positions of the frame, the signalized spheres were used as control points. Their image coordinates were measured semi automatically by centroid operators and finally bundle intersection led to a mean accuracy for the external orientation of about 0.8 mm.

2.3. Matching process

The matching process is performed independently for each triplet acquired by each turn of the frame. An automated multi-image matching process[1,2] based on the adaptive least squares method[4] determines a dense set of corresponding points in the three images starting from a few seed points. The template image is divided into polygonal regions according to which of the seed points is closest (Voronoi tessellation). Starting from the seed points, the set of corresponding points grows automatically till the entire polygonal region is covered (figure 6). This process is repeated for each polygonal region to cover the whole image.

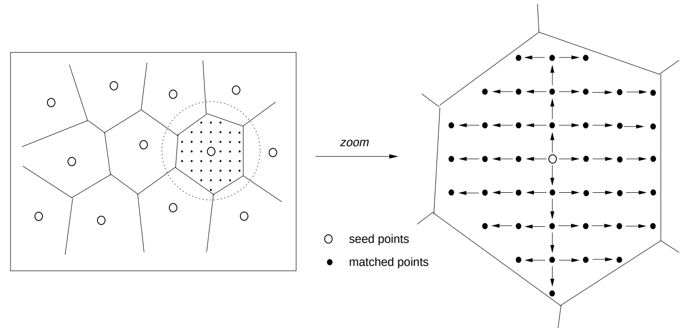

Fig. 6: Search strategy for the establishment of correspondences between images

As the blood vessel branching casting had a complete lack of natural texture, the projection of an artificial texture was required to perform successfully the matching process. For this purpose, two slide projectors projected a random pattern from two directions(figure 3). Figure 7 shows the effects achieved.

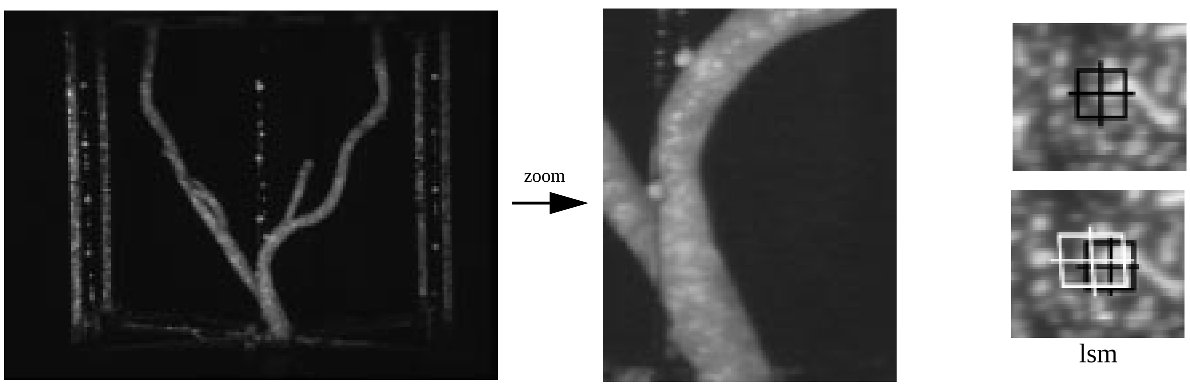

Fig. 7: Random pattern projection is required to perform the automated matching
left: acquired image of the blood vessel branching with artificial texture projection; centre: zoomed image;
right: least squares matching algorithm: top: template image, bottom: search image

As the object was wide, the projected texture resulted relatively unfocused in some regions of the surface (see zoomed image). This undesired effect reduced the accuracy potential of the matching process. Moreover, the shape of the branching was critic: the main branching (iliaca externa) was only about 17 pixels thick in the image. For the matching process, a patch size of 11x11 pixels was chosen, therefore only a thin part along the centre of the branching could be matched. Occlusions caused by the fixation frame, the signalized spheres and the branching itself, too disturbed the automated matching procedure.
Combining all these effects, the matching process didn’t result so highly automated as expected. However good matching results were achieved and dense sets of matched points could be drawn for all the 8 turns.

2.4. 3-D point clouds

The 3-D coordinates of the matched points were computed with a mean accuracy of 0.2 mm by forward ray intersection using the known calibration and orientation data. This process was performed independently for the 8 data sets and the results merged together into a cloud of about 13000 points (figure 8, left). A filter was required to reduce the amount of redundant data (overlap between data sets), to get a more uniform density of the point cloud and to reduce the noise. The implemented filter divides the object space in voxels of variable dimensions and replaces the points contained in each voxel by the centre of gravity. As result, the 3-D data is more uniformly distributed and the noise reduced. Figure 8 shows the point cloud before (left, 13223 points) and after the filtering process using 2 different reduction levels (in the centre 8040 points and right 2537 points).

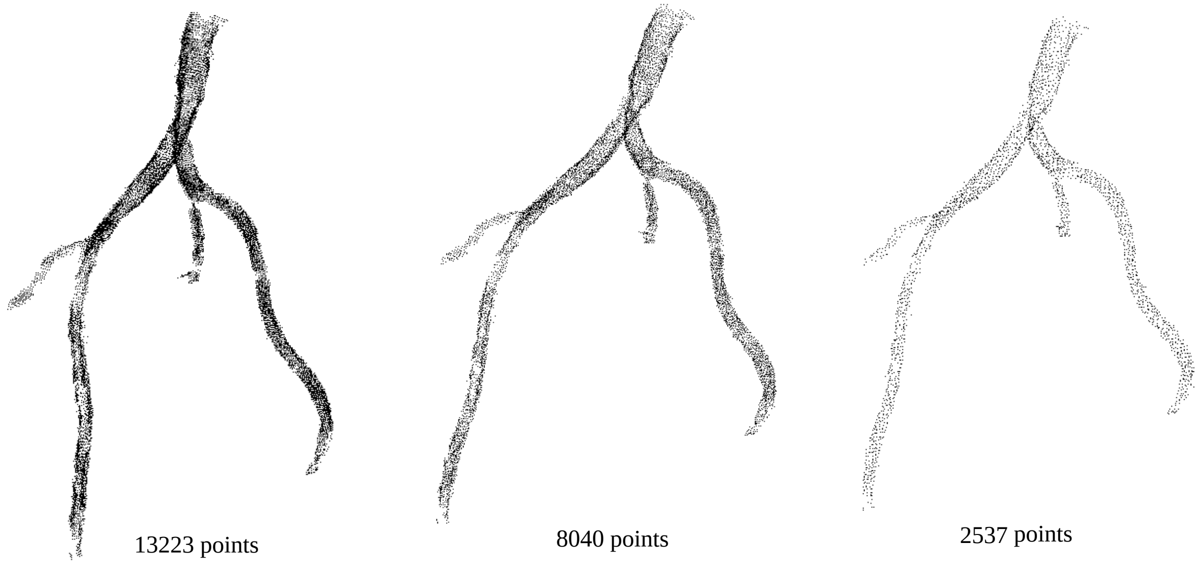

Fig. 8: Original 3-D point cloud (left) and two level of filtered data (centre, right)

3. MODELING

In this work, the modeling process was intended only for visualisation purposes. The most difficult task was the generation of a complete and unique digital surface model for the blood vessel branching. Indeed the 3-D point cloud was very dense in some regions and poor in others, mostly where the object was very thin. For example, the two iliacas interna weren't fully measured, because of their extreme thinness; therefore these two parts were excluded from the modeling process.

In order to generate a surface model starting from unorganised 3-D point cloud, non-standard procedures had to be applied. The triangulation mesh was created with a commercial software (Wrap of Geomagic) and manually edited to adjust the orientation of the single triangles and to remove the bad ones. Figure 9 shows the results of the modeling process. It is good in the region of the aorta abdominalis and the iliaca communis, but rather poor at the end of the iliacas externa, where the blood vessels were very thin.

Fig. 9: DSM of the blood vessel branching for visualisation purposes

4. CONCLUSIONS

In this paper our methods and techniques used to acquire the shape of a blood vessel branching casting of the aorta and its main branches were described. A photogrammetric approach was chosen among others for its versatility. Preliminary results were presented and the main problems discussed. Among the future works, it was planned to acquire CT-, MR- and DS- angiography data and prepare castings for 9 cases. Furthermore, for the comparison between the 3 medical imaging systems (CTA, MRA, DSA) and the reference data, a common format has to be defined.

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