3D Interactive Virtual Angioscopy*

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Abstract. In this paper, we present a system for interactive explorations of extra- and intracranial blood vessels. Starting with a stack of images from rotation angiography, we apply virtual clips to limit the segmentation of the vessel tree to the parts the neuroradiologists are interested in. Furthermore, methods of interactive virtual endoscopy are applied in order to provide an interior view of the blood vessels.

Keywords: Virtual Environments, Virtual Angiography, Computer Assisted Diagnosis.

1. Introduction

A common procedure in neuroradiology is the examination of extra- and intracranial blood vessels. After the injection of a contrast agent via endovascular catheter, X-rays are used to acquire 2D projection images of vessels. These images are of high resolution but lack spatial information due to the projection method. Several other non-invasive techniques are available to visualize vessel trees and to provide spatial information. One advanced technique is *rotation angiography*, which provides a volumetric representation of the respective blood vessels and the surrounding tissue. After a segmentation and classification operation, the blood vessels of the scanned area can be reconstructed from volume data. However, more blood vessels of the respective area are usually visualized than the vessels of interest. This leads to a situation where the actual important information might be hidden behind the less important information. Two techniques are applied to solve this situation. The application of virtual clips limits the segmentation of the vessel tree to the part of the vessels the neuroradiologist is interested in. The second technique applies methods from virtual endoscopy [2,7] to generate an interactive environment for the vascular examination from a point of view which is inside the vessels.

In this paper, we briefly outline virtual clips in Section 2 and present the virtual endoscopy system used for virtual angiography in Section 3. In Section 4, we will present our results and conclude the paper in Section 5.

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2. Virtual Clips

The first step after the data acquisition is the segmentation of the vessel tree from the image stack. Standard 3D region growing-based segmentation algorithms can be used as well as advanced segmentation methods [10]. However, arterial and venously blood vessels are usually segmented, thus increasing the visual complexity. To reduce this complexity, we selectively display details of the vascular tree. Specifically, we apply *virtual clips* to limit the subsequent segmentation to parts of the complex vessel tree.
To specify the virtual clip, the user interactively picks an area on a MIP of the image stack, which is associated with the vessel surface (Fig. 1). This point is interpreted as the center of a balloon which inflates until the vessel is blocked (Fig. 2). This process is controlled by a balloon shape constraint volume growing algorithm. During the growing, the surface of the balloon (thick black surface in Fig. 1 and 2) is either inside the vessel or intersects with the surface of the vessel. Once the surface inside of the vessel is partitioned into two disconnected segments, the balloon completely blocks the vessel, thus realizes a virtual clip (Fig. 2).

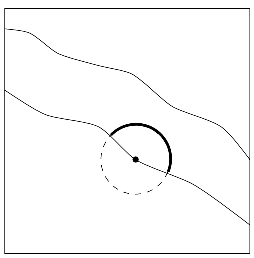


Figure 1. Before the vessel is blocked, there is only one connected area, which is on the surface of the balloon and inside the vessel.

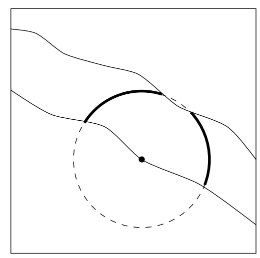


Figure 2. If the area on the surface of the balloon inside the vessel is partitioned into two segments, the vessel is blocked.

3. Virtual Endoscopy

Research on virtual endoscopy is one of the most active areas in virtual medicine. The developed methods were applied to virtual colonoscopy [7,9], bronchoscopy [5], ventriculoscopy [1,2], and angiography [4,3,6]. However many systems either lack flexibility or interactivity which is necessary to apply the methods in daily routine.

Based on the pre-segmented image stack from rotation angiography, a polygonal representation of the respective vessel tree is computed. For interactivity, this representation is subdivided into individual entities using the octree decomposition scheme (Fig. 3). During the interactive virtual exploration, the virtual angiograpy systems hierarchically checks which of the individual subdivision entities are located completely or partially within the field of view. Only those are considered potentially visible and are rendered. All other entities are not visible, hence they are not rendered. Depending on the size of the individual datasets, we achieved a culling rate of approximately 31.9 %, and a framerate of 16.3 fps on an HP B180/fx4 graphics workstation.

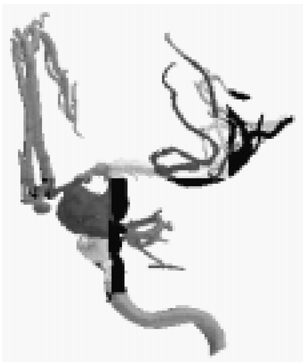


Figure 3. Octree decomposition of reconstructed vessel tree.

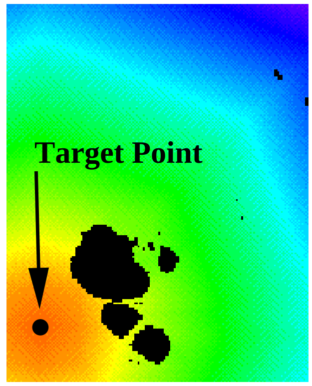


Figure 4. Potential field coding the drift to the target point.

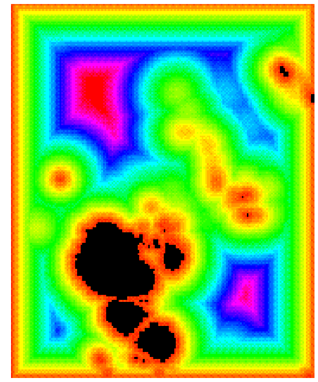


Figure 5. Potential field coding the distance to the outer vascular surface.

Most virtual endoscopy applications either automatically generate an animation of a fly-through of the respective part of the body, or the user can freely navigate through it. The navigation of the first approach is limited to a VCR-like functionality [3,9,8]. However, if the structure of interest is not in the focus of the pre-specified path of the camera, it needs to be refined and re-generated. This is a potentially very time-consuming task with very limited flexibility.

The second approach provides full flexibility for navigation [5]. Unfortunately, anatomical structures, as they can be found in patient datasets, are very complex. Even for a specifically trained physician, it can be difficult to navigate to the target. Furthermore, collision avoidance is a costly operation which is frequently not available in these systems.

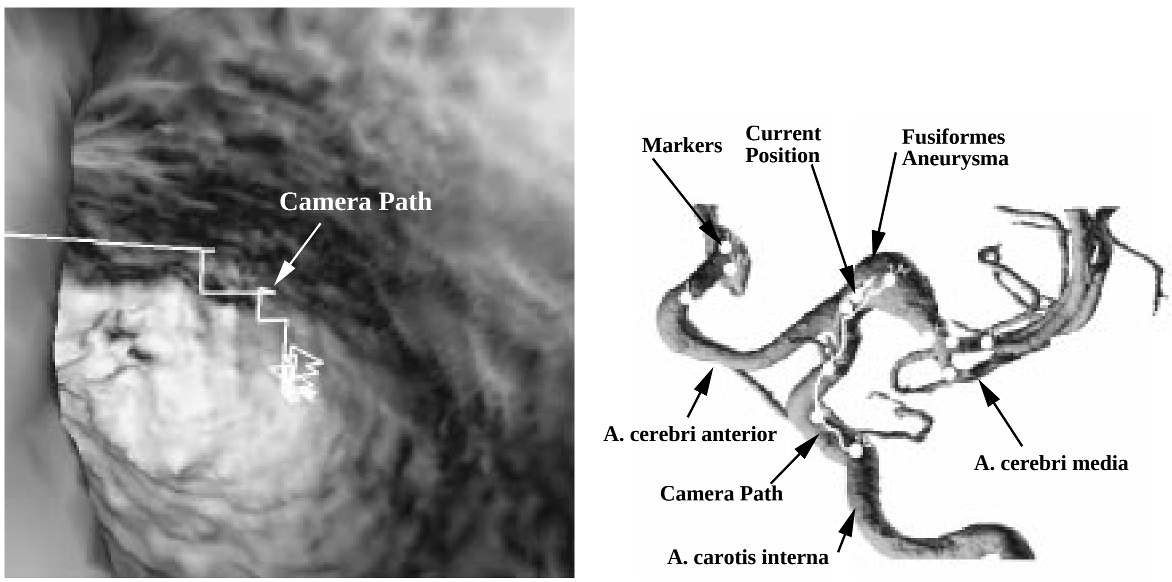
In our approach, we adopted a guided-navigation paradigm in order to implement full navigation flexibility, combined with user guidance, and an efficient collision avoidance scheme [7]. Specifically, we apply image processing techniques to the pre-segmented volume dataset to calculate three distance fields which are interpreted as potential fields by our virtual camera. Two of these fields represent the drift of the camera from a specified start point to a specified target and vice versa (see Fig. 4[1]). The third potential field codes the distance from any position in the pre-segmented volume to the surface (actually the isosurface) of the respective vessel (see Fig. 5[2]). If the camera approaches the inner vascular surface, repulsion forces circumvent the penetration of this surface. Together with the user interaction, interpreted as a force, a set of kinematic rules calculates the movement of the camera.

Depending on the image acquisition modality, the vessel tree is not connected due to segmentation and contrast problems. In those cases, disconnected parts of the tree can be examined either separately in different sessions, or they can be treated as parts of one unified, but disconnected structure.

[2]Pre-processing is usually based on the interior of the vascular systems. For didactic purposes, these figures show the pre-processing results of the exterior of the vascular system.

4. Results

We applied the presented virtual angiography system to a variety of angiography-based volume datasets. After a pre-processing of approximately 15 minutes, we examined the interior of the vascular systems using the virtual endoscope.
In this paper, we focus on a rotation angiography dataset of a 41 years old patient with a fusiform aneurysm of the *Middle Cerebral Artery* (A. cerebri media), which are located at the base of the skull, below the anterior horns of the lateral ventricles of the human brain. Figure 6a shows the endoscopic view into the aneurysm, and Figure 6b gives an overview of the reconstructed vessel tree, including the markers and current position of the virtual camera.



(a) (b)

Figure 6. Virtual Angiography: (a) View through virtual endoscopy, (b) overview of reconstructed vessel tree (B/W for print contrast).

5. Conclusion and Future Work

In this paper, we presented a virtual angiography system, based on advanced segmentation using virtual clips and on a virtual endoscopy system. Interactive performance on a graphics workstation and intuitive handling was achieved using a visibility culling scheme and adopting the guided-navigation paradigm.

In the future, we will focus on more advanced visility culling schemes to further reduce rendering complexity. This will enable interactive angiography even on low-end graphics workstations and PCs. Another future research focus will be the clinical evaluation of this system. Furthermore, other applications of virtual endoscopy will be explored.

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