SILHOUETTE FUSION OF VASCULAR AND ANATOMICAL VOLUME DATA

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ABSTRACT

In this paper we present a novel method for the combined hybrid visualization of the cerebral blood vessels, segmented from a 3D rotational angiography dataset, and datasets containing the soft tissue anatomy, such as CT or MR. This visualization method is targeted at the use in interventional treatment of vascular pathologies and endovascular treatment of the neoplastic tissue. Our method distinguishes itself since it offers the possibility to provide the clinician with a maximum amount of contextual information about the spatial relationship and topology of both datasets, without compromising the ease of use and interpretation. Further it is discussed how an interactive visualization can be implemented on off-the-shelf graphics hardware, and it is indicated which clinical benefits can be achieved.

1. INTRODUCTION

Interventional X-ray angiography procedures are based on the real-time 2D minimally invasive image guidance of endovascular devices through human vessels. The imaging modality of choice for the interactive tracking of the guide wires and catheters is C-arm X-ray angiography. 3D rotational angiography (3D-RA) has significantly improved the standard 2D angiography imaging by adding the third imaging dimension and as such allows for better understanding of vessel morphology and mutual relationship of vessel pathology and surrounding branches. Prior to the intervention, commonly a diagnostic 3D dataset was acquired, using imaging modalities such as CT or MR. Our goal is to present a combined visualization of vasculature, which was segmented from the 3D-RA reconstruction, and anatomical data containing the surrounding tissue, such as a CT or MR data. The resulting image should be easy to interpret, while presenting clearly the spatial relationship of the vessels in its context, the surrounding tissue. This is especially the case, since it is to be used in an interventional environment (as opposed to a diagnostic one).

Image Fusion is the domain of combining two (or more) datasets in a mutual visualization. In prior work dealing with the fusion of volumetric datasets, two classes of algorithms can be distinguished:

3D Compositing, whereby structures further from the viewer are obscured by closer ones. This includes surface rendering techniques, such as iso-surface rendering [1] and mesh rendering [2], as well as direct volume rendering of multiple datasets [3,4,5,6,7] and combining surface and volume rendering [8,9]. The advantage of this class of algorithms is the fact that the spatial relationship and topology between the datasets is very clear. Obscured structures can be made visible by using a high level of transparency, though this tends to clutter the resulting image with information, or by using clip planes, clipping a part of one dataset.

Overlaying is the other class, whereby selected internal structures influence the resulting image, regardless whether they are obscured. In its simplest form this means that the resulting image is composed of the combination of the separate 2D projection of both datasets [10], using e.g. blending, but also the combination of volume rendering techniques with Maximum Intensity Projection [11] can also be considered to be a member of this class. The benefit of this method is the fact that no (relevant) information can be hidden because of occlusion. On the downside, however, the representation of the topology of the data sets is lost.

We intend to use the best of both classes, by combining them in a hybrid approach, without cluttering the result with an overload of data, and thus yielding an easy to interpret image. New to the state of the art is our focus on the clinical aspects of adding contextual information to the intervention.

2. OUR APPROACH

The use of the fused image in an interventional environment poses several constrains to the visualization method. First of all, since the clinician rather wants to focus on the intervention, the user interaction, including in the pre-processing step, should be limited to a minimum. The manipulation of the visualization should be interactive and easy to use. Further the resulting image should be easy to

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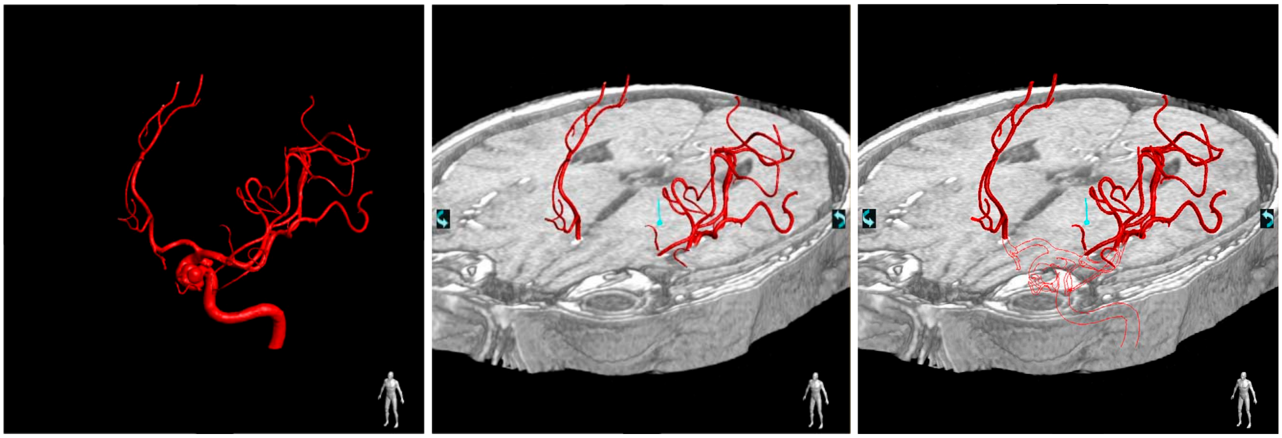
(a) (b) (c)

Figure 1: (a) cerebral vessels, segmented from the 3D-RA dataset, (b) the cerebral vessels, combined with a volume rendered slab out of a MR dataset, which obscures the aneurysm, (c) the segmented vessels and MR slab, overlaid with the silhouette of the vessels

interpret, and clearly show the spatial relationship between the depicted datasets. It is also of importance that the full morphology of the blood vessels is visible, since they are the center of attention during the treatment.

Our method is based on 3D compositing of the segmented vessels with a direct volume rendered thick slab out of the anatomical dataset. The silhouette of the vessels is overlaid on the resulting image, to show the parts of the vessels obscured by the slab. This process is implemented in three passes: in the first pass the segmented vessels are rendered (figure 1a), in the second pass the slab of the anatomical dataset is mixed into the scene (figure 1b), and finally the silhouette of the vessels is rendered on top of the resulting image (figure 1c). All passes can be easily implemented on consumer graphics hardware, employing the GPU, which leads to high frame rates and thus interactive manipulation.

The registration of the 3D-RA volume and the anatomical dataset, as well as obtaining a model of the segmented vessels in the 3D-RA dataset, is performed in a pre-processing step.

The slab can be moved by the user along its normal, showing different parts of the anatomical dataset. Further its width and orientation can be adjusted. The intersection of the vessels and the slab clearly show the spatial relationship of the vessels and the surrounding tissue.

3. PRE-PROCESSING

The pre-processing steps need to be performed only once. The first step consists of determining the registration between both datasets. Since we focus on cerebral applications, and there are only limited elastic transformations of the anatomical structures within the head, we can use a rigid registration. Rigid registration further has the property that it is relatively stable and fast, compared to elastic registration, which certainly is a advantage in an interventional setting. We apply Mutual Information as registration method, as described by Maes et al. [12], because it performs very well on inter-modality registration, and does not need any a priori knowledge of the datasets. 3D-RA reconstructions may have a very high spatial resolution (a voxel can be as small as 0.1 mm), but tend to have a lot of noise in the dynamic range. Therefore the vessels, bones and sinuses are the only structures that are well visible, and can serve as landmarks. To reduce the sensibility to noise we use a limited number (16-32) of grey levels for the 3D-RA dataset.

A triangulated mesh of the segmented vessels is needed, to mix the vessels and the slab out of the anatomical volume. In order to obtain such a mesh, the second pre-processing step consists of the segmenting the vessels in the 3D-RA volume. This can be done by applying a simple threshold, due to the use of iodine contrast medium. It can be improved by using a more sophisticated algorithm instead of a threshold, as e.g. Bruijns proposes [13]. From the segmented volume a mesh is extracted (e.g. by applying the marching cubes algorithm [14]).

4. MIXING THE VESSELS AND THE SLAB

Mixing the vessels and the slab out of the anatomical volume form the first two passes of the proposed method. In the first pass, the triangulated mesh, representing the vessels, is rendered in the frame buffer. Simultaneously the depths of the triangles are written in the z-buffer. This can be efficiently implemented by using the standard functionality of the DirectX or OpenGL [15] API.

In the second pass, the slab is mixed into the scene using direct volume rendering. The direct volume rendering equation has to be evaluated for each ray. In our case, one ray for every pixel in the view port is defined. The volume rendering equation can be approximated by the following summation:

$$i = \sum_{n=0}^{N} \left(\alpha_n c_n \cdot \prod_{n'=0}^{n} (1 - \alpha_{n'}) \right) \quad (1)$$

whereby i denotes the resulting color of a ray, α_n the opacity of the volume at a given sample n, and c_n the color at the respective sample.

This summation can be broken down in N iterations over the so-called over operator [16], whereby the rays are traversed in a back to front order:

$$C_{n+1} = \alpha_n \cdot c_n + (1 - \alpha_n) \cdot C_n \quad (2)$$

Here C_n denotes the intermediate value for a ray. For Equation 2 standard alpha blending, offered by DirectX or OpenGL, can be used. A set of textured slices, containing the slab data, are then blended into each other, whereby the slab is sliced from back to front [17,18,19,20]. The intermediate results C_n are written in the frame buffer, where the triangulated mesh already is present. The registration matrix is applied to the position of the slices, which makes a resampling of the slab data to the grid of the 3D-RA data unnecessary, leading to a better image quality [3].

To actually mix the triangulated mesh and the direct volume rendering, we test the z-buffer at each iteration of the over operator. If the z-buffer test shows that, for this particular pixel, the position of the present sample of the ray is further away from the viewer than the triangle in the frame buffer, the frame buffer remains unchanged. The first sample lying closer to the viewer will take the present value of the frame buffer as input, which then actually is the color of the triangulated mesh at that position. In this way the color of the triangulated mesh is blended into the volume rendering equation at the appropriate place.

5. ADDING THE SILHOUETTE

The silhouette render technique we apply is based on the method described by Raskar and Cohen [21]. In order to render a silhouette, first the front faces (triangles with a normal pointing to the viewer) of the mesh are rendered to the z-buffer only. This can be achieved by drawing the triangles with a completely transparent color, or by switching the color mask off. Consequently the wire frame of the back faces (triangles with a normal pointing away from the viewer) of the mesh are rendered, but this time with a solid color (red in our case), a line thickness larger than 1 pixel (2 pixels in our case), and z-test enabled.

This process will lead to lines only being drawn where the front facing and back facing triangles meet, and thus to a silhouette of the mesh. Again the whole silhouette rendering can be easily implemented to employ the graphics hardware using either the DirectX or OpenGL API.

6. CLINICAL USE

The ease of interpretation of the rendered images is essential for the use in a minimally invasive intervention. The silhouette of the vessels offers a full representation of the vessel tree at the locations that otherwise would be hidden by the anatomical slab, without overloading the screen with information. The intersection of the slab and the vessels offer a morphologic assessment of the tissue surrounding the vessels, and allows for an accurate determination of the exact location of hemorrhages, arteriovenous malformations (AVM), thrombus, etc., which are visible in the CT or MR dataset, with respect to the vessels.

The slab can be moved, its width can be changed and its orientation can be rotated freely, to visualize different parts of the anatomical dataset. In this way the optimal view of a certain pathology can be determined. The GPU implementation of the rendering offers interactive speed throughout.

Silhouette fusion may be used as a visualization method in the following treatments: a) determination of the optimal position for intra-arterial particle injection in endovascular embolization of intracranial neoplastic tissue, b) determination of the AVM location prior to stereotactic radiation surgery, c) determination of the optimal position for intracranial stenting in cases where aneurysms are pressing on surrounding eloquent and motoric brain tissue, d) determination of the vessel portions to be embolized in e.g. hemorrhagic stroke, e) determination of the vessel segments where thrombolytic therapy should be applied in e.g. ischemic stroke or vascular vasospasms.

7. CONCLUSIONS

In this paper a method for the combined visualization of the cerebral blood vessels, segmented from 3D-RA datasets and datasets containing the surrounding anatomy, such as CT or MR has been presented. The method was especially targeted at the use in minimally invasive procedures, and distinguishes itself in the fact that it simultaneously allows the assessment of the spatial relationship of both datasets, and the complete representation of the vessel tree, without cluttering the resulting image with data.

The steps necessary to achieve this visualization have been described. There are two pre-processing steps: registration and obtaining a model of the segmented vessel in the 3D-RA dataset. The actual rendering is composed of three passes: rendering the vessels, rendering the slab into the existing scene, and drawing the silhouette of the vessels on top of the scene. It was indicated how these passes can be implemented to employ the possibilities of modern off-the-shelf graphic cards, allowing interactive manipulation, and therefore adding to the ease of use, as well as to the 3D perception of the data (depth from motion).

Further possible clinical applications have been identified, and it has been demonstrated how the presented visualization method can be employed in those applications.

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