Interactive and Intuitive Visualization of Small and Complex Vascular Structures in MR and CT

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Abstract

The spatial understanding of vascular information obtained with CT and MR is tremendously assisted by direct volume rendering since it provides semi-transparent views of the entire data giving insight to hidden structures. Ensuring a convenient diagnosis of complex vessel topology, we propose an approach based on 3D texture mapping which ensures interactive frame rates. The method proved to be very suitable for the visualization of intracranial aneurysms within CTA and MRA. Its full value is demonstrated by meaningful representations of the inner ear and of tiny vessels in the spinal channel obtained with a MR 3D-CISS sequence. Since a small portion of the whole data is often sufficient for a more detailed investigation, a new technique using interactive clipping of arbitrary geometry, as presented in [1], was evaluated. The integration into OpenInventor ensures intuitive manipulation of the volume and the clipping geometries. For further anatomical orientation and the comparison to DSA different registration procedures are applied.

1 Introduction

Different imaging modalities provide information about vascular structures and their diseases. There is DSA *(Digital Subtraction Angiography)* which produces 2D projection images of very high spatial and temporal resolution. In order to obtain 3D information, CTA (*Computed Tomography Angiography*) and MRA (*Magnetic Resonance Angiography*) are applied. As an advantage, MR techniques are minimal invasive with new scanning sequences like 3D–CISS *(Constructive Interference in the Steady State)* having the potential to access further information.

However, in clinical routine the analysis of the tomographic data is typically based on the inspection of single slice images. Since it is difficult to mentally reconstruct the available information to a correct model, volume visualization assists the understanding of complex vessel topology considerably. Other approaches which have been presented [2, 3, 4, 5] for the diagnosis of cerebrovascular diseases and the planning of neurosurgery rely on polygonal representations of the structures. However, this requires time–intensive initial segmentation of the data. Contrary to that, direct volume rendering proved to be a better approach [6]. Applying separate functions for color and opacity, groups of specific data entries are enhanced or suppressed making separate segmentation dispensable. The resulting semi–transparent views give insight to interior structures or show objects which are normally hidden.

An important issue for a convenient analysis is the interaction between man and machine with most of the presented systems having limited capabilities for the manipulation of the data. A very interesting approach to overcome these limitations was introduced by the “Virtual Workbench”, presented in [7]. A real 3D interface allows the user to reach directly into the virtual space. Contrary to that, we rely on a standard workstation set–up with 2D input devices.

After a survey of our visualization approach in section 2, interactive clipping of objects with arbitrary geometry is presented, which was previously published in [1]. Subsequently, in section 3 different registration techniques are outlined which assist to improve the anatomical orientation and allow for a comparison with DSA. Finally, a diversity of examples shows the value of our approach for the visualization of small and complex vascular structures.

2 Visualization

A convenient and fast understanding of complex vessel topology and very small vascular information requires the interactive adjustment of color and opacity values and the viewing direction. Therefore, an approach is applied based on 3D textures, as introduced by [8], which we expect to be available on PCs in the near future. After loading the data to texture memory, planes parallel to the image plane are clipped against the bounding box of the volume. Rendering is then performed by texturing the resulting polygons and blending them into the frame buffer.

Since planning of interventions also requires the knowledge of the size of objects and their relative location, convenient tools are available to specify trajectory paths and to measure the distance of points. Visually adjusting the size of simple geometric objects to the shape of structures within the 3D display provides information about the volumetric size. For a comprehensive investigation, structures that are presented very close, are shown in a second window from a more distant view point.

In case of pre–segmented data different tags are attached to the voxels of every sub–volume. During rendering these tags map the data entries to different ranges of a single color look–up table. This leads to different visualization of locally separate structures which cover the same range of original data values.

Due to the integration into the OpenInventor frame work, previously presented in [9], which is a 3D–toolkit built on top of OpenGL, a standardized interface is provided. Different 3D viewers, editors and manipulators ensure intuitive manipulation. Thereby, interactive and user–guided exploration of vascular structure is considerably supported.

Clip planes are very important features in order to access interior structures by suppressing visualization in a half–space. They are addressed separately and manipulated interactively with one of the manipulators of OpenInventor. However, it is often desirable to extract or suppress a box of arbitrary size and orientation. As presented by [1], it is possible to account for this by taking advantage of the OpenGL stencil and depth buffer. For each plane of the rendering procedure only those parts of the texture are considered which are inside the clip object. Thereby, this approach is independent of the applied geometry and allows interactive clipping of objects with arbitrary shape.

3 Registration

For better anatomical orientation and identification of critical structures like the optic nerve different registration procedures are available which allow to combine data of complementary information leading to more meaningful images. Since no fiducial markers are used, retrospective methods are applied which rely on anatomical structures.

In case of two 3D data sets a point based procedure provides an initial alignment by performing a least squares optimization of a set of corresponding anatomical landmarks. Subsequently, a more accurate solution is obtained with an approach based on mutual information which integrates registration into the process of visualization, as suggested in [10]. Similar to the technique used for direct volume rendering the method uses the imaging and texture mapping subsystem of graphics computers. Thereby, all trilinear interpolation operations are completely performed with hardware assisted 3D texture mapping. The histograms of the data sets which are necessary for the calculation of mutual information are obtained with different hardware accelerated imaging operations.

For the comparison with DSA (see Figure 1) a method was implemented which allows for the registration of 2D images and projection images of 3D data sets [11]. After distortion correction of the DSA images, starting values for the automatic registration procedure are determined. Therefore, corresponding 2D and 3D vessel locations are selected using three orthogonal MIP images along the main axes within the MRA data set. After performing a least squares fit of the corresponding vessel locations the final transformation is obtained by an automatic conjugate gradient optimization based on mutual information.

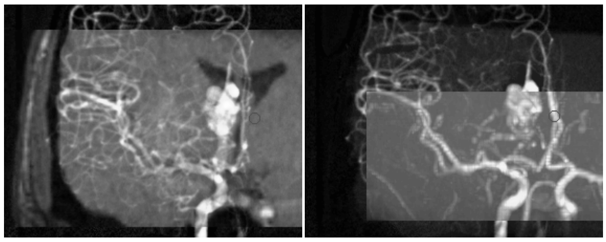

Figure 1. Comparison of vessel representation by blending DSA and MRA after registration: (left) DSA showing vessels including aneurysm and slice image of MRA — (right) DSA (darker) and maximum intensity projection of MRA (brighter).

4 Results and Discussion

All visualization was performed on an *Indigo² Maximum Impact* and a *SGI Onyx Reality Engine II.* Concerning the trilinear interpolations the underlying hardware of both workstations deliver the same order of magnitude of performance. The following examples demonstrate the value of our approach for the delineation of very small vascular structures:

- Figure 2 shows a spinal dural arteriovenous malformations *(dAVM)*. Direct volume rendering (e,f) of a MR scan using a 3D-CISS sequence visualizes the vessels in relation to the brain stem and the medulla oblongata. Due to the nature of the data (see slice image in g) a "tagged" volume was created after segmentation of the spinal marrow (black) and the tissue containing the vessel information (white). A more detailed description of the medical aspects is presented in [12].

- For the diagnosis of an incidental cerebral aneurysm (see Figure 3), registration of CTA and MR(T1) allows to identify the position of the lesion relative to the optic nerve. After applying pre–defined look–up tables for an initial delineation of the vessel structures, color and opacity values were adjusted interactively.
- Similar to vascular information in angiographic data structures of the inner ear (< 10 mm) are optimally delineated (cochlea (a) and the semi–lunar canals (b) in relation to the canal of the facial nerve).
- Figure 5 demonstrates the visualization of a MRA data set showing intracranial vessels and an aneurysm. In comparison to CTA, the applied MR methods are less invasive and allow clear inspection of leasions which are close to bone structures since they are not contained in the data. After applying an appropriate color look-up table a semi–transparent representation of the aneurysm allows to clearly analyse its relation to the adjacent vessels in a convenient way. A more detailed description of the medical aspects is presented in [13].
- In Figure 6 a sub–volume containing the essential vascular structures is extracted by applying a cuboid for the interactive clipping with arbitrary geometry.

The selection of an appropriate visualization method for a specific type of data mainly determines the diagnostic value of the resulting images. Direct volume rendering was the only approach to render dAVMs in MR 3D–CISS and the structures of the inner ear. Using a semi–transparent representation it produced most informative images for complex vessel topology in MR– and CT–angiography. Since the applied visualization approach does not include lighting effects, the selection of edge enhancing color look–up tables considerably enhances the perception of depth. Additionally, the ability of real–time image generation and the facilities of intuitive manipulation provided by the integration into OpenInventor contributed most to a convenient and fast analysis of the data.

5 Conclusion

An interactive and intuitive approach for the visualization of small and complex vascular structures was presented which effectively assists pre–operative planning. Using direct volume rendering based on 3D texture mapping intracranial aneurysms in MR– and CT–angiography are optimally presented for diagnosis. The presented results demonstrate the value of our approach which has an impact to improve the diagnosis of dAVMs.

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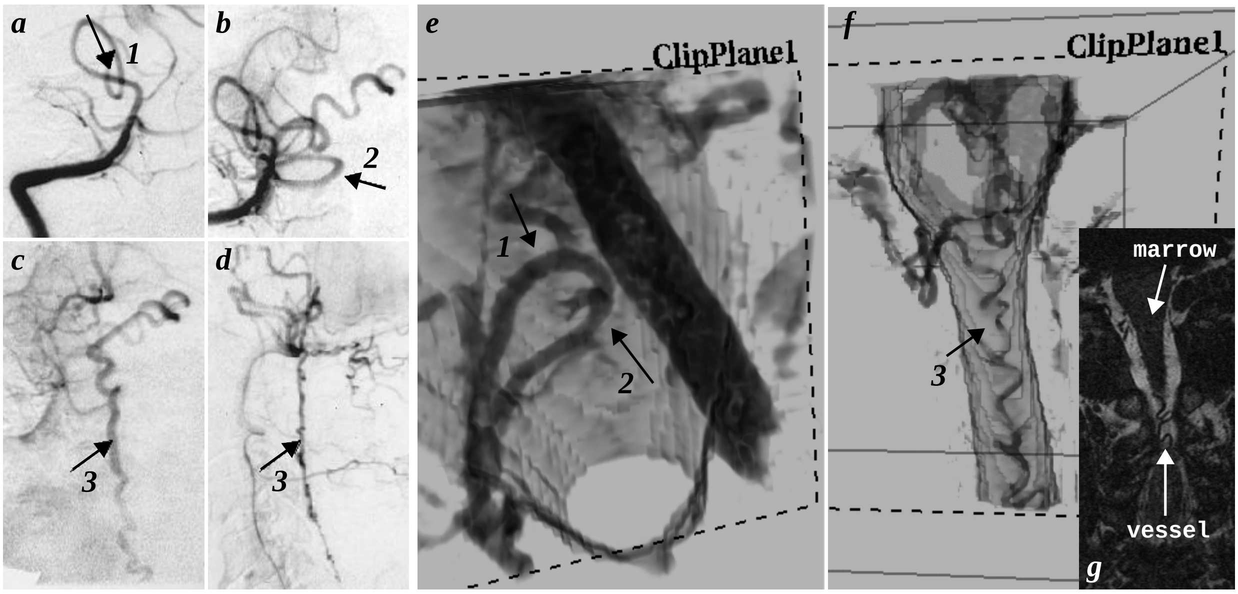

Figure 2. Spinal dural arteriovenous malformation (dAVM): DSA (a-d) — (e,f) direct volume rendering of a "tagged" MR 3D-CISS data set after segmentation of the marrow and the tissue containing the vessel information (arrows indicate corresponding landmarks).

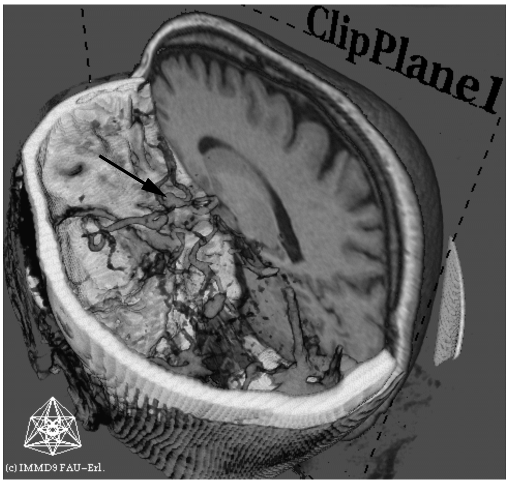

Figure 3. Fusion MR(T1) and CTA showing aneurysm.

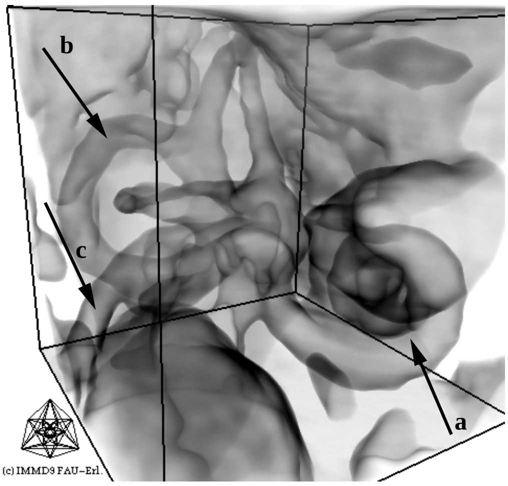

Figure 4. Structures of the inner ear within CT.

Figure 5. MRA showing aneurysm.

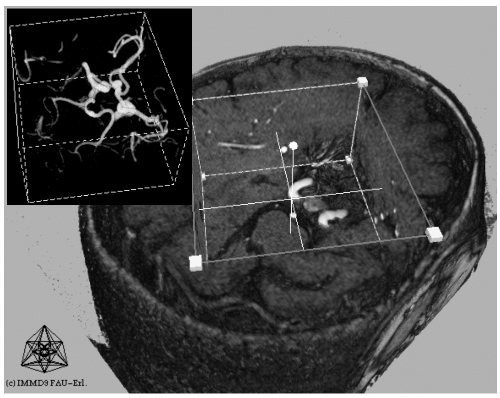

Figure 6. Interactive clipping with arbitrary geometry.