Standardized Analysis of Intracranial Aneurysms Using Digital Video Sequences

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Abstract. CT-angiography is a well established medical imaging technique for the detection, evaluation and therapy planning of intracranial aneurysms. Different 3D visualization algorithms such as maximum intensity projection, shaded surface display and direct volume rendering support the analysis of the resulting volumes. Despite the available flexibility, this general approach leads to almost unreproducible and patient specific results. They depend completely on the applied algorithm and the parameter setting chosen in a wide range. Therefore, the results are inapplicable for inter-patient or inter-study comparisons. As a solution to this problem, we suggest to make the visualization fully independent of any user interaction. In consequence the main focus of the presented work lies on standardization and automation which guarantees comparable 3D representations for the analysis of intracranial aneurysms. For this purpose, we introduce a web-based system providing digital video sequences based on automatically performed hardware accelerated direct volume rendering. Any preprocessing such as the setting of transfer functions and the placement of clip planes is performed according to a predefined protocol. In addition to an overview using the whole volume, every dataset is divided into four subvolumes supporting a detailed inspection of the vessels and their branches. Overall, the value of the system is demonstrated with several clinical examples.

Keywords: Visualization, Standardization, Automation

1 Introduction

Over the last decade CT-angiography (CTA) was established as one of the most important imaging techniques for the analysis of various vascular pathologies. For the immediate examination and fast detection of intracranial aneurysms CTA is a common approach. Depending on the size of the aneurysm the detection rate with CTA results to 85–95 % [1,2]. However, digital subtraction angiography (DSA) still represents the golden standard providing the highest spatial and temporal resolution.

In addition to the actual image acquisition strategy the subsequent post-processing of the datasets is of crucial importance for a valuable medical evaluation [3]. A common strategy in clinical routine is maximum intensity projection (MIP) as demonstrated in Fig. 1a. Along each ray of integration it considers only the voxel with the highest intensity value and projects its value onto the viewing plane. Contrary to its popularity based on

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its inherent robustness, MIP leads to inconsistent images missing any depth information. Another well established technique is shaded surface display (SSD) shown in Fig. 1b which generates iso-surface representations. Since only the first layer of voxels defined by a threshold is rendered along each ray of integration, efficient software based algorithms are applied. As a drawback of this approach any density information of the original data is lost.

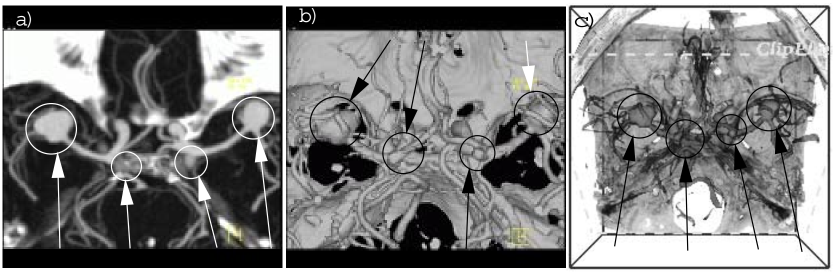

Fig. 1. Different visualization techniques of the same CTA dataset showing 4 aneurysms (→): a) maximum intensity projection b) shaded surface display and c) direct volume rendering

The most comprehensive 3D visualization technique is direct volume rendering (dVR) (see Fig. 1c). Following the image based strategy it considers the entire volume data by summing over all values along every ray of integration. Or, it projects every voxel onto the image plane applying the object based strategy. As a result, various software solutions have been suggested including ray casting [4] and shear warp factorization [5]. However, hardware supported approaches gained increasing attention achieving most impressive results [6,7]. Taking into account the size of medical image data and the required visualization quality, direct volume rendering based on 3D texture mapping [8,9,10] on reasonably scaled graphics computers represents an optimal approach for the analysis of intracranial aneurysms.

In general, modern interactive visualization environments provide a great variety of degrees of freedom ensuring high interactivity and flexibility. Among various rendering parameters this comprises mostly the definition of thresholds, the precise adjustment of transfer functions for color and opacity values, or simply the choice of a suitable visualization strategy. Aiming at optimized 3D representations supporting the evaluation of difficult cases, this process is very time-consuming. Overall, it requires comprehensive expertise even if predefined settings are provided. Furthermore, analyzing the data by rotating or zooming the volume in an efficient and time saving way is critical with respect to application in clinical routine. As a result, any inter-patient or inter-study comparisons are extremely difficult. To overcome these drawbacks, standardization of 3D visualization is an important issue. For this purpose we present a web-based fully automatic approach addressing the meaningful delineation and volume rendering of aneurysms based on CTA data and the generation of digital video sequences.

In section 2 the developed web-based approach is presented outlining technical features such as the web interface and security issues. To obtain standardized digital video sequences from automatic direct volume rendering of high quality and reproducibility, several procedures had to be developed. This comprises the placement of clip planes and the extraction of specified subvolumes for a closer inspection of risked locations. All these procedures are described in section 3. Further on, the scenario for the evaluation of our approach is presented in section 4 which also discusses the potential for clinical environments.

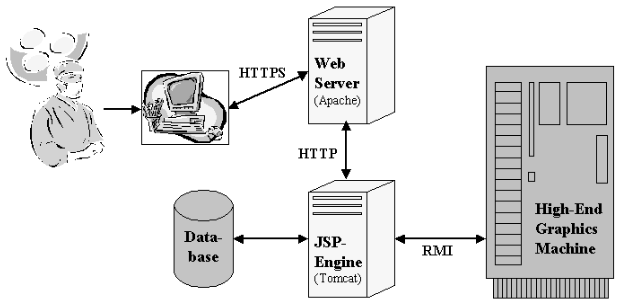

Fig. 2. Overview about the system architecture

2 System Architecture

The suggested approach was implemented as a web service. It supports clinical 3D analysis in generating standardized digital video sequences automatically via the Internet. In this section the underlying architecture as illustrated in Fig. 2 is briefly outlined which is described in detail in [11].

For the communication with the remote system a web-based user interface is provided which presents patient related data to the physician. At the beginning of a session it allows sending DICOM data via the Internet onto a high-end graphics computer. At the end of the automatic volume rendering it presents the generated videos for down load. JSP (Java Server Pages) technology is employed to transfer data and to create each HTML page dynamically. This technology offers easy handling, and is available for virtually any platform. Since the graphics server should only be responsible for the rendering, a different computer is employed to manage the web service. In order to communicate between these two computers and to launch different processes from one computer on the other one, Java RMI (Remote Method Invocation) is used.

Since medical data contain patient related information, it is of crucial importance to provide high security. Therefore, our system permits access only to registered users after login based on password verification. Furthermore, one is automatically logged out after a specific time period, if there was no communication in order to prohibit access of unauthorized persons. Ensuring safe transfer of the image data and any information to or from the web service encoding via HTTPS is used.

3 Algorithms

Our system includes several specialized algorithms which are essential for the automatic preprocessing and volume rendering of the applied CTA datasets. Thereby, these procedures perform three important tasks which physicians have to do in interactive environments. Firstly, the appropriate adjustment of transfer functions for color and opacity values to clearly delineate the target structures. Secondly, the detection of intracranial aneurysms. Thirdly, the transformation of the volume to visually access all relevant locations in a convenient way. Specifically, this refers to the definition of a patient specific flight path according to a predefined setting. In this context, the main focus lies in the creation of several subvolumes extracted from the original data. These subvolumes allow inspecting typical locations for the existence of aneurysms.

Subvolumes. The detection of intracranial aneurysms, especially small aneurysms, is a very difficult task. It depends on various factors such as the visualization technique, the experience of a physician and the amount of information inherent to the data. Important indications about single structures can be hidden by other structures like bones (in our case mainly the skull base) or other blood vessels. For this reason, it is important to restrict the volume of inspection. Additionally, one can focus on the specific locations since intracranial aneurysms often grow at branches of blood vessels. Nevertheless, it is important not to omit parts of the image data. Mainly, aneurysms can be found at the tip of the basilar artery, the left and right cerebral artery and at the communicating artery. The presented system supports a semi-automatic approach to define the position of these critical points. For this purpose, one has to specify the position of the clivus which is a bony structure lying centrally within the volume. It serves as a reference point. As a result of measurements performed by our clinical partners, the distance between the clivus and every single critical point was determined for several datasets and the mean value was calculated. These four values are used to specify the critical points. They also represent the centers of the subvolumes. Since the size of the subvolumes (60 mm in each dimension) is uniformly scaled for safety reasons in such a way that they overlap in any case it is not necessary to specify the exact position of the critical points.

Clip Planes. In case of the applied CTA scans important information about arteries is often hidden by veins located in the occipital part. Therefore, it is most helpful to virtually cut off these disturbing vessels from rendering by defining a clip plane which suppresses one half space form rendering. It is used within the original volume which gives an overview visualization about the whole situation and within the subvolume around the basilar artery. For the two remaining subvolumes its application is not necessary. According to our experiments the position of the plane is optimal if located 30 mm dorsal and parallel to the clivus (compare Fig.3).

Transfer Functions. After a reduction of the topological information using subvolumes and a clip plane, it is also necessary to reduce the structural information. In addition to the data inherent noise the information about various soft tissues enclosing the target structures prohibits a clear 3D representation of vascular structures. Using a transfer function for opacity values these structures are easily made transparent considering respective lower Hounsfield units. Further transfer functions for color values allow the effective accentuation of vessels and bone even if a light model is missing during rendering with 3D texture mapping [9]. In consequence, the locations of intracranial aneurysms are easily detected. In order to adjust a predefined setting of these transfer functions a lot

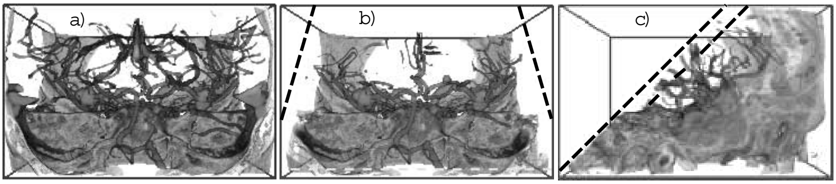

Fig. 3. The predefined clip plane: a) The whole volume data without any clip plane. It is not possible to look into the critical regions. b) The clip plane is 30mm in front of the clivus and rotated by $45°$. c) Using the clip plane the critical locations are visible

of expertise is required. Besides, this process remains time-consuming although the required effort was already reduced to a minimum using simple manipulation operations. As a solution to this drawback an approach was previously presented [12] which allows an automatic calculation. A reference dataset and a related optimized function are used to adapt the setting on-the-fly to a submitted volume.

Standardized Camera Path. An important part of the presented approach is the generation of standardized rendering sequences recorded to digital video files. In general, standardization is an essential issue for the diagnosis of intracranial aneurysms in order to achieve comparable results for medical studies. For this purpose, 50 patients were analyzed at the Division of Neuroradiology, University of Erlangen-Nuremberg and the typical approach of the data was studied. Thereby, the most common locations of intracranial aneurysms were defined which are the anterior communication arteries (ACA), the bifurcations of the medial cerebral arteries (MCA) and the internal carotid arteries (ICA). Based on this experience a camera path was developed taking into account essential directions of view as following:

1. Posterior overview — provides the best view for the vertebro-basilar system.
2. Lateral views — important for the analysis of the internal carotid arteries.
3. Multiple views — necessary in order to examine the medial cerebral arteries.

Concerning the entire dataset, the camera moves initially from posterior to anterior and then to left and right lateral. For a closer inspection, the volume is zoomed and the preceding movement to lateral views is repeated. Consecutively, the subvolumes are rendered with a circular flight of 360 degrees.

Rendering Process. Using the predefined camera paths, the actual visualization process is launched. Thereby, the volume rendering is performed with an application developed at the Universities of Erlangen-Nuremberg and Stuttgart. It is integrated in the OpenInventor class hierarchy and takes advantage of 3D texture mapping capabilities of graphics subsystems providing high frame rates and rendering quality [9].

In the beginning, details of the volume data extracted from the DICOM headers and the calculated coordinates of the clip plane described in section 3 are loaded. Then, the predefined setting of transfer functions are adapted to the volume data. Finally, five digital video sequences are generated, one for the entire volume and one for each of the four subvolumes.

During the rendering process the camera position is sampled in steps of small degrees along the predefined camera path. Following a circular path this results in a smooth movement. At each step the visualization tool renders the scene into pbuffer which is a special offscreen buffer. Then, its content is copied to a file. At the end, all images are automatically converted to a digital video of a user-defined format (e.g.: MPEG, AVI).

4 Results and Discussion

For the volume rendering a SGI Onyx Infinite Reality3 (2×R12000, 400 MHz) equipped with 1 GB of 3D texture memory was used. It provides large scale and fast trilinear interpolation capabilities. The actual web service was established on a standard Linux PC (AMD Athlon 1.2 GHz).

The described system was developed in cooperation with the Div. of Neuroradiology, Dept. of Neurosurgery of the University of Erlangen-Nuremberg. Two physician evaluated the system in terms of quality, speed and reliability. During the evaluation process datasets of 15 patients were examined. The important issue of theses tests was the visual detection of the intracranial aneurysms based on the resulted digital video sequences. All image data contained a total of 19 aneurysms which were detected previously with DSA by a different physician. In addition to the detection, it was also of major interest to obtain information about the shape and neck of the aneurysms.

As a result 18 of the 19 aneurysms were detected. One aneurysm of the internal cerebral artery was not detected since it was covered by bone structures. Another large aneurysm close to the skull base was detected but the definition of the neck was not possible. The remaining aneurysms located above the skull-base were analyzed recognized correctly with a better definition of the shape and neck in five cases when compared to DSA. Overall, the video sequences were of good diagnostic quality. The mean time of calculation including the transfer of the data and the automatic generation of video-sequences was about 60 minutes.

For the first time our approach allows for a reproducible 3D-visualization of intracranial vasculature making the time-consuming and individual manipulation of interactive visualization environments superfluous. Thus, the physician must not be familiar with specific manipulators and techniques of volume rendering in order to use this approach for the investigation of intracranial vessels. As a general result, the web service allows a user-independent and standardized visualization of constant quality. Beyond this, high-end graphics computers are now accessible for a much wider range of clinical institutions performing CTA examinations.

Our initial results indicate that aneurysms lying above the skull-base are accurately depicted while the visualization of aneurysms lying within the area of the skull-base is still problematic. Thus, further algorithms have to be developed in order to separate the blood vessels exactly from bone.

5 Conclusion and Future Work

The results of the investigations and the consequential conclusions confirm that the proposed approach is applicable in medical practice. The support for the physicians is fully acceptable. Also the depiction of the intracranial aneurysms were mostly of a higher quality than in the case of DSA. But the results show also the problems of our approach. In case of aneurysms which were above the skull base the results were satisfying. The problems are visible in case of aneurysms which involve the skull base. One technical solution for this problem is to remove the bone and to separate the blood vessels. Due to the partial volume effect a simple threshold-based elimination is insufficient. In this case more complicated approaches, e.g. combinations of region-based segmentation approaches and Watershed transformation to remove the partial volume effect are necessary. These approaches are subject to future work.

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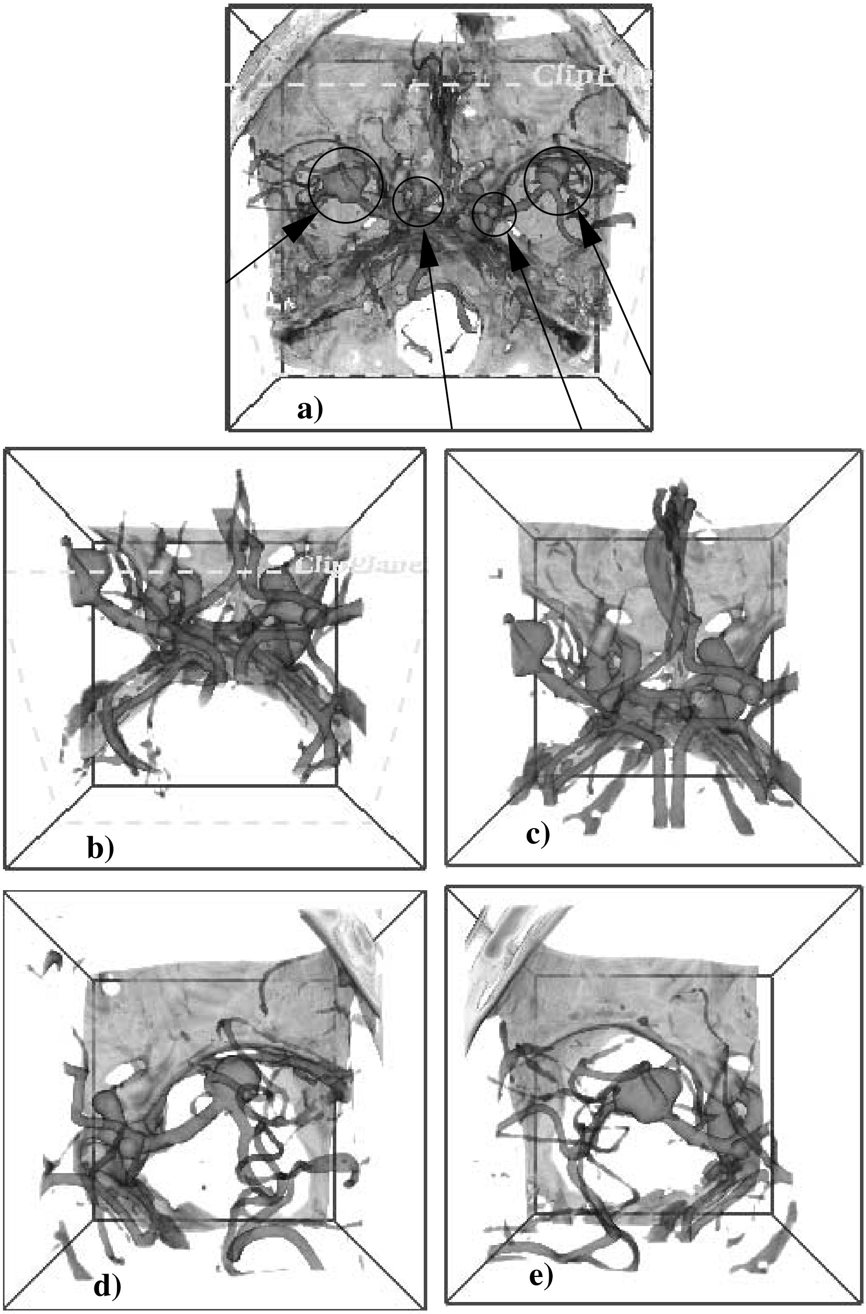

Fig. 4. The complete volume data with the corresponding sub volumes: Fig. a) shows the volume data, the marked positions demonstrates the recognizable intracranial aneurysms. The 4 subvolumes represents the regions around b) the internal carotid c) the anterior communication artery d) the left and e) the right medial cerebral artery.