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TECHNICAL REPORT

Smart Linking of 2D and 3D Views in Medical Applications

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Abstract

This paper presents two techniques for the linking of 2D and 3D views in medical applications. Hereby, the goal is a better integration of 3D volume visualization into the diagnostic workflow. Until now, the main obstacle for a good integration is the time-consuming process to adjust various parameters. The LiveSync interaction metaphor is a new concept to synchronize 2D slice views and 3D volumetric views of medical data sets. A single intuitive picking interaction on anatomical structures which are detected in 2D slices results in an automatically generated 3D view. To further improve the integration contextual picking is presented as a method for the interactive identification of contextual interest points within volumetric data. Our results demonstrate how these techniques improve the efficiency to generate diagnostically relevant images and how contextual interest points can, e.g., facilitate the highlighting of relevant structures.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Computer Graphics]: Methodology and Techniques Interaction Techniques; J.3 [Life and Medical Sciences]: Medical Information Systems

1 Introduction

Although, volume visualization algorithms have seen substantial improvements in quality, accuracy, and performance in recent years, their use is limited to few specific applications in clinical diagnosis. The dominant viewing mode of medical data for diagnosis is the investigation of 2D slice images. 3D visualizations are primarily used to get an overview of the anatomical structures. However, scrolling through slices becomes rather inefficient with an increasing amount of slices. Besides, there are still complicated cases where the diagnostic reading can be improved by using 3D visualization. Examples are tiny structures like vessels or pathologies like lung nodules or colon polyps. Linking different 2D and 3D representations of the data has the potential benefit to provide significant enhancements in efficiency.

This paper presents our recent efforts to tightly integrate 3D visualization into the diagnostic workflow [KBKG07, KBKG08, BKKG08, KBKG09]. The LiveSync interaction metaphor is a concept to synchronize 2D views and 3D views of medical data sets. In this approach the goal is to automatically generate a meaningful 3D view on a structure which is detected in a 2D slice. The synchronization is triggered by a simple picking action where the user moves the mouse over the structure of interest on the 2D slice and presses a hot-key. All rendering parameters to set up the 3D volumetric view are derived automatically and the clinician is provided with a synchronized 3D view instantly. A second approach is based on picking interactions which are directly performed on the volume rendered image. By taking contextual information into account which are automatically extracted from the DICOM (Digital Imaging and Communications in Medicine) images and the setup of the medical workstation this technique allows the interactive identification of interest points within volumetric data. The obtained positions can be utilized to highlight a structure in 2D views, to interactively calculate approximate centerlines of tubular objects, or to place labels at contextually-defined 3D positions.

2 The LiveSync Interaction Metaphor

The manual setup of a meaningful 3D view for structures detected in cross-sectional images is often a rather time-consuming task. Many parameters, such as camera position, clipping planes, or transfer function need to be adjusted by the user in order to get an expressive visualization. The whole process has to be performed repeatedly for each new structure of interest. LiveSync attempts to simplify this process by automatically generating good views for interactively picked structures in 2D slices. This functionality can by activated on demand by moving the mouse over the interesting structure and pressing a hot-key. Several heuristics are applied to set up all the needed parameters from this single interaction. Depending on the quality of the instantly generated result, small manual changes might be necessary to refine the 3D view by adjusting the view parameters

2.1 Viewpoint Selection

Previous approaches for automatic viewpoint selection for volumetric data mainly focused on the detection of globally optimal views under a given transfer function [BS05, TFTN05] or they concentrated on a specific application area such as angiography data sets [CQWZ06]. Our work attempts to find a good viewpoint for any structure of interest which is identified in the 2D slice view. In the presented system the factors which influence the choice of a good viewpoint include the shape of the structure of interest, its spatial relation with respect to surrounding objects, the viewpoint history, and a data-specific definition of preferred viewing directions. A spherical parameterization of the viewpoint quality for the various criteria is chosen to provide a compact representation. These viewing spheres are deformed in a way that high radial distances represent good viewpoint candidates. In the following, some details about the chosen input parameters are given:

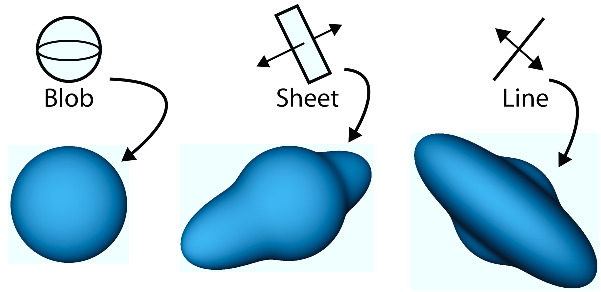

Figure 1: The viewing sphere which is generated for the local shape estimation is deformed according to the major volumetric extent of the structure.

Feature Shape: The local shape of the picked structure is an important factor for the viewpoint estimation. To extract information about the shape of the feature we combine a local segmentation based on an approach presented by Huang and Ma [HM03] with a principal component analysis of the identified member voxels. The metric of Westin et al. [WBKK97] is used to classify the feature as isotropic, planar, or linear, based on the obtained eigenvalues. Figure 1 illustrates how the corresponding viewing spheres are deformed based on this analysis. If the object has a volumetric extent (blob), then basically all viewpoints are of the same quality (left). For a planar structure (sheet) the viewpoints which are orthogonal to the sheet are favored (middle). If a tubular structure (line) is determined, the preferred viewpoints are aligned along a ring which is orthogonal to this line (right).

Feature Visibility: A criterion to estimate viewpoint quality is the visibility of the structure of interest. To determine if a certain viewpoint provides good visibility of the selected structure, rays are cast from the picked point and analyzed regarding occluding structures. Further the distance along the ray from the picked point to the exit position of the structure which is determined during the local segmentation is of relevance. Opacity is accumulated along the ray and an occlusion is detected as soon as a small opacity threshold is exceeded. The accumulation starts after the ray exited the structure of interest. More space between the picked feature and occluding structures is preferred as this allows more flexibility in the placement of a clipping plane. Figure 2 illustrates this process.

Viewpoint history: The last viewpoint is used as a parameter for the selection of the next viewpoint. This means that the system tries to find a good viewpoint close to the last one if this does not counteract the other parameters.

Patient orientation: Scanned medical data contain information about the patient's position and orientation. Taking into account knowledge about the performed procedure, a rough estimate of the preferred viewing directions is possible.

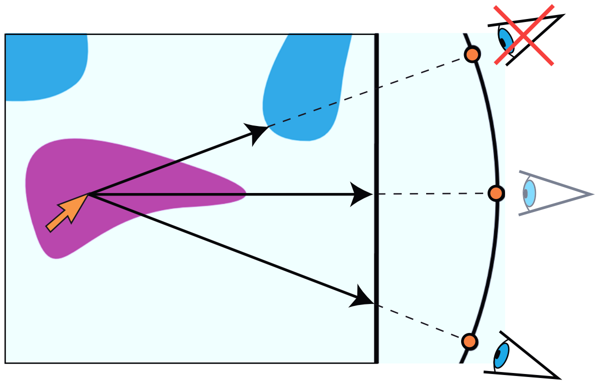

Figure 2: Starting from the picked position, visibility rays are cast to points which are equally distributed on the surface of the viewing sphere. Samples along the rays are analyzed to detect when it exits the structure of interest and at which position the object gets occluded by other structures.

As all these components are represented in a uniform parameterization, the individual deformed viewing spheres are weighed and combined to estimate a good overall viewpoint on the picked structure. The conceptual design of LiveSync is not limited to the presented input factors and can be easily extended to support different indicators for a good viewpoint.

2.2 Transfer Function Tuning

In volume rendering a transfer function maps data values to visual attributes such as colors and opacities. The manual setup of an appropriate transfer function is often a rather time-consuming and not very intuitive process and thus often too complex for real-world medical applications. Often medical workstations provide transfer function presets which are tailored for specific types of examinations. Usually in this context the transfer function is defined by a color look-up-table and a linear opacity ramp. Inspired by an approach presented by Huang and Ma [HM03] we take knowledge about the distribution of scalar values within the extracted object into account to fine-tune an existing ramp-like transfer function. This adjustment is based on statistical properties of the scalar values. An example is shown in Figure 3.

2.3 Clipping Strategies

Clipping planes play an important role to handle occlusions. Medical workstations typically provide view-aligned and object-aligned clipping planes. We use the results of the visibility calculation described in Section 2.1 to automatically set up either view-aligned or object-aligned clipping planes according to the preferences of the physician. Figure 3 illustrates how a view-aligned clipping plane is placed to clip away occluding structures.

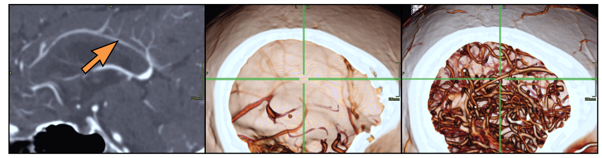

Figure 3: Automatic viewpoint selection, transfer function tuning, and clipping. Left: Picking a position on the slice. Middle: The structure of interest is not visible with the current setting of the opacity transfer function. Right: Automatically adjusted transfer function makes the vessel visible.

2.4 Results

We performed an informal evaluation of the proposed approach with an experienced radiology technician. She was asked to generate diagnostically relevant volume renderings of pathologies in different data sets. This task was first performed manually and then with the proposed interaction metaphor. Figure 4 shows an exemplary result for a polyp in the colon. The generation of the manual adjustments result (left) took about 3 minutes whereas our proposed method provided the result (right) instantly. For other pathologies such as lung nodules or aneurysms we obtained similar results. The conclusion of the evaluation was that the effort to localize pathologies diminished considerably when LiveSync was used. In most cases the instantly provided views were already very good and only small manual adjustments had to be performed to obtain an optimal image. The overall impression of the LiveSync feature during the evaluation was that it provides an excellent additional functionality. This opinion is also supported by radiologists getting demonstrations of the LiveSync functionality.

3 Contextual Picking of Volumetric Structures

Often highly specialized methods are used to detect various anatomical structures within volumetric data. For instance vessel enhancement filters based on eigenvalue analysis of the Hessian matrix have been proposed, e.g.,

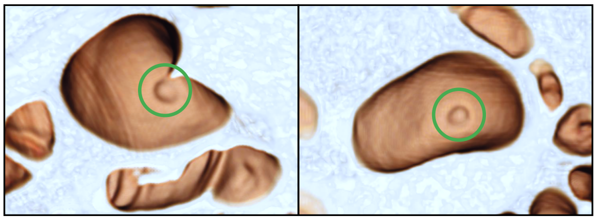

Figure 4: A manually adjusted image (left) to get a good view on the colon vs. a LiveSync-generated image (right).

by Frangi et al. [FNVV98]. We present contextual picking as a generalized system to contextually identify volumetric interest points. It is initiated by positioning the mouse cursor on the 3D view and pressing a hot-key. Our method is based on abstract definitions of anatomical structures in a knowledge base and on an initialization step.

3.1 Knowledge Base

A knowledge base consists of a ray-profile library and contextual profiles. The ray-profile library holds ray-profile samples (intensities and gradient magnitudes) of various anatomical structures. Figure 5 shows ray-profile samples for several structures. A contextual profile for a certain structure bundles the needed information to react on a contextual picking operation. In the XML format it describes the following components: The type of the structure, a list of keywords, minimal and maximal extent of a structure, a representative mean ray profile built from the samples in the ray-profile library, and the default reaction to a picking operation. We provide an easy-to-use interface for the generation of ray-profile samples. They are added to the library by a domain expert.This step is not visible to the physician who just uses the contextual picking.

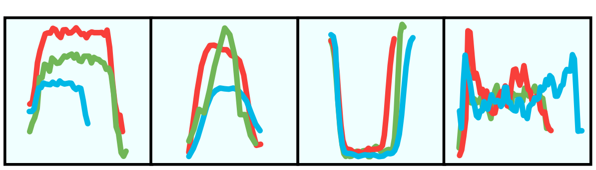

Figure 5: Three ray-profile samples are shown for the aorta, a vessel, the airway, and a vertebra (from left to right).

3.2 Initialization

Typically for a certain type of examination only a small number of structures is relevant for the diagnosis. For instance in vascular examinations veins and arteries are of special interest whereas in an orthopedic examination the spine and bones are more important structures. An initialization step is performed whenever a new data set is loaded into the workstation. The DICOM header as well as the current setup of the medical workstation is analyzed to extract the relevant meta data for selecting the applicable contextual profiles.

3.3 Contextual Picking Action

After a single or several contextual profiles are automatically selected, the picking can be performed directly on the 3D view and the system provides an instant feedback. For each contextual picking, the current ray profile is analyzed to detect close similarities in the selected contextual profiles. This analysis is done by a profile-matching algorithm which evaluates a cost function to measure the degree of similarity. Based on the outcome of this matching the respective action is taken. Three actions have been implemented so far. The default action is the highlighting of the center of the picked anatomical structure in MPR views. Further, contextual picking is integrated into a spine labeling system to demonstrate its potential to place labels at meaningful 3D positions. Finally the system allows the calculation of approximate centerlines of picked tubular structures.

3.4 Results

In Figure 6 the contextual picking is illustrated for a head CT data set. When the position indicated by the arrow is picked in the 3D view (left), the contextual airway profile gives the best response and the corresponding position is highlighted in a 2D slice view (right). All contextual picking-related computations are performed interactively and thus it is possible to trace along structures to, e.g., calculate approximate centerlines interactively.

4 Conclusion

In this paper we presented two techniques to incorporate 3D visualization into the diagnostic workflow. Both are integrated into a real-world medical workstation which is under development by our collaborating company partner. For the LiveSync interaction metaphor we got

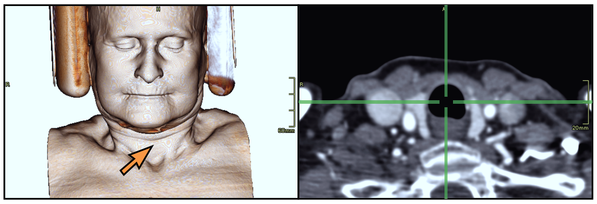

Figure 6: Contextual picking of the airway (left). The identified 3D position is used to provide a meaningful MPR view (right).

a very positive feedback from an informal evaluation. There it was shown that our method has the potential to considerably improve the efficiency of diagnosis in clinical routine. This opinion is also supported by radiologists getting demonstrations of the LiveSync functionality. One comment was that this is exactly the right way to encourage more radiologists to use and to benefit from 3D visualizations.

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