Real-Time Virtual Endoscopy for MR-Guided Aortic Interventions

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Introduction

Moving from traditional diagnostic MR imaging to MR-guided interventions requires not only specialized pulse sequences, but also novel means of visualization and navigation. Current real-time MR visualization techniques include 3D views of single or multiple 2D slices, projection images and volume rendering (alpha blending/MIP mapping) [1]. For aortic interventions, e.g. stent placement, it would be beneficial for the physician to be able to appreciate the entire area of interest, as opposed to one slice or projection. In addition to giving the physician a better understanding of the instrument position, this technique could also help to detect complications such as accidental perforation of the vessel wall.

We propose an interactive, segmentation-based approach to render a virtual endoscopic view of the aorta in real-time. A 3D/4D model is generated and then continuously updated based on the acquired MR images. The model construction, updating and rendering is integrated in the Interactive Frontend (IFE), a graphical scanner control and automation framework [2].

Methods

The IFE framework in conjunction with its underlying real-time pulse sequence provides the functionality to acquire and process scanned MR images in real-time and to change scan plane and other imaging parameters on the fly. To create the geometric model used for rendering the 3D view, scanning is started at an initial plane which is manually placed at the distal end of the abdominal aorta, perpendicular to the luminal axis. The circular aorta cross section is then located and its contour detected by a specialized image segmentation module based on the level-set framework [3]. After adding the contour points to the model, the scan plane is successively advanced along the vessel. The scan plane is also automatically rotated to remain perpendicular to the luminal axis. This is done by locally estimating the direction of the main axis based on the current model.

The geometric model of the aorta is implemented as a cylindrical 3D mesh defined by vertices corresponding to points on the inner vessel wall. Points from consecutive slices are connected by a triangular mesh. Rendering is done inside the IFE using OpenInventor/OpenGL graphics primitives, giving the user flexibility to navigate the model and view it both from the outside and inside. In addition to viewing the model, image slices can be transparently superimposed on the 3D scene to provide a multimodal view.

The expansion and contraction of the aorta over the course of the cardiac cycle is taken into account either by performing the acquisition only during a defined window of the ECG or by creating multiple models for discrete phases of the heart cycle. The latter approach leads to a more accurate 4D model that can be visualized in sync with the ECG.

During a procedure, after the model is created, position and shape of the aorta can change due to respiration, patient movement or deformations caused by the intervention itself, e.g. stent deployment or accidental puncture of the wall. To take those effects into account the model has to be updated continuously by analyzing real-time scans in the area of interest, which can be defined either manually or by analyzing the current field of view in the 3D scene view. Segmentation is performed on the incoming images and the geometrical aorta model is updated accordingly.

Typical real-time parameters for model updating with a TrueFISP sequence are TR/TE/FL 1.7-2.7/0.85-1.35/50-55, GRAPPA rate 2 acceleration, in plane resolution 1.5-2.4 mm, slice thickness 8 mm, and 15-20 frames/sec during free breathing on a Siemens 1.5T Espree scanner. Thus the window for processing each frame is around 50 msec, including segmentation, model updating and rendering.

Segmentation and model building was tested offline on four 4D datasets. They were acquired as a stack of 15-27 overlapping axial TrueFISP cine series (8-40 images per heart cycle) with TE/TR/FL 1.48/2.96/70, matrix from 88x128 to 138x192, reconstructed pixel size 1.77x1.77 mm, slice thickness 6 mm, overlap 2 mm, accelerated with GRAPPA rate 2, acquired during breathhold on a Siemens 1.5T Espree scanner. Scanner control was simulated by cutting out MPR planes from the 4D datasets corresponding to the predicted scan position and orientation.

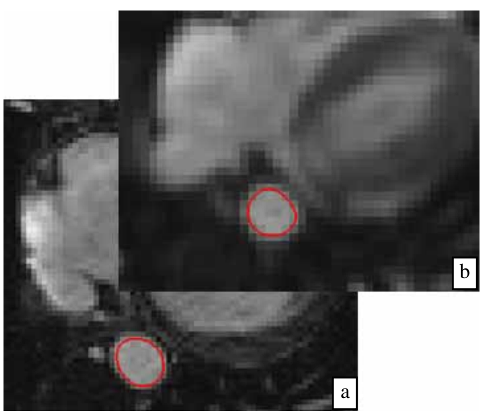

Figure 1: Segmented contour at different resolutions

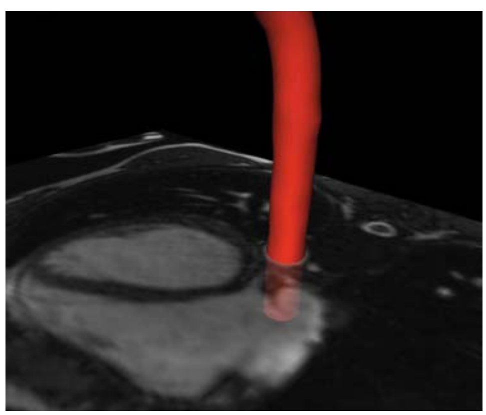

Figure 2: Aorta 3D model outside view

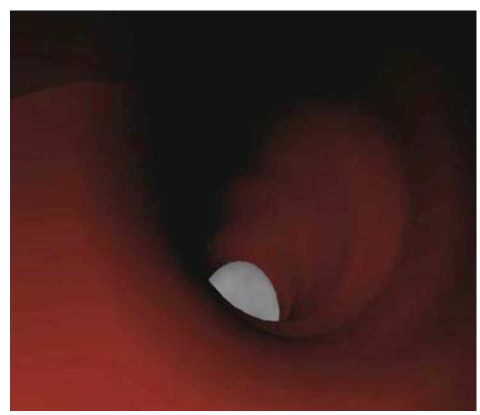

Figure 3: Virtual endoscopic view

Results

Segmentation time for each slice was less than 1 msec, making it suitable for real-time usage. An example contour extracted by the algorithm on a high resolution image for model generation is shown in Figure 1a, while an example contour on a real time image for model update is shown in Figure 1b. Segmentation accuracy by visual inspection was good in both high resolution and real time images. The resulting 4D model, one for each phase of the heart cycle, gave a good impression of the morphology of the vessel as well as its expansion and contraction over the course of a cardiac cycle. Two views of one of the models are shown in Figure 2 and Figure 3.

Discussion

We propose a novel approach to viewing and navigating scanned MR data during the intervention by creating and rendering a 4D geometrical model of the targeted anatomy. Integrated in a real-time scanner control framework this method may give the physician a better overview of the region of interest and help assess potential complications. Future work on the system will include real-time rendering of an active catheter in the scene, and validation of the approach with *in vivo* studies.

References

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