Real-Time 3D Visualization of the Heart

J. Y. Cheng[1], J. M. Santos[1,2], and J. M. Pauly[1]
[1]Electrical Engineering, Stanford University, Stanford, CA, United States, [2]HeartVista, Inc., Los Altos, CA, United States

Introduction: Cardiac procedures, such as atrial fibrillation (AF) therapy, are limited by a lack of guidance visualization. This leads to difficulty in performing the treatment with accuracy and efficiency, which results in lengthy procedure times in excess of 3 hrs. Currently, visualization tools used in AF include 3D modeling of the patient's heart prior to the therapy or real-time 2D fluoroscopy. These approaches do not give immediate real-time visual feedback or provide the amount of information available in MR (e.g. electric current, blood flow). We focus on improving the procedure through 3D MR visualization [1-2]. For proper guidance, we allow the user to switch between a high frame rate (~45 fps) 2D acquisition [3] and a slower depth-informative 3D scan. We present a practical solution to improve AF therapy through real-time 3D visual feedback.

Methods: Real-time 3D cardiac imaging requires improvement in (1) data acquisition and (2) image display. The data acquisition and visualization were implemented in the real-time MR system, RTHawk [4], on a 1.5 T GE Signa EXCITE scanner using Kitware's Visualization Toolkit. The system allowed real-time scan control (over parameters such as location and orientation) to provide a way to response to the developed visualization.

(1) To obtain a 3D dataset fast enough to avoid motion blurring from the heart, a multi-slice spiral sequence was used. We limited the number of slices to 3-5 to yield enough depth information while keeping the frame rate high. The 4 interleave spiral sequence had a resolution of 2x2 mm^2, a FOV of 20 cm, and TE/TR of 3.84/22.32 ms yielding 44.8 slices/s with a sliding window. The T1 weighted slices were acquired with a slice thickness of 5 mm and a separation of 5 mm.

(2) For computation efficiency and proper depth perception, the atrial wall was extracted from the reconstructed images (Fig. 1) and rendered as polygons using a marching cube algorithm [5]. A transparent slice was rendered on top of the surface to assess accuracy of the rendering and to provide more information about the volume.

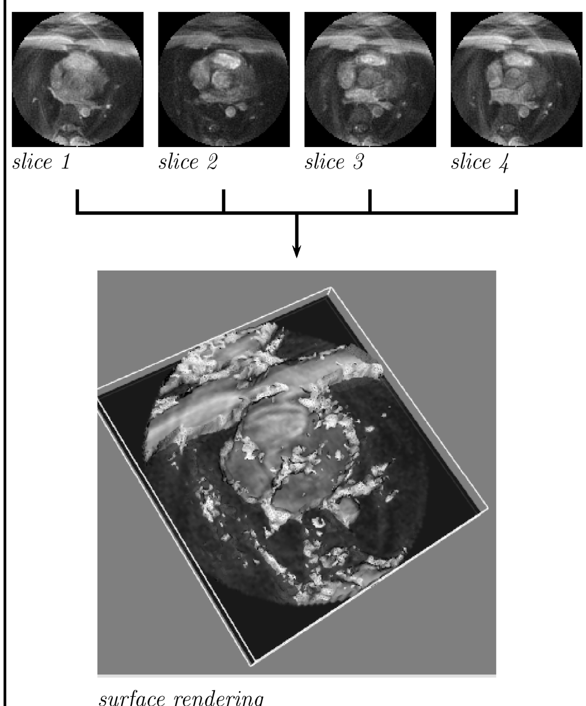

Figure 1: Four slices were obtained, segmented, and rendered as polygons in real-time. A transparent 2D image was superimposed onto the surface rendering to aid visualization.

Results and Discussion: The use of a multi-slice sequence and a 3D slab sequence was explored. However, given the 3D slab acquisition rate, motion blurring may be a significant problem. Therefore, a multi-slice sequence was favored, as each slice is coherent but portrays a slightly different time step. This results in a 89.30 ms time difference between each slice (if a whole slice is acquired before the next). Different schemes can be applied to increase the rate. For example, slice acquisition can be interleaved and the slices can be reconstructed using a sliding window. The main limitation regarding the acquisition was that all slices must have the same intensity level. This makes the tissue segmentation simple and quick.

The visualization provides a way to give the operator depth information using the acquired images. In Fig. 2, the developed 3D display was compared to the standard slice display. The curvature of the atrial wall in z can be readily visualized as compared to the case of viewing the slices in 2D. The surface rendering can also be freely rotated and enlarged to provide more depth. Other visualization techniques such as maximum-intensity-projection could be used, but the surface rendering method has a faster computation time which is required to keep up with the high data rate. It also creates a simpler model to highlight other MR-available information such as blood flow or catheter location.

Noise and aliasing contributed to degradation of the rendering quality. Streaking artifacts in the images translated to improper segmentation of the heart wall, as seen in the extraneous surface rendering around the heart (Fig. 1). As long as the signal intensity of the streaking is low enough or outside the area of interest, the rendering quality does not suffer. Also, the marching cube algorithm and the interpolation function used for the surface rendering allow us to decrease the resolution. Current resolution is 2x2x5 mm^3, but it can be lowered slightly while taking note that the atrial wall is only 2 mm thick.

In the T1 weighted images in both Figs. 1 & 2, the outer atrial wall was rendered due to the high signal intensity from the fat around the heart. However, for uses in interventional guidance in the heart, the surface of interest is the inner atrial wall. The use of a multi-slice SSFP sequence will be explored in the future to render this inner wall.

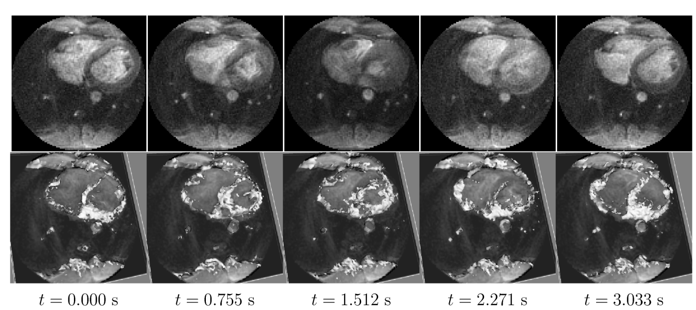

Figure 2: A series of time sequential scans were acquired for the heart in real-time. The spiral multi-slice sequence (4 slices) was used to obtain the data axially. In the bottom row, the 3D visualization of the same acquisition is shown. For comparison, the 2nd slice is displayed as a 2D image in the top row.

Conclusion: Real-time surface rendering along with a transparent 2D image provides a practical means of improving interventional guidance by incorporating depth perception.

References: [1] Bomans et al, MRI 1991. [2] Gutman et al, JCMR, 2002. [3] Nayak et al, MRM, 2004. [4] Santos et al, IEEE EMBS 2, 2004. [5] Lorenson et al, Computer Graphics, 1987. [Acknowledgement: NIH R21 EB007715.]