Real-Time 3D MRI with Random Undersampling Trajectories to Visualize Endovascular Catheters and Contrast Inflow

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Introduction: Real-time magnetic resonance (MR) imaging has been proposed as a method for device tracking and visualization by several research groups [1-3]. MR imaging has several advantages over the gold standard X-ray imaging, including: 1) Superior contrast between soft tissues, 2) potential for oblique 3D imaging, and 3) absence of ionizing radiation. Challenges with real-time MR imaging include design of fast acquisitions and efficient processing, which has led to most real-time MR implementations to be strictly 2D, or bi-planar rather than 3D. Several new methods have been proposed for reducing image acquisition time through undersampling, and in addition reconstruct images from the undersampled data. Many modern reconstructions are non-linear and thus very computationally intensive and do not lend well for real-time applications. Undersampling which creates incoherent aliasing can be performed at the penalty of increased apparent noise in images, and with compressed sensing type reconstructions, this noise level can be reduced but at the expense of computational demand [5]. It is our hypothesis that we can perform fast imaging with random undersampling to visualize contrast inflow and gadolinium filled catheters at a higher frame rate. In this study we designed a hardware configuration and software application for fast MR image reconstruction and viewed the result on the MR console. We then timed the application imaging reconstructions at various volume sizes and report the results. Random undersampling trajectories that result in incoherent aliasing are used to accelerate the 3D acquisition by factors of 2× and 4×, but only a linear transform (fast Fourier transform) is used for reconstruction to maintain low latency.

Table 1 – Hardware Configuration and Software Configuration

Component	Hardware	Software	Package
CPU	3.4 GHz 8 Core Intel i7	OS	OpenSUSE
RAM	8 GB 1866 MHz DDR3	Libraries	Qt 4.7
GPU	NVIDIA GTX 570		FFTW [4]
Hard Drive	Intel 510 SSD 120 GB		VTK

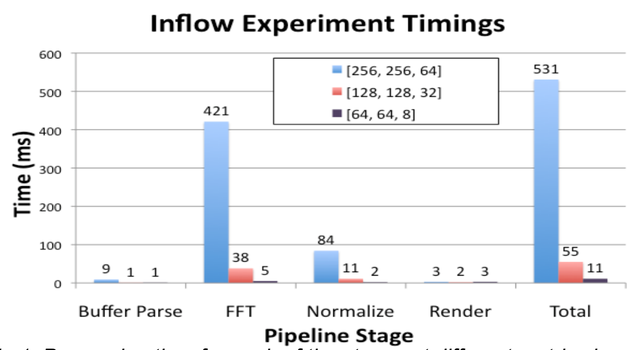

Fig 1: Processing time for each of the stages at different matrix sizes

Methods: Experiments were performed with a 3 T MR scanner (Discovery MR 750, General Electrical Healthcare, Wisconsin, USA). A hardware solution was assembled and a software application was written to perform the real-time imaging (Table 1). The application was run on the scanner console computer via X11 display. Random undersampling trajectories were generated with a compressed sensing style probability density function [5]. A 3D spoiled gradient recalled echo (SPGR) sequence was modified to perform the random undersampling. An aortic arch flow phantom was used to simulate catheter navigation and contrast agent injections. The raw volume data was acquired and processed in real-time for several matrix acquisition sizes and the time required to run each reconstruction stage was measured.

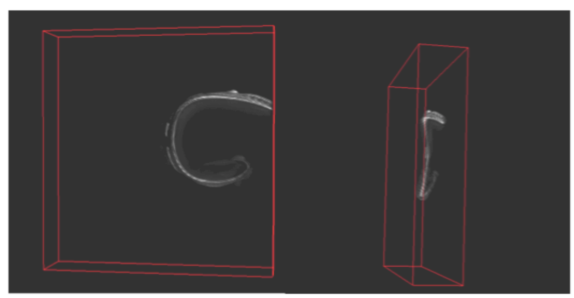
Fig 2: Catheter and guidewire pair visualized with 2x acceleration.

Results: The undersampling was found to be effective with a 20% central zone sampling scheme, *i.e.*, 20% of the center was acquired. Processing times of the stages are shown in Fig 1, processing times are much below respective acquisition times even with acceleration. Images of a catheter/guidewire combo are shown in Fig 2 at two separate angles demonstrating the ability to localize a device at different viewpoints. Example images of a contrast agent injection are shown in Fig 3.

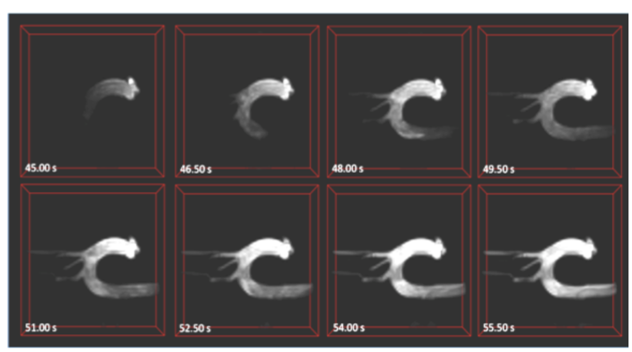

Fig 3: Contrast agent inflow through anthropomorphic phantom. Eight temporal phases are shown 1.5 s apart, for a 64x64x8 matrix acquisition.

Discussion: Real-time MR imaging is fundamentally limited by the underlying physics and acquisition. Random undersampling trajectories can improve imaging speeds while maintaining high computational efficiency. We demonstrate here a method of fast image reconstruction for real-time applications, where feedback may be required for the operator. The timing of processing stages gives a state-of-the-art lower bound for image reconstruction speed of rectilinear acquisitions. The results demonstrated are here are pre-clinical, our future endeavor will be to demonstrate application of this system in a large animal model.

References:

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