Online Real-Time Visualization of an Active Catheter Using Compressed Sensing in Interventional MRI

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Introduction: In interventional MRI, it is crucial to visualize catheter devices in real time. Compressed sensing (CS) has been recently proposed as a promising approach to accelerate MR imaging and data acquisition of sparse objects [1]. Images obtained from active catheters have been considered to be inherently sparse due to their high contrast-to-noise ratio and suppressed background intensity [2,3]. Thus this application is ideally suitable for increasing the frame rate for visualization with CS. However, current literature reports on this topic are limited to date to offline simulation studies, and true real-time visualization is hindered due to the bottleneck of time-consuming non-linear iterative CS image reconstruction. In this work the feasibility of using an online CS-framework for the application of catheter visualization was explored. An undersampled CS MR acquisition scheme and an efficient CS image reconstruction algorithm were integrated into an interactive online real-time pulse sequence.

Methods: *Image Acquisition*: Three acquisition schemes with one full sampling (RF=1) and two random undersampling masks (RF = 2 and 4) along the phase encoding direction were designed and applied to a 2D interactive real-time sequence (Figure 1). Variable density masks were used to sample center of the k-space with more coverage than the peripheral regions.

Image reconstruction: An efficient CS image reconstruction algorithm called Total Variation Based Compressed MRI (TVCMRI) [4] was adapted and implemented into the image reconstruction system (ICE – Image Calculation System, Siemens Healthcare). Based on an offline simulation, TVCMRI offered faster convergence speed with fewer iterations compared to other algorithms while preserving details of the object structure.

Online Study: A phantom study was carried out on a 3T MR scanner (MAGNETOM Trio a Tim System, Siemens Healthcare, Erlangen, Germany) to test the integrated CS acquisition and online reconstruction framework for visualizing active catheters. A thick slice (slice thickness = 100 mm) was acquired to achieve an effect similar to projection imaging. A single channel of a custom built electrophysiology catheter (SurgiVision, Inc., Irvine, CA) was turned on for imaging (micro coil closest to the catheter tip). Catheter images without (RF = 1) and with (RF = 2 and 4) random undersampling were acquired separately with a 2D SSFP sequence. The imaging parameters were: matrix size 256×256, FOV 300×300 mm^2, slice thickness 100 mm, TE/TR = 2.4/4.8 ms, bandwidth = 558 Hz/pixel, flip angle = 70º. Standard Fourier transform reconstruction and TVCMRI reconstruction were used for the fully sampled and CS sampled cases, respectively.

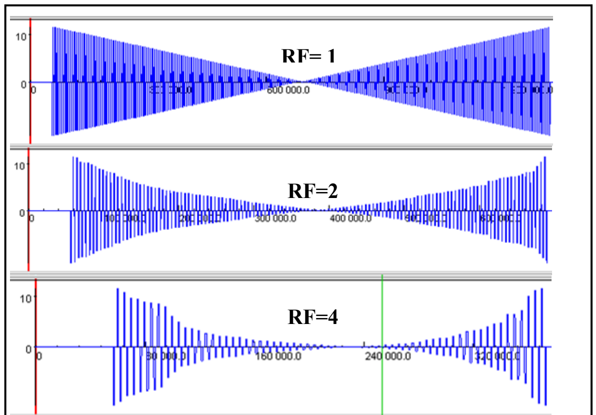

Figure 1. Acquisition schemes of the pulse sequence in phase encoding directions (256,128 and 64 lines respectively).

reduction factor (RF)	1	2	4
acquisition time (ms)	1200	600	400
frame rate (fps)	0.83	1.67	3.33
online image reconstruction time (ms)	1.1	310.0	353.1

Table 1: Comparison of acquisition time, frame rate and online image reconstruction time among different reduction factors.

Results: Table 1 compares the acquisition time and frame rates for the different reduction factors. In addition, the online image reconstruction time in the scanner is listed. The online reconstruction time by standard FT reconstruction was on the order of a millisecond for a 256×256 dataset, while the reconstruction by TVCMRI took several hundreds of milliseconds. Although the online CS reconstruction time was significantly longer compared to a standard FT reconstruction, the CS reconstruction was still faster than the acquisition rate for all reduction factors. Figure 2 shows an example of online reconstructed images of a moving catheter (~ 5 cm/s) with reduction factors of 2 compared to the fully sampled image series.

Discussion and Conclusion: In this work, we presented a feasibility study on the use of CS for online real-time catheter visualization. The results from our study illustrate that a framework of online real-time CS acquisition and reconstruction can be successfully established, resulting in frame rates sufficient for real-time visualization of a moving catheter with typical velocity. Future work includes incorporating partial Fourier and parallel imaging into the sequence and supporting multi-channel acquisition which will enable the visualization of multiple micro coils along the catheter.

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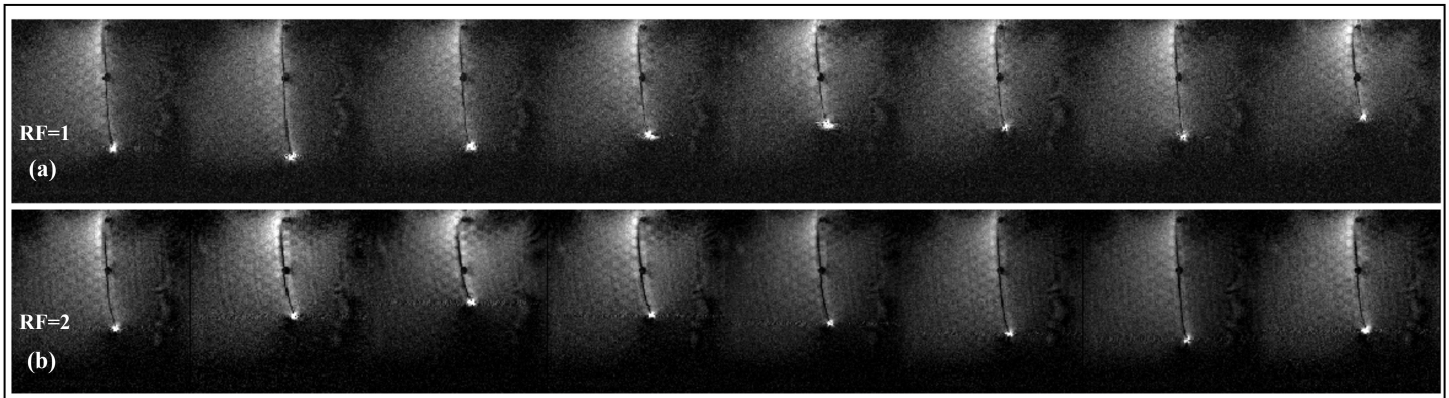

Figure 2: An example of online reconstructed image series of a moving catheter fully sampled (a) and acquired using a random undersampling with reduction factor of 2 (b). Note that the images were acquired in two imaging sessions so the relative catheter positions are not expected to be identical.