Compressed Sensing for Highly Accelerated 3D Visualization of 19F-Catheters

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Introduction

Tracking and visualization of interventional devices (such as catheters) is an essential prerequisite in MR-guided interventions. In particular, the visualization of the length of the catheter is important in cardiac catheterization to prevent the formation of undesired loops. A number of approaches for visualizing devices have been developed, including both passive and active techniques. [1]. However, these methods are either associated with safety concerns or suffer from insufficient, direction-dependent contrast as well as long response times. A promising alternative approach for visualization of interventional devices is the use of 19F MRI offering an RF safe modality with direction-independent contrast using commercially available catheters [2]. However, temporal resolution is poor, when acquiring 3D image information of the full length of the catheter. Recently, a method for true 3D visualization of interventional devices [3] using Compressed Sensing (CS) [4] was introduced, exploiting the inherently sparse signal of active catheters.

The present work assesses the potential of accelerated 19F-MR imaging of catheters filled with Perfluoro-15-Crown-5-Ether ($C_{10}F_{20}O_5$) [5], combining the advantages of a safe catheter design with accelerated 3D imaging employing CS.

Materials and Methods

Perfluoro-15-Crown-5-Ether has one resonance frequency (Figure 1) which maximizes signal-to-noise ratio (SNR) and prevents chemical shift artifacts. The compound's safety profile has been indicated for applications in humans [5].

Three-dimensional data of a passive catheter of 10 cm length and 2.5 mm lumen diameter filled with Perfluoro-15-Crown-5-Ether (Exfluor, USA) were acquired on a 3T MR system (Achieva, Philips Healthcare, Best, The Netherlands) using a dynamic single-shot TFE sequence (voxel size 2 mm^3 isotropic, acquisition matrix 140x108x75, receive BW 2451 Hz). The catheter was moved along a bent tube (Ø 4mm) placed in an Agar phantom. An experimental transmit/receive surface coil (14x14 cm^2) was used for 19F imaging.

Random undersampling in the two phase encoding directions with total undersampling factors of 25, 49, 74, 99, 123, 147 and 170 was retrospectively applied and data were reconstructed using a constrained CS algorithm [3]. Instead of using the noise level as termination criterion as in conventional CS, the length of the catheter was incorporated to control cessation of the iterative reconstruction procedure. In addition, the reconstruction window was confined to a volume around the current catheter position thereby reducing the search space in reconstruction. The reconstruction window was updated with every time frame reconstructed. The radius of the window was set according to the amount of dislocation expected from frame to frame. The number of voxels the catheter intersects was determined from the known length of the device and defined the minimum number of iterations plus a 10% safety margin for the iterative reconstruction algorithm. To assess reconstruction quality, the root-mean-square (RMS) error, cross-correlation and the number of correctly reconstructed points were determined relative to the fully sampled ground-truth data.

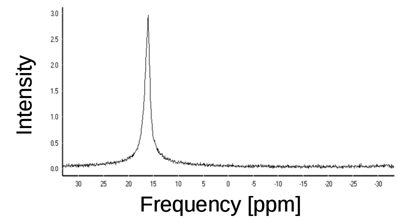

Figure 1: *Spectrum of Perfluoro-15-Crown-5-Ether* has one resonance frequency which maximizes SNR and prevents chemical shift artifacts.

Results

Figure 2 compares RMS errors, cross-correlation of reconstructions of a catheter, oriented in phase encoding direction, for increasing undersampling factors and two levels of base SNR (3 signal averages mimicking improved 19F detection hardware). The maximum number of iterations was set to 60. Figure 3 shows maximum intensity projections of the reconstructed images.

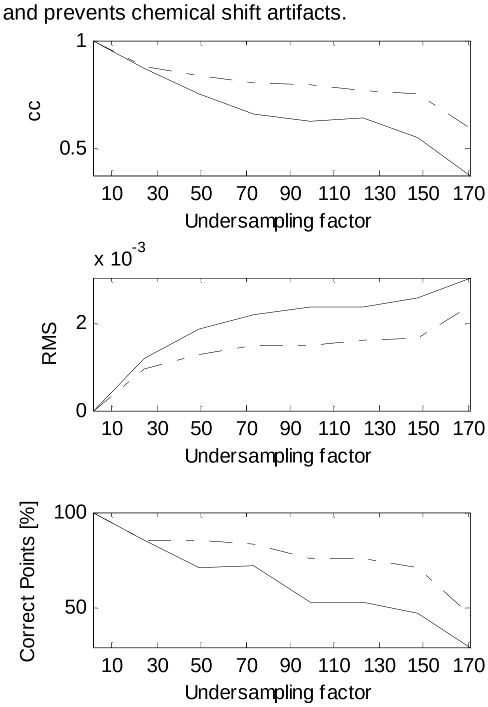

Figure 2: *Performance of CS reconstruction.* Cross-correlation (upper), RMS (middle) and number of correctly reconstructed points (lower) of the reconstructed images from different undersampling factors. Solid line: single acquisition; dashed line: 3 signal averages.

Discussion and Conclusion

The simulations presented demonstrate that image quality of CS reconstructed images decreases slowly with increasing undersampling while the catheter outline remains detectable up to undersampling factors of 123 and 170 for single and three-average acquisitions, respectively. With the experimental setup, undersampling factors of greater than 120 were possible corresponding to update rates of about 9 frames per second. Due to limitations in setting RF power and the center frequency of excitation, three signal averages were acquired to account for the experimental shortcoming. By using optimized hardware and sequence parameters this issue can be addressed and even higher frame rates may be possible in the future. This makes 19F-based catheter imaging employing CS a promising approach to accelerate 3D catheter visualization for improved device navigation.

Acknowledgements

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Reference

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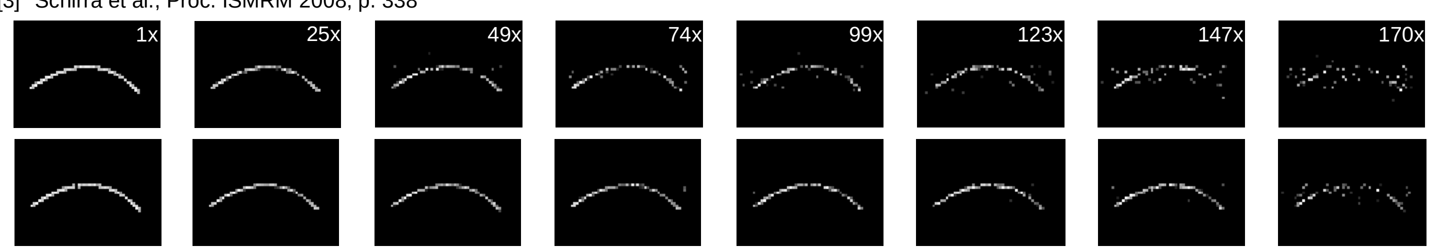

Figure 3: *19F-Catheter image reconstruction using CS.* Maximum intensity projections of a epresentative time frame reconstructed from data with increasing undersampling from a single average acquisition (upper row) and three signal average data (lower row).