Constrained Compressed Sensing for fast 3D Visualization of Active Catheters

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Introduction

Fast visualization of catheters in 3D is indispensable for safe and convenient navigation in MR-guided interventions. With standard dynamic 3D imaging methods sufficient spatial resolution is difficult to achieve at the required temporal rates. The advent of MR-safe guidewires [1] holds great promise for operating active devices without hazardous heating effects in-vivo. With respect to accelerated imaging, active devices lend themselves well to undersampling methods given their confined sensitivity volume. Methods such as Compressed Sensing (CS) [2] are ideally suited to exploit the image sparseness inherent to images acquired with active catheter antennae.

While CS allows for fast data acquisition times, its iterative reconstruction algorithms are time-expensive. Thus, the number of iterations has to be as low as possible in order to meet the real-time requirements for catheter tracking.

In this work, the feasibility of using CS for accelerating 3D imaging of active catheters is investigated. Dedicated constraints are introduced, taking into account the known catheter length and the catheter position, in order to keep the computational burden of the reconstruction step to a minimum.

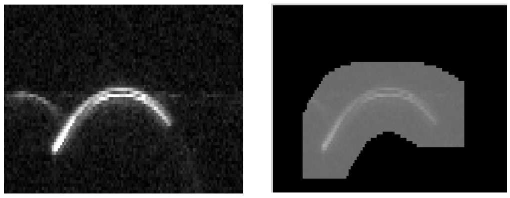

Figure 1: *Left: Reconstruction based on fully sampled data. Right: Windowing limits the search space in CS reconstruction (gray).*

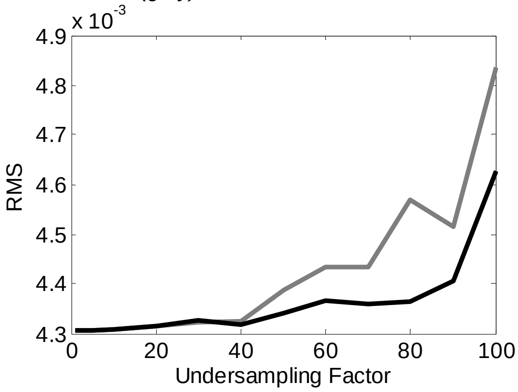

Figure 2: *Quality measure using RMS. Windowing (black) improves the quality of the reconstruction in comparison to unwindowed reconstruction (gray).*

Materials and Methods

Three-dimensional data of an active catheter consisting of a single resonant loop of 10 cm length were acquired on a 1.5T Philips Achieva system (Philips Medical Systems, Best, The Netherlands) using isotropic image resolution of 1.5 mm^3 (168x102x188 voxels). The catheter was moved in a bent tube (Ø 4mm), placed in an Agar phantom (T1~1100 ms).

Random undersampling of the phase encodes up to an undersampling factor of 100 was applied and data were reconstructed using the Orthogonal Matching Pursuit (OMP) 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 (Figure 1). 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 50% safety margin for the OMP algorithm. To assess reconstruction quality the root-mean-square (RMS) error was determined relative the fully sampled ground-truth data.

Results

Figure 2 compares RMS errors for increasing undersampling factors using unwindowed CS (gray curve) versus windowed CS reconstructions (black curve). In both cases, the maximum number of iterations was set to 200. It can be seen that RMS increases only moderately up to a factor 90. Beyond 90-fold undersampling image quality starts degrading significantly.

Discussion and Conclusion

CS allows for high undersampling factors rendering real-time acquisition possible. Knowledge about position and geometry of the object to be recovered can be used to establish constraints for signal recovery. Applying a reconstruction window improves RMS, yet the critical acceleration factor remains similar compared to the unwindowed reconstruction.

The proposed constraints lead to a minimal number of iterations in OMP yielding reconstruction times on order of one second on a Matlab implementation. In addition, confining the search space improves reconstruction accuracy as reflected in the RMS error measures.

Code optimization and parallel processing are subject to ongoing investigations to further speed up reconstruction.

References

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[3] Tropp and Gilbert, “Signal recovery from random measurements via Orthogonal Matching Pursuit”, unpublished Manuscript, 2005

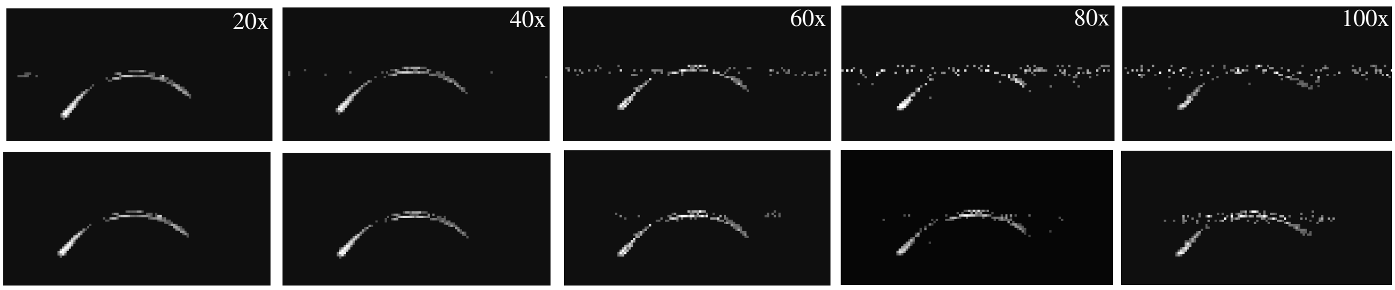

Figure 3: *Reconstructions (maximum intensity projections) from undersampled data with different undersampling factors (left to right). Unwindowed reconstruction with 200 iterations (upper row). Windowed reconstruction with 200 iterations (lower row).*