A Framework for 3D Visualization of Active Catheters using Compressed Sensing

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Introduction

A crucial requirement in MR-guided interventions is the visualization of catheter devices in real-time. However, true three-dimensional visualization of the full length of catheters has hitherto been impossible given scan time constraints.

Compressed Sensing (CS) has recently been proposed as a method to accelerate MR imaging of sparse objects [1]. Images acquired with active interventional devices [2] exhibit a high contrast-to-noise ratio and are inherently sparse therefore rendering CS ideally suited for accelerating data acquisition (Fig. 1).

We propose a framework for the visualization of active catheters in 3D employing CS to gain high undersampling factors making real-time applications feasible. Constraints are introduced taking into account prior knowledge of catheter geometry and catheter motion over time to improve and accelerate image reconstruction. The potential of the method is demonstrated using computer simulations and phantom experiments.

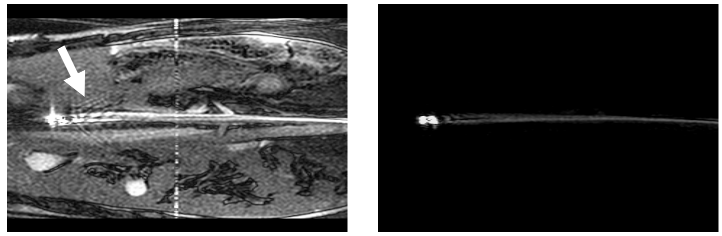

Figure 1: *An active guidewire in a pig model (left). Data acquired with the antenna of the interventional device leads to an image of high sparsity due to the sharply localised sensitivity profile (right).*

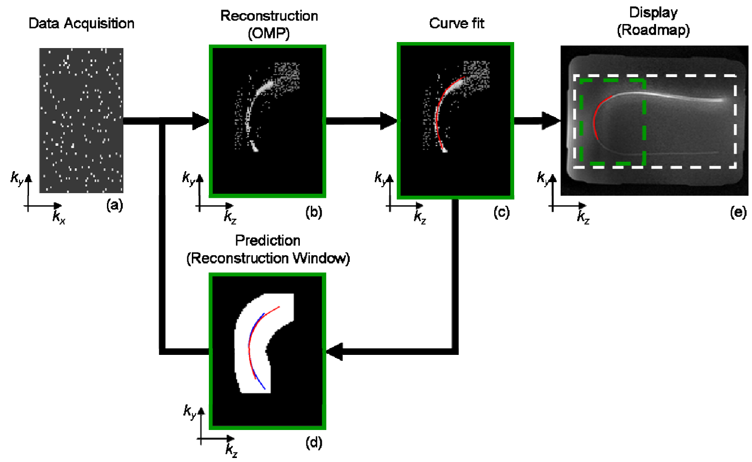

Figure 2: *Framework for 3D catheter visualization. Randomly undersampled data (a) are reconstructed using OMP (b). A constrained curve fit is used to extract the catheter center line (c) which is then used to define a reconstruction mask for the subsequent time frame (d). The current curvature of the catheter (red) is overlayed on a pre-acquired roadmap (d) and used for deriving the reconstruction window for the next time frame (e, white area).*

Methods

The framework is shown in Figure 2, which consists of 4 different parts:

Data acquisition

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. The catheter was advanced in a bent tube (Ø 4mm), placed in a Gd-doped Agar phantom (T_1~1100 ms), and image data were taken at several increments of catheter shift.

Data reconstruction

Random undersampling in 2 phase encoding directions (Fig. 2a) was applied with various undersampling factors and data were reconstructed using the Orthogonal Matching Pursuit (OMP) algorithm (Fig. 2b) [3]. Image reconstruction was parallelized and distributed to several processors of a computing grid to ensure short response times.

To reduce the number of iterations in the OMP algorithm, a mask around the current catheter position was defined and updated with every frame.

Curve fit

The curvature of the current catheter position was derived by applying a constrained curve fit to the reconstructed image points taking the length of the catheter into account (Fig. 2c). The mask was defined as the volume around the catheter center line using a radius of 13 mm (Fig. 2d). The radius was chosen according to the maximum catheter displacement expected between successive time frames.

Display

The center line of the catheter was used for visualization on a pre-acquired roadmap (Fig. 2e).

Results

Image reconstructions from 85-fold undersampled data of three exemplary time frames with the catheter center line overlay are demonstrated in Fig. 3a-c. Corresponding roadmaps are shown in Fig. 3d-f. The center line of the catheter extracted from highly undersampled data corresponded well with the underlying geometry with positional errors on the order of the image resolution. Reconstruction times per frame were cut by a factor of 92 using a parallelized Matlab implementation.

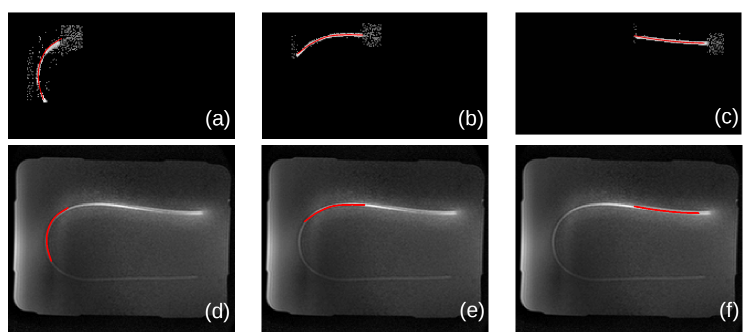

Figure 3: *Catheter tracking. Reconstructions of exemplary time frames with center line overlay (red) (a-c). Corresponding roadmap frames (d-f).*

Discussion

The proposed framework holds great potential to facilitate 3D visualization of active catheters at high frame rates. Parallelization and confining the reconstruction window have been proposed to reduce relatively long reconstruction time down to acceptable values.

References

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