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Passive Magnetic Resonance Catheter Tracking with Spatial Wavelet and Temporal Constraints

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Introduction: Images of endovascular devices have historically been captured with real time x-ray imaging. MR has several advantages for endovascular device tracking with MR imaging, including: 1) superior soft tissue contrast, 2) ability to perform 3D imaging, and 3) the absence of ionizing radiation. There are two general approaches for MR catheter tracking, either actively, where MR signal is measured from the catheter, or passively, where gadolinium contrast agent is used to enhance the catheter in images. The acquisition time required to fully sample the image volume at the resolution to see a catheter is much too long for tracking purposes, and for this reason acceleration is required. Frame rates of 4 to 5 Hz are required to freeze physiological motion in the thoracic cavity during tracking [1,2]. High frame rates are readily achievable with 2D imaging [1]; highly limited slice coverage or poor slice resolution catheter detection. With a TR constrained to values >2.5 ms by stimulation limits on modern gradient systems, and a desire to acquire a 64×64×16 acquisition matrix, an acceleration of >12× is desired. Compressed sensing (CS) experiments have demonstrated high levels of acceleration with active tracking experiments, and for dynamic contrast enhanced bolus passage tracking, up to factors of >36× [6]. [3,4]. Our experience with passive catheter tracking in initial 2D imaging suggests that compressed sensing will be highly effective [1,5]. In this work, we perform passive MR catheter tracking in a phantom, with undersampling of 12.2× in order to obtain full-image frame rates of 4.7 Hz. Undersampled images are reconstructed from an image model with L_1-norm-based penalties promoting sparsity in the wavelet domain, spatial-temporal finite difference domain, and the difference from a fully sampled reference image.

Methods: Data were acquired with a 3 T MR scanner (Discovery MR 750, General Electrical Healthcare, Waukesha, WI). An SPGR sequence was used for catheter tracking with flip/TE/TR of 14^0/1.1 ms/2.5 ms, and a matrix acquisition size of 64×64×16. The sequence was modified to prospectively undersample using a probability density function (Fig 1a). A polyethylene catheter was used inside an aortic arch phantom (Elastrat Sàrl, Geneva, Switzerland), and filled with 4% gadolinium contrast agent (Magnevist; Berlex Canada, Pointe-Claire, QC). Fig 1b shows an example of the phase encode lines that are collected for one time frame. Images were reconstructed by minimizing the cost function,

$$\min_{m} \left(\left\| Fm - y \right\|_2^2 + \lambda_1 \left\| \Psi m \right\|_1 + \lambda_2 \left\| \bar{m} - m \right\|_1 + \lambda_3 \left\| \mathrm{TV} m \right\|_1 \right)$$

where F denotes the Fourier operator, Ψ is the spatial wavelet operator, $m, \bar{m}$ are the image and temporally averaged image, and TV is the total variation operator. Additional rendering was performed with T_2*-weighted roadmap images for catheter overlay using the visualization toolkit (VTK).

Results: The constrained maximum intensity projection (MIP) reconstructions generated as the endovascular catheter is being withdrawn from the phantom (Fig 2) illustrates the high temporal frame-rate, enabling clear depiction of catheter motion without evidence of temporal blurring that results from the constrained reconstruction. Fig 3 shows a rendering of the catheter superimposed on the acquired roadmap image. The same temporal frame at multiple orientations is shown demonstrating an advantage of 3D tracking.

Discussion: We were able to prospectively accelerate catheter tracking images by a factor of 12.2×, allowing a temporal resolution >4 Hz. Strategies to limiting the number of iterations, or the number of images used in the temporal average would reduce latency, the current computational requirement of using the conjugate gradient to iteratively minimize the cost function limits the real time applicability. Nonetheless, this work demonstrates that the L_1 reconstruction techniques are much desired for 3D MR catheter tracking.

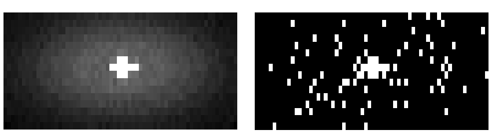

Figure 1: Probability density function of the sampling scheme (left) and an example sampling trajectory (right).

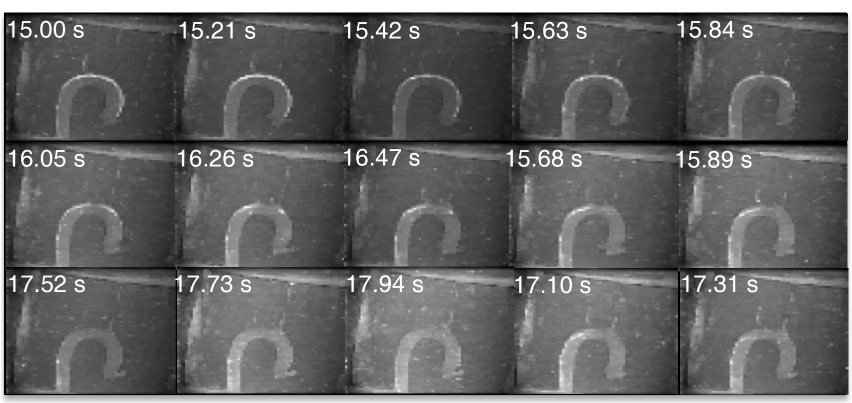

Figure 2: Images reconstructed with cost fucntion. MIP in the 16 Point direction. A temporal frame rate of 4.7 Hz while the catheter is being withdrawn.

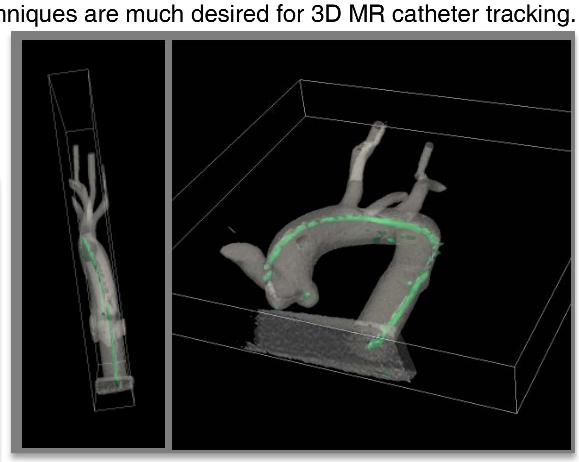

Figure 3: 3D visualization overlay by means of VTK visualization. The roadmap image catheter is outlined with green inside the phantom is rendered with the outer transparent iso-surfance and the arch. Multiple orientations are achievable from each frame as the data is being collected in 3D.

References:

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