3D MRI-guided Passive Catheter Tracking and Visualization using HYPR-based Techniques

O. Unal[1,2], J. Velikina[1,2], and C. M. Mistretta[1,2]
[1]Department of Medical Physics, University of Wisconsin, Madison, WI, United States, [2]Department of Radiology, University of Wisconsin, Madison, WI, United States

INTRODUCTION

Catheter tracking and visualization require both good spatial and temporal resolution. Achieving simultaneously both high temporal and spatial resolution is extremely difficult with current methods that use Cartesian k-space acquisition employing phase encoding. To date, passive device tracking and visualization techniques have typically been limited to two dimensions [**1-2**]. This is somewhat unfortunate since one of the major advantages of MRI over X-ray is the ease in which 3D multiplanar imaging can be accomplished. In addition, 2-dimensional catheter tracking and visualization techniques do not convey information about motion in the projection direction, nullifying this major advantage. To overcome these limitations, we need novel solutions. Recently developed novel reconstruction technique called Prior Information Constraint Compressed Sensing (PICCS) [**3**], which takes advantage of both compressed sensing and spatio-temporal correlations of images in a time series, when used in combination with radial or radial/Cartesian acquisition (stack-of-stars) MR acquisition techniques, allows improved temporal and spatial resolution than previously attainable without compromising signal-to-noise ratio (SNR). This technique is therefore well-suited for 3D MRI-guided passive tracking and visualization of therapeutic devices such as catheters. The objective of this study was to evaluate *in vitro* and *in vivo* performance of PICCS-based MR techniques to passively track and visualize catheters filled with Gd-DTPA or coated with MR-visible coatings [**4**].

MATERIALS AND METHODS

Images were reconstructed using both the standard filtered backprojection (FBP) and PICCS techniques. In catheter tracking and visualization, the major change from one time frame to another is the movement of the catheter through the vasculature while the anatomy itself remains basically unchanged. Thus, if we have a complete delineation of the anatomy from prior images, then the prior knowledge can be utilized to constrain the image reconstruction for a specific time frame in a series of time-resolved images, which leads to the PICCS technique. The choice of the objective function greatly depends on the particular application and the kind of images one expects to reconstruct. Typical choices for the measure of sparsity are the l_1 norm of the image or the l_1 norm of the gradient of the image. The former is defined as the sum of absolute values of all pixels comprising the image and reflects image sparsity in the most intuitive way. The l_1 norm of the gradient image is also known as the total variation (TV) of the image. Images were reconstructed iteratively by solving the following objective function subject to data consistency condition utilizing a conjugate gradient method. A 3D hybrid radial/Cartesian (stack-of-stars) MR imaging technique was implemented and used for the passive tracking and visualization of catheters on a 1.5 T scanner using 6 F catheters filled with Gd-DTPA. For each subset of interleaved radial acquisition in the kx-ky plane, a series of kz partitions are acquired [**5**]. Typically, 6-10 partitions with 36-60 mm slab thickness, and RBW = ±62.5 kHz, 256 X 4-8 projections per partition are continuously acquired.

RESULTS AND DISCUSSION

Figure 1 demonstrates how the choice of the objective function affects the reconstructed image quality. These 256x256 images of a catheter in a phantom were reconstructed from a severely undersampled stack-of-stars acquisition (16 projections only) using the new PICCS reconstruction technique developed since last submission. This corresponds to an undersampling factor of 25 relative to the Nyquist sampling criterion. As expected, for such a high undersampling factor, the FBP image (a) contains significant streak artifacts that would prevent a clinician, or an automated program, from identifying the location of the catheter tip accurately. However, since the desired image is very sparse with the only significant signal coming from the catheter itself, l_1 norm minimization produces an image (b) in which the streaks and background are greatly suppressed and the catheter location is unambiguous. This example illustrates why it is important to choose a proper objective function corresponding to the imaging task since using the TV minimization approach for the same dataset produces an image (c) of inferior quality.

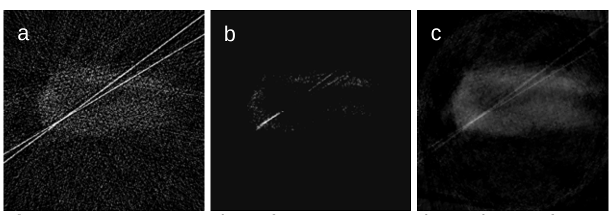

Figure 1: *Reconstruction of a 256x256 catheter image from 16 projections using a) FBP, b) l_1 norm minimization, and c) TV minimization.*

Typically, a gridding scheme is combined with FFT to reconstruct images obtained with non-Cartesian MR acquisitions. However, for a highly undersampled dataset, the interpolation errors will eventually become intolerable and cause severe image artifacts. Therefore, it is important to implement reconstruction algorithms without gridding. In this work, we converted radial projections into Radon space using projection-slice theorem. After this conversion, standard algebraic reconstruction technique (ART) used in x-ray CT [**6**] was employed to reconstruct images. The minimization of the objective function was implemented using the deepest descendent method. The quality of the reconstructed images also depends on the choice of the sparsifying transform. In this work, the sparsity of the image was further improved by subtracting the target image from the prior image reconstructed from the union of several interleaved radial datasets acquired at different time frames. In this work, we also demonstrated that other sparsifying transform such as gradient or Laplacian of the image may not be appropriate for passive tracking and visualization of catheters.

CONCLUSIONS

Our preliminary results suggest that the PICCS technique for passive tracking and visualization of catheters is feasible and offers relatively streak-free images with high SNR for undersampling factors of 25 or more.

REFERENCES

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