A View-sharing Compressed Sensing Technique for 3D Catheter Visualization from Bi-planar Views

C. O. Schirra[1], S. Weiss[2], S. Krueger[2], R. Razavi[1], S. Kozerke[1,3], and T. Schaeffter[1]
[1]Division of Imaging Sciences, King's College London, London, United Kingdom, [2]Philips Research Europe, Hamburg, Germany, [3]Institute for Biomedical Engineering, Univeristy and ETH Zurich, Zurich, Switzerland

Introduction

Fast visualization of catheters is indispensable for MR-guided interventions. Recently, Compressed Sensing (CS) was introduced as a method for accelerated 3D catheter visualization exploiting the inherent sparsity of the given signal acquired with an active device [1]. However, the frame rate of the 3D CS technique is still too slow (i.e. 3 frames/s) to capture fast changes of the catheter (e.g. flipping). As known from X-ray fluoroscopy, the 3D shape of a device can be determined from two bi-planar views [2].

We propose a new method based on bi-planar imaging using two perpendicular 2D projection views. For fast MR-imaging of the two projection views a randomized view-sharing (VS) 1D phase encoding scheme was applied allowing for image reconstruction of the catheter shape using CS. Furthermore, the VS scheme allows for simultaneous acquisition of anatomical images from which organ motion can be detected. A novel catheter design is used that combines a micro-coil for tip-tacking and a single-loop antenna for visualization of the catheter shape. The method was assessed in a simulation and its feasibility was tested in an in-vivo pig experiment.

Materials and Methods

Catheter Design: The active catheter was constructed with a small solenoidal tip coil connected in series with a 10cm single loop antenna followed by a safe transmission line [3]. This combination allows simultaneous tip tracking and shape visualization and prevents RF coupling and associated heating.

Catheter Imaging: Two orthogonal projection images (Fig. 2a) were obtained in an interleaved way using R-fold random VS undersampling (Fig. 2b). The excitation of a large slab for both views ensured imaging of the catheter inside the slab while maintaining the steady-state of the transversal magnetization in the volume for both views. Given the catheter design, high signal was obtained at the tip and lower while constant signal along the first 10cm of the shaft resulted from the resonant single loop.

Catheter Visualization: Image reconstruction involved two steps: First the catheter tip position was calculated by determining the maximum value in the CS reconstructions in both views and reprojecting the positions in 3D (Fig. 2a). Secondly, the catheter shape was reconstructed using a penalized CS reconstruction [1] in both views. On these images, a 2D to 3D curve was performed (Fig. 2a) using the tip position and the length of the catheter (10cm) as constraints. VS reconstruction was used to obtain anatomical projection images at R-fold reduced frame rate.

Experiments: All data were acquired on a 1.5T system (Philips Healthcare, Best, The Netherlands) using a T1-weighted TFE sequence. In order to test the accuracy of the catheter visualization 18 sets of fully sampled views of the catheter were acquired from different angles (increment 10°). This allowed the reconstruction of high quality images as reference in order to compare CS reconstruction. Flipping of the catheter with different speeds was simulated from fully sampled images (Fig. 3b) and CS reconstructions (Fig.3c) were compared to VS reconstruction (Fig.3a), both from 5-fold undersampling. Reconstruction quality was assessed by measuring the cross-correlation (CC) between the reconstructions and the original images (Fig. 3d) and measuring the sidelobe-to-peak ratio (SPR) of the tip (Fig.3e). In-vivo, the method was tested during cardiac catheterization of a 40kg pig. The catheter was visualized using the described method (single-shot TFE, TR/TE/flip 1.77/0.87/5°, acquisition matrix 450x250 mm2, slice thickness 250 mm, BW 2231 Hz, 4-fold undersampling). The reconstructed catheter outline was then displayed on a pre-acquired high-resolution roadmap (Fig. 4a). Furthermore, data simultaneously measured with the imaging coil was used to extract respiratory motion (Fig. 4c) from anatomical projection images (Fig. 4b).

Results

CS reconstruction (Fig. 3c) showed significant improvement of image quality in comparison to VS reconstruction (Fig. 3a). With a subsequent curve fit, the complete catheter shape could be reconstructed using the tracked tip position and the known length of the line as constraints. Figure 3 shows improved image quality of CS reconstruction, whereas VS reconstruction results in significantly lower CC and a higher SPR due to residual aliasing and blurring. In the in-vivo experiment, the catheter was successfully traced (Fig. 4a) and respiratory motion determined from the coronal anatomical image (Fig. 4b,c).

Discussion and Conclusion

The novel catheter design in combination with bi-planar imaging employing CS and VS reconstruction was shown to enable for precise tracking of the tip position and robust recovery of the catheter outline in 3D. VS reconstruction allowed for display of anatomical detail at lower frame rates and permitted extraction of respiratory motion in the in-vivo situation which may be used for motion modelling in the future[4]. With an active device in transmit/receive mode, excitation of thin slices is possible [5] which would improve anatomical imaging further. With the proposed method 3D visualization of the catheter at about 10 frames per second was achieved in-vivo. Since the performance of CS also depends on base SNR, higher frame rates are possible through base SNR improvements. In summary, the method presented holds considerable potential for improving accuracy and navigation of active interventional devices.

References

[1] Schirra et al., Proc. ISMRM 2008, p. 338
[2] Rhode et al., IEEE TMI 2005, 24:1428-40
[3] Weiss et al., MRM 2005, 54:18
[4] King et al., Proc. ISMRM 2008, p. 2999
[5] Weiss et al., Proc. ISMRM 2008 p. 283

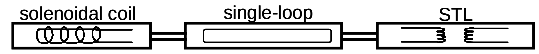

***Figure 1:** Catheter design. A solenoidal coil for tip tracking is combined with a single-loop antenna for shaft visualization and a safe transmission line (STL).*

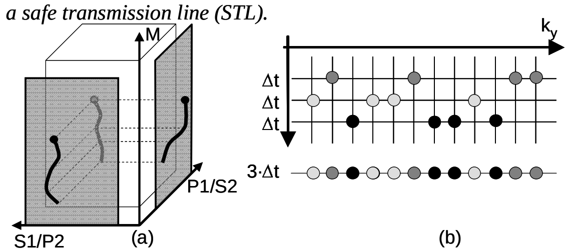

***Figure 2:** (a) Slab excitation for two orthogonal projections (M readout, P phase encoding). The catheter shape is found with a 2D-3D curve fit (gray). (b) The sampling scheme allows accelerated CS reconstruction and simultaneous VS reconstruction with lower temporal resolution.*

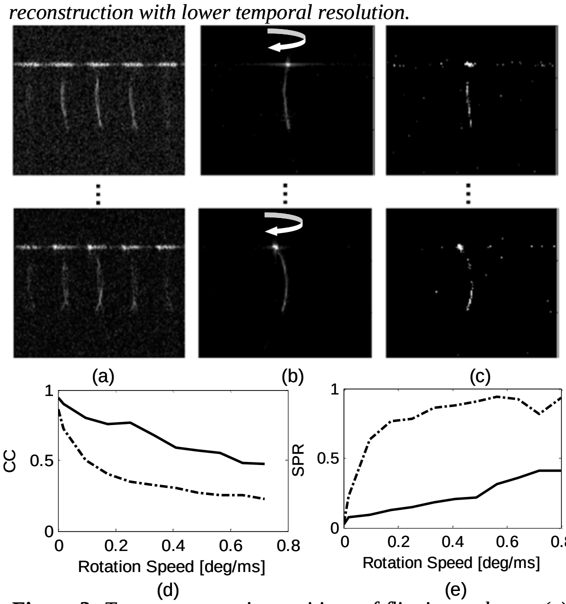

Figure 3: *Two representative positions of flipping catheter; (a) VS reconstruction, (b) fully sampled reference, (c) CS reconstruction. (d) Cross-correlation decreases with increasing rotation speed. (e) Sidelobe-to-peak-ratio of tip remains moderate with CS (dashed: VS, solid: CS).*

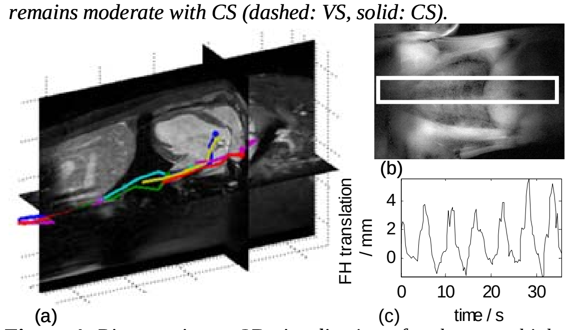

Figure 4: *Pig experiment. 3D visualization of catheter on high-resolution roadmap (a). The anatomical images (b) are used to derive respiratory motion (c).*