High framerate positive contrast needle tracking: Compressed Sensing and view-sharing accelerated co-RASOR reconstruction

Frank Zijlstra[1], Bo S. van Leeuwen[2], and Peter R. Seevinck[1]
[1]*Image Sciences Institute, UMC Utrecht, Utrecht, Netherlands,* [2]*Dept. of Clinical Sciences of Companion Animals, Faculty of Veterinary Medicine, Utrecht University, Utrecht, Netherlands*

Introduction: The superior soft tissue contrast, lack of ionizing radiation and multiplanar imaging capabilities make MRI a highly favorable modality for real-time needle guidance, facilitating a multitude of applications including biopsies, cryo- and RFA ablations, brachytherapy and local delivery of therapeutics. The success of minimally invasive procedures relying on passive tracking of interventional devices, however, depends on many factors, including the accuracy and specificity of the depiction of the device with respect to the anatomical background and the robustness of the visualization technique. We have recently demonstrated that accurate depiction of needles with high positive contrast is feasible, using a method called center-out Radial Sampling with off-resonance reconstruction (co-RASOR) [1]. By introducing a frequency offset, Δf_0, to the central reception frequency, f_0, either during signal reception [1] or retrospectively during reconstruction [2], an off-resonance image can be created in which small paramagnetic objects, including titanium needles, are depicted with high positive contrast at their exact location. Simultaneously, background signal can be suppressed by subtracting the on-resonance image.

Ideally, a real-time needle tracking sequence should preserve the anatomical background, while dynamically visualizing the needle with adequate spatial and temporal resolution, and with high CNR and specificity, allowing for accurate guidance and positioning of the needle tip in the target area. For that aim, we have developed a 2D method which enables fast, robust and highly specific depiction of an MRI-compatible titanium needle in concurrence with the surrounding tissue using a combination of Compressed Sensing (CS), view-sharing and co-RASOR reconstruction.

Methods: *Acquisition:* A fully sampled dynamic 2D center-out radial UTE sequence of a phantom was acquired on 1.5T (Achieva, Philips Healthcare, Best, The Netherlands) while various paramagnetic needles (MRI chiba, Somatex, 22G, 0.7mm, 100mm) were inserted and retracted at different angles relative to B_0. Imaging parameters included: FOV = 192x192mm^2; slice thickness = 6 mm; scan matrix = 128 x128; TE/TR = 0.96/3.56ms; 256 FID profiles of 164 samples each; 200 dynamic frames; dynamic scan time = 0.91s. The raw radial profiles were retrospectively undersampled using a bit-reversed profile order [3], such that for an acceleration factor of N a fully sampled radial k-space is acquired over N frames. To a certain extent this profile order facilitates uniformity of angles in consecutive frames.

Reconstruction: Since retrospective co-RASOR reconstruction operates in k-space, we can apply this directly to the raw radial profiles to create the k-space of the background-suppressed (BS) image: $s_{bs}(k) = s_{offres}(k) - s(k)$ with $s_{offres}(k) = s(k) \cdot e^{-i2\pi\Delta f_0 k}$, where Δf_0 is the frequency offset. CS can be applied to the reconstruction of the BS image just like any other image, allowing radial undersampling. The BS-co-RASOR image is highly sparse in the image domain, making CS acceleration a natural choice. CS reconstruction is performed with a non-linear Conjugate Gradient optimizer, using the NUFFT operator [4] and L1 norm and Total Variation regularization. Additionally, view-sharing was used to further reduce the dynamic scan time. The view-sharing acceleration factor V indicates that the profiles from the previous $V-1$ frames are shared, while only reusing the outer 100 samples, therefore not using the center of k-space of the shared profiles. The CS acceleration factor C indicates the undersampling factor of the final radial k-space after view-sharing. This results in a total acceleration factor of $V \cdot C$. Figure 1 shows the sampling scheme and view-shared profiles for $V = 2$ and $C = 2$. The anatomical on-resonance image is reconstructed directly from all profiles from the past $V \cdot C$ frames, which form a fully sampled radial k-space.

Post-processing: Instead of using the magnitude of the reconstructed complex BS-co-RASOR image directly (i.e. $|I_{bs}|$), a better contrast can be obtained by performing background-suppression only on the magnitudes of the images: $I_{mag\_bs} = |I_{onres} + I_{bs}| - |I_{onres}|$. Here, the first term is equivalent to the off-resonance image. Using this magnitude subtraction makes positive values more specific to the needles, which may be used as an overlay on the anatomical image, as shown in Figure 2.

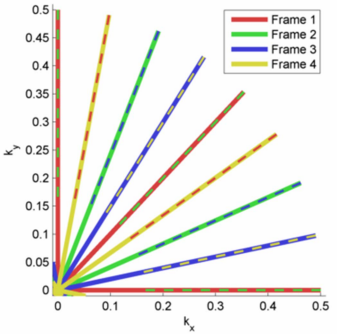

Figure 1. *Bit-reversed radial sampling scheme for 2x view-sharing and 2x CS acceleration. Dashed lines indicate view-sharing with the previous frame.*

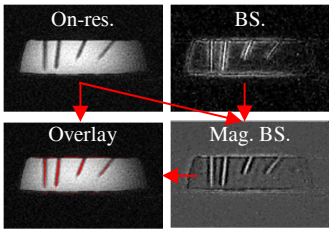

Figure 2. *Post-processing of the reconstructed images (top row) into magnitude background-suppressed and needle overlay images (bottom row)*

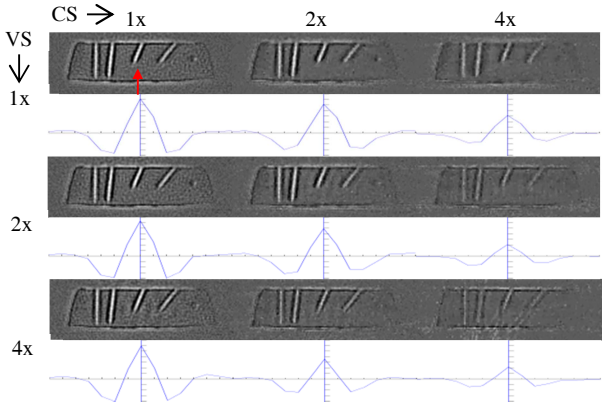

Figure 3. *Magnitude BS-co-RASOR images for different CS and view-sharing (VS) acceleration factors. For each image an average cross-section of the 3rd needle (arrow) is shown.*

Results and discussion: Figure 3 shows the reconstructed positive contrast for different acceleration factors. 2x CS and 2x view-sharing acceleration would result in one frame per 228 ms, while maintaining good contrast. The anatomical image would completely refresh once per 911 ms. It is clearly visible that CS acceleration degrades the contrast a lot more than view-sharing acceleration. View-sharing, however, decreases the temporal resolution of the high frequency components, resulting in some blurring during movement.

For all reconstructions in Figure 3 a single frequency offset was chosen. Despite the varying angle of insertion (45 to 90 degrees relative to B_0) all needles have sufficient contrast. However, if necessary, the frequency offset may be determined automatically to improve contrast of a specific needle at a specific angle. The cross-sections of the needles show clear negative side-lobes directly next to the positive lobe. The presence of these lobes may be used to further improve detection and visualization of the needle. This may actually be a necessity to maintain sufficient contrast when complex anatomy is present. Currently the reconstruction time is about 8 seconds per frame. Reconstruction methods more suited towards dynamic sequences may improve this. In combination with GPU acceleration we think real-time reconstruction should be achievable.

Conclusion: We have demonstrated a method for dynamically visualizing both needles and an anatomical background. By applying co-RASOR on raw radial profiles we show it is possible to create image-based sparsity to support the use of CS acceleration. Combined with view-sharing, a fourfold acceleration can be applied with only limited loss of contrast in the needles. While further experiments are needed to show accuracy and robustness in realistic scenarios, the method shows promising results for application to MRI needle guidance.

References: [1] Seevinck et al., MRM, 2011; 65:146-156 [2] De Leeuw et al., MRM, 2013; 69:1611-1622 [3] Chan et al., MRM, 2012; 67:363-377 [4] Fessler, J Magn Reson, 2007 October; 188(2): 191–195.