CURVELETS, A NEW SPARSE DOMAIN FOR DIFFUSION SPECTRUM IMAGING

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PURPOSE: Diffusion Spectrum Imaging (DSI) [1] is a model-free technique in diffusion MRI (dMRI) that uses the Fourier relationship between the diffusion signal, P(q), in q-space and the Ensemble Average Propagator (EAP), p(r). Because the number of q-space samples is proportional to the scan time, obtaining the whole q-space is unfeasible in many clinical applications. Compressed Sensing (CS) [2] allows accelerating DSI acquisitions by reconstructing the EAP from a significantly reduced number of q-space samples [3]. Nevertheless, the reconstruction performance is highly dependent on the sparse domain, which has not been fully studied for the specific DSI technique. In this work we propose a new sparse domain based on Curvelets [4], a multi-resolution geometric analysis that incorporates explicitly an angular decomposition with parabolic scaling and location to characterize bounded curve-singularities in a sparse matter. We show that this domain allows higher accelerating factors for DSI and thus significantly shortens the scan time in comparison with Wavelets.

METHODS: The q-space data was simulated with a Multi-Tensor-Model on a Cartesian 11x11x11 grid. The Tensors [3] were generated for two fibers crossing at 60° with a q_{max} = 65.471 mm^{-1}, D_{11} = 2.00 nm^2s^{-1}, FA = 0.8, MD = 0.85 nm^2s^{-1}. Q-samples were chosen by a Gaussian under-sampling pattern [3]. We used a standard L1 CS reconstruction [5]. Since quality of the reconstruction may be sensitive to the under-sampling pattern, we run the reconstruction for 50 different under-sampling patterns for each accelerating factor from 2X (128 q-samples) to 8X (32 q-samples) to evaluate two sparse domains: Cohen-Daubechies-Feauveu (CDF) 9/7 Wavelet [6] and Curvelets. To measure the 3D EAP quality we used the root-mean-square-error (RMSE), the Jensen-Shannon divergence [6] and the Return To Origin Probability (RTOP) [7]. For a possible fiber tracking application, the angle deviation was determined by computing the two main directions of the Orientation Distribution Function (ODF).

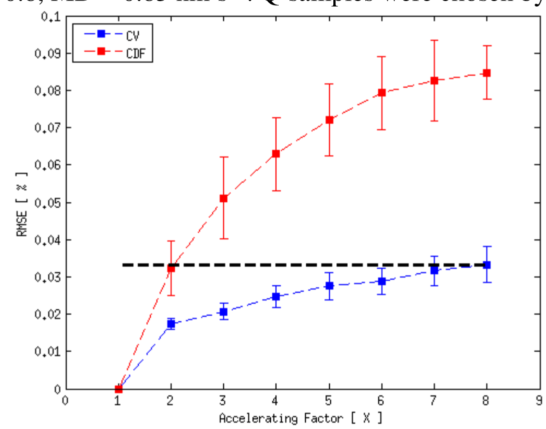

Figure 1. Mean and standard deviation of the RMSE for accelerating factors from 2X to 8X for 50 different Gaussian under-sampling patterns.

RESULTS: Figure 1 shows that Curvelets has a lower RMSE for all the accelerating factors in comparison with CDF 9/7 Wavelets. This is also the case for the Jensen-Shannon Divergence. Curvelets overestimates the RTOP for lower accelerating factors. Figure 2 shows an example of reconstructed ODF when Curvelets or Wavelets are used as the sparse domain for CS with an accelerating factor of 6X. Figure 3 shows the angle deviation when using Curvelets or Wavelets. The angle deviation from Curvelets is closer to the ground truth up to an accelerating factor of 6X.

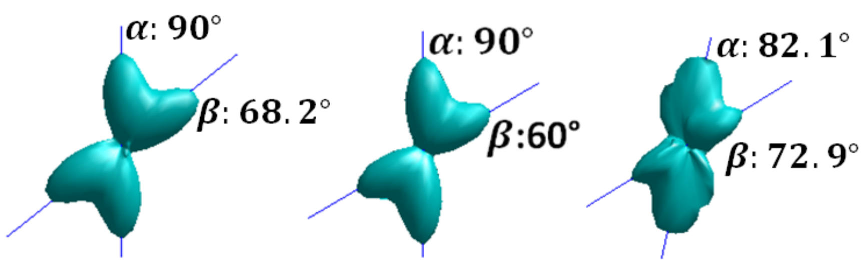

Figure 2. ODF and angle of fibers reconstructed. Left: Curvelets reconstruction. Middle: Ground Truth. Right: Wavelets reconstruction.

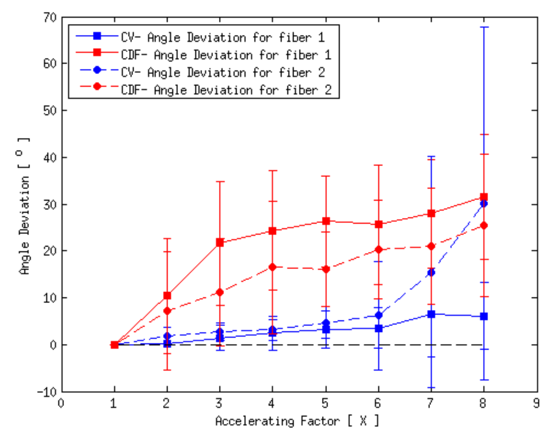

Figure 3. Mean and standard deviation of the angle deviation for the two fibers when using Curvelets or Wavelets for reconstruction.

DISCUSSION & CONCLUSION: In this work we show that Curvelets are a better domain to characterize the EAP than the CDF 9/7 Wavelet up to an accelerating factor of 6X. The results show that Curvelets basis reconstructs the EAP with better RMSE, leading to an improved reconstruction for a given accelerating factor or providing the same reconstruction quality at a higher accelerating factor in comparison with Wavelets. The results for the angle deviation with respect the ground truth show that Curvelets recovers more precisely the angles from the crossing fibers up to an accelerating factor of 6X. Finally, an accelerating factor of 4X was confirmed to achieve good results in the past[3], but with Curvelets we have increased this accelerating factor.

REFERENCES: [1] Weeden et al, MRM 2005 [2] Candes, IEEE S&P 2008 [3] Menzel et al, ISMRM 2011[4] Candes, AMS 2003 [5] Lustig et al, ISMRM 2007 [6] Saint-Armant et al, ISMRM 2011 [7] Özarslan et al, NeuroImage 2013 [8] Kuo et al, J Neurosci Methods 2013