Comparing Fourier to SHORE Basis Functions for Sparse DSI Reconstruction

Alexandra Tobisch[1,2], Thomas Schultz[2], Rüdiger Stirnberg[1], Gabriel Varela[3], Hans Knutsson[4], Pablo Irarrázaval[3,5], and Tony Stöcker[1,6]
[1]*German Center for Neurodegenerative Diseases, Bonn, Germany,* [2]*Department of Computer Science, University of Bonn, Bonn, Germany,* [3]*Biomedical Imaging Center, Pontificia Universidad Católica de Chile, Santiago, Chile,* [4]*Linköping University, Linköping, Sweden,* [5]*Department of Electrical Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile,* [6]*Department of Physics and Astronomy, University of Bonn, Bonn, Germany*

INTENDED AUDIENCE Neuroscientists, computer scientists, MR physicists, or related, who are interested in advanced diffusion MRI techniques and fast acquisition of intra-voxel structural parameters

INTRODUCTION Compressed Sensing (CS) theory has been widely applied to accelerate Diffusion Spectrum Imaging (DSI) acquisition [1], while still providing high angular and radial resolution of intra-voxel microstructure [2, 3]. Several groups have proposed to reconstruct the diffusion propagator from sparse q-space samples by fitting continuous basis functions [4-6]. Among these, the SHORE basis has recently been found to perform best, in particular when combined with CS principles [6]. However, to our knowledge, this approach has never been compared to traditional CS reconstruction, which is based on combining the discrete Fourier transform with a sparsity term. Our work presents such a comparison.

METHODS We use the Camino Monte-Carlo simulator [7] to generate pulsed gradient spin echo [8] diffusion signals (q_{max} = 65.507mm^{-1}, g_{max} = 26.79mT/m, δ = 57.4ms, Δ = 65.9ms) for 257 samples distributed on a Cartesian 11x11x11 q-space grid. Due to the antipodal symmetry of the diffusion signal, this sampling corresponds to Nyquist-sampled data and provides the ground truth to evaluate the reconstruction results. Accelerated DSI acquisitions are simulated by drawing samples from the ground truth data, based on isotropic sampling schemes [9] matched to the Cartesian grid. For Fourier-based CS-DSI, it was shown that this scheme outperforms standard random undersampling patterns [10]. N=32-128 samples (each scheme unique and optimized) correspond to acceleration factors from 2 to 8. Diffusion signals for one voxel containing two fiber bundles with crossing angles of 55° and 90° are simulated. Rician noise with SNR of 10, 20 and 30 is added to the signals. For each parameter combination, we further vary the orientation of the crossing structure by random 3D rotation to simulate brain microstructure with well-defined but unknown orientations. We use the Fourier- [2, 3] and the SHORE-based [6] CS approach to recover the diffusion propagator. The first applies total variation (TV) regularization, whereas the latter includes an *l*1 norm regularizer that promotes the sparsity of the SHORE coefficients. The regularization parameters are tuned manually for optimal results. Furthermore, we compare angular and radial SHORE bases orders of 6 and 8. Four different metrics are used to evaluate the deviation of the reconstruction from the ground truth: the normalized mean square error (NMSE), the return-to-origin probability (P0), the angular error and the crossing angle of peaks in the orientation distribution function (ODF). For Fourier-based DSI, the ground truth for the calculations of the NMSE and P0 corresponds to the Nyquist-sampled diffusion signal that is smoothed by a Hanning window [1]. For each metric, the mean and standard deviation of the error values are calculated over 600 different orientations of the crossing fiber structure.

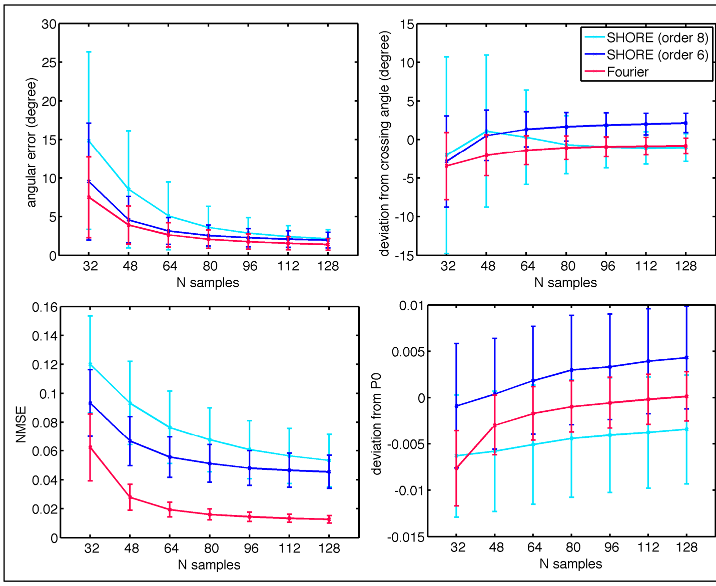

Fig. 1. Mean and standard deviation for all metrics over 600 orientations of the 55° crossing structure (SNR of 20, angular and radial SHORE bases orders of 6 and 8): the angular error, the deviation from the crossing angle of the ground truth, the normalized mean square error (NMSE) and the deviation from the return-to-origin probability (P0) of the ground truth.

RESULTS AND DISCUSSION For each metric, Fig. 1 shows the mean and standard deviation calculated for 600 different orientations of the 55° crossing fiber structure, an SNR of 20 and angular and radial SHORE bases orders of 8 and 6. The latter is found to improve the modeling of the diffusion profile compared to an order of 8, which indicates that SHORE-based CS recovery does not improve through increasing the number of basis functions. For Fourier-based CS-DSI, the NMSE and the return-to-origin probability are closer to the ground truth and the angular information is reconstructed slightly better than for SHORE-based CS-DSI. Fig. 2 visualizes the ODF for the ground truth and the ODF after CS recovery on the example of N=64 samples to demonstrate superior ODF quality when using the Fourier transform for sparse DSI recovery. In summary Fourier-based CS-DSI reconstruction outperforms the recovery of the signal modeled in the SHORE basis for simulated DWI. Up to an acceleration factor of 8 Fourier-based CS-DSI data captures better the diffusion profile, which improves the extraction of intra-voxel structural parameters.

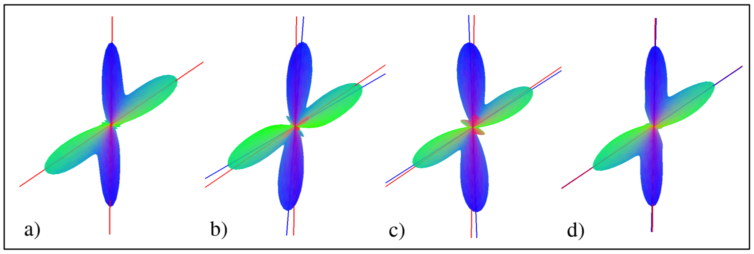

Fig. 2. N=64: ODF of the ground truth (a), ODF of SHORE-based CS-DSI with order 8 (b), ODF of SHORE-based CS-DSI with order 6 (c) and ODF of Fourier-based CS-DSI (d), all with orientation color coding; Red and blue lines depict ODF peak orientations of the ground truth and the reconstruction, respectively.

CONCLUSION Our results indicate that the discrete Fourier transform with TV regularization provides more accurate reconstruction of sparse DSI samples than CS using the SHORE basis. Future work will extend this comparison to include non-Cartesian isotropic sampling (omit matching to the Cartesian grid), which is assumed to be beneficial for SHORE-based CS-DSI but not possible for standard Fourier-based CS-DSI. Further, we will investigate phantom and in-vivo MRI data and aim for more robust SHORE reconstruction by integrating additional constraints to close the gap between Fourier- and SHORE-based CS-DSI.

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