Non-Cartesian Compressed Sensing for Diffusion Spectrum Imaging

E. Aboussouan[1], L. Marinelli[2], and E. Tan[2]
[1]Barrow Neurological Institute, Phoenix, AZ, United States, [2]GE Global Research, Niskayuna, NY, United States

INTRODUCTION: One important limitation of DTI is its inability to resolve multiple crossing fibers within a voxel. Diffusion Spectrum Imaging (DSI) allows such resolution by Nyquist sampling a 3D q-space[1] for each voxel. The water displacement probability ("propagator") corresponds to the Fourier transform of the MR signal as a function of $\vec{q}$. This high dimensionality imposes a trade-off between resolution in diffusion space and scan time. It has been proposed [2,3] to accelerate DSI through the application of compressed sensing (CS)[4] in the three q-space dimensions. Rather than sampling a subset of a Cartesian q-space, we propose to further minimize coherent aliasing by undersampling q-space according to a non-Cartesian sampling pattern.

METHODS: The reconstruction is performed by a conjugate gradient minimization $x=\arg\min(|Fx-y|_2+\lambda|\Phi x|_1)$, where x is the data in the propagator space and F denotes the sampling density weighted inverse 3D NUFFT operator[5]. Consistency is enforced with the q-space measurements (y) while optimizing sparsity for the total variation of the propagator (Φx), which is assumed to be sparse. In addition to the sparsity requirement, proper CS reconstruction requires the sampling PDF to satisfy incoherence conditions [3]. Rather than undersampling a Cartesian grid as previously proposed, we distribute points arbitrarily according to a desired PDF(Fig.1) which has been found experimentally to be a good tradeoff between angular resolution and noise robustness. The radius of the sample is chosen by mapping a uniform random variable onto the desired radial distribution. An electrostatic repulsion algorithm is then performed to distribute the points angularly. Relaxing the Cartesian constraint allows the sampling pattern to take a radial distribution which is much closer the desired one than in the Cartesian case. Fig. 1 compares the Cartesian and non-Cartesian patterns and their respective radial distributions histograms.

RESULTS: 3D diffusion propagator data were simulated for crossing fibers and different amounts of additive noise. The corresponding spherical q-spaces of 523 points were downsampled to 128 non-Cartesian points (acceleration factor of R=4) using a NUFFT. Fig. 2 compares Orientation Distribution Function (ODF) glyphs obtained using this method to one obtained by an iterative soft thresholding reconstruction [2] from a downsampled Cartesian dataset. Both methods were implemented in Matlab. Preliminary *in vivo* data were obtained for each method from a healthy human volunteer using an EPI scan on a GE 1.5T Signa scanner equipped with an 8 channel brain array. The acquisition parameters were: TR/TE = 3000/126 msec, FOV = 24cm, slice thickness = 4cm, 96 x 96 x 6 slices, bmax = 8000 sec/mm^2. Subsets of the resulting ODF glyphs taken from the splenium of the corpus calosum are shown in Fig. 3.

DISCUSSION: Analysis of the simulations found the non-Cartesian reconstructions to be more resistant to noise. Comparisons of the preliminary *in vivo* results seem to support that conclusion. This can be in part due to the reduced coherent aliasing and in part to the setting of the parameter λ. Contrary to the parameter-free iterative soft thresholding, the proposed minimization has a free parameter λ which can be seen as an explicit tradeoff between robustness to noise and angular resolution. Although the total variation of the propagator space might not be the sparsest representation of diffusion in crossing fibers, it has the advantage of not assuming a given diffusion model. In its current implementation, the non-Cartesian reconstruction is ~50 times slower than its Cartesian counterpart. The implementation could be significantly optimized but would remain somewhat slower than the Cartesian method mainly due to the NUFFT operations.

REFERENCES: [1] Kärger J. *et al.* Magn Reson 51,1, [2] Menzel *et al.*, ISMRM 2010 Meeting, abstract 1698, [3] Lee N. *et al.*, ISMRM 2010 Meeting, abstract 1697, [4] Lustig M. *et al.* MRM, 58, 6, [5] Fessler, J. IEEE T-SP, 51, 2, [6] Khare K. *et al.*, ISMRM 2010 Meeting, abstract 346

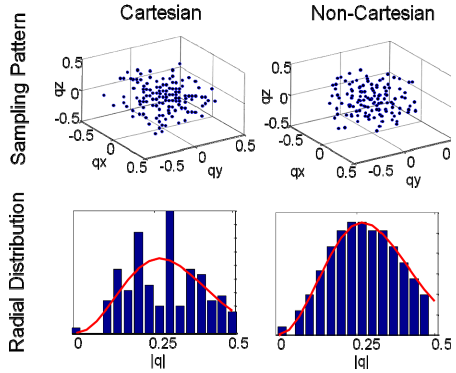

Figure 1: Sampling patterns and sampling densities vs. normalized q-space radius, q. The red line reflects the desired Gaussian distribution N(0,.19) shown in the radial dimension of 3D q-space.

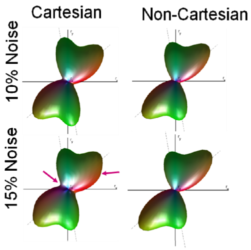

Figure 2: Simulation ODF results. Non-Cartesian sampling and reconstruction is more robust to noise, as seen in the widened ODF glyphs in the Cartesian case (red arrows).

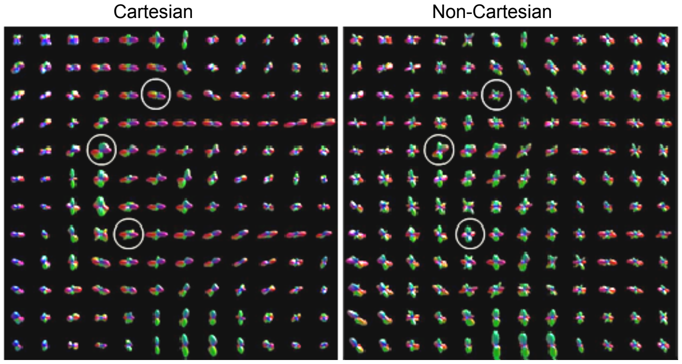

Figure 3: *In vivo* ODF results. Voxels of interest have been circled.