Alternate grids for diffusion weighted imaging and associated reconstruction algorithms

Submission No:

4504

Authors:

Cory Ahrens[1], Stefan van der Walt[2], Fernando Perez[3]

Institutions:

[1]Tech-X Corporation, Boulder, CO, [2]University of Stellenbosch, Stellenbosch, South Africa, [3]University of California, Berkeley, Oakland, United States

Introduction:

High angular resolution approaches to diffusion weighted imaging (DWI) require the diffusion signal to be sampled at multiple points on a spherical grid in q-space, either at a fixed q value (q-ball imaging) or by sampling three-dimensional q-space (diffusion spectrum imaging). Previous q-space sampling methods have been based on, e.g., minimum energy grids or iterative subdivision of an icosahedron [Tuch 2004]. While these grids appear to be almost uniform, they were not designed with function representation in mind. Here we introduce new spherical grids that are nearly optimal for representing localized functions on the sphere and indicate how they can be used to develop new algorithms for High Angular Resolution Diffusion Imaging (HARDI).

Methods:

Our construction builds upon an extension to the sphere of the notion of one-dimensional Gaussian integration. With Gaussian integration any polynomial function up to a certain order can be integrated exactly with a finite number of evaluations by suitably choosing node location and weight. The extension of this idea to the sphere [Ahrens 2009] allows for the construction of grids that exactly integrate spherical harmonics up to a specified order. Additionally, these grids provide an efficient representation of localized functions on the sphere, an ideal feature for HARDI imaging where fibers produce localized signatures. These two features combined, make these grids an appealing candidate for sampling diffusion gradient directions.

In order to visualize the coverage uniformity of an n-point grid on the sphere, we assign at each point a Gaussian density exp(-s^2/(2*sigma^2)), where s is the arclength measured along the sphere and sigma^2=2/(n log(2)). This models each Gaussian as a disk of diameter equal to its full width at half maximum, and covers the surface of the sphere evenly with these disks. Fig. 1 shows the coverage of our grid with 72 points. Fig. 2 shows a symmetrized version of a 64-point grid regularly used for diffusion tensor imaging at UC Berkeley (the displayed version has thus 128 points). Note the much lower uniformity of coverage of the latter, despite its higher density of nodes. Intuitively, the more uniform coverage of the new grid should lead to more efficient sampling.

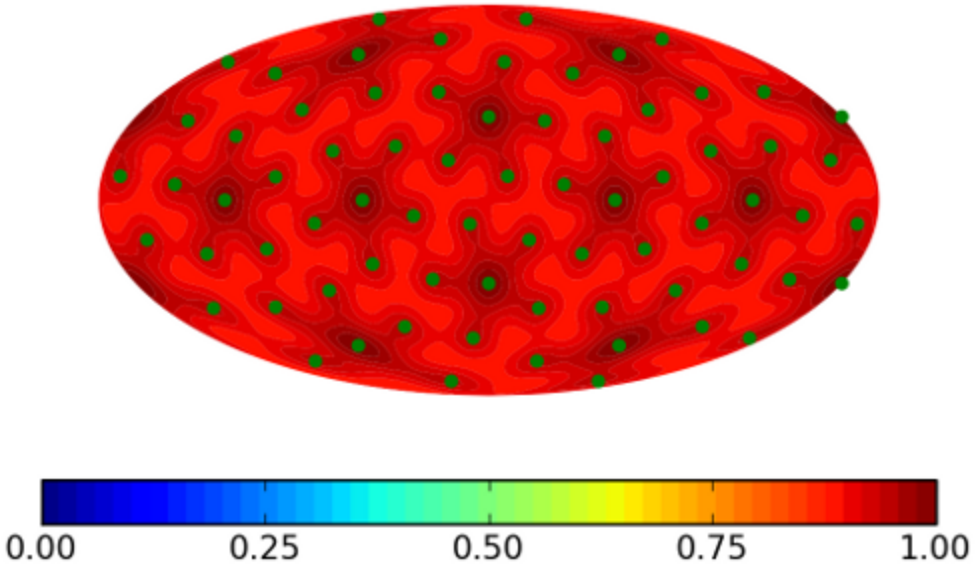
Using the above grids and the reproducing kernel for subspaces of spherical harmonics, we construct efficient representations for localized functions on the sphere. A spectral extension of this kernel improves its localization properties, with minimal oversampling. Using ideas similar to [Michailovich 2009] and the reproducing kernel representation, we develop an algorithm to recover primary directions in which fibers cross a voxel. Combining this with an L-1 minimization [Candes 2010] enables us to recover the coefficients that correspond directly to specific fiber directions.

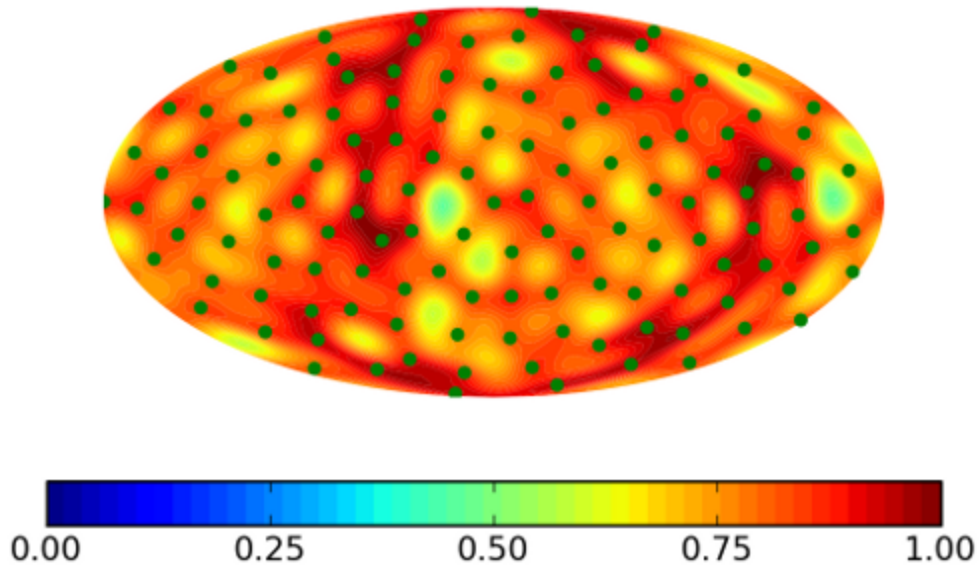
Results:

We present numerical simulations showing the viability of these grids and the new reconstruction algorithm for sampling and representation of localized diffusion signals driven by crossing fibers. We are currently testing their suitability for reconstruction of complex diffusion signals as well as comparing their robustness to that of the grids currently in widespread use in DWI.

Conclusions:

Our results at this point are preliminary, but if these grids perform successfully in more complex tests, we will have a principled approach to construction of efficient schemes for HARDI. In our scheme there is a precise notion of maximal order of spherical harmonic used in the representation and hence it becomes possible to make a principled decision, based on signal to noise ratio considerations, about the proper number and location of gradient directions for an optimal acquisition scheme.





Imaging Methods

Diffusion MRI

Abstract Information

References

Ahrens, C. (2009), 'Rotationally invariant quadratures for the sphere', Proceedings of the Royal Society A, vol. 465, pp 3103--3125.

Candes, E. (2010), 'Compressed sensing with coherent and redundant dictionaries', arXiv:1005.2613v3.

Michailovich, O. (2009), 'On approximation of orientation distributions by means of spherical ridgelets', IEEE Transactions on Image Processing, vol. 19, no. 2, pp 461--477.

Tuch, D.S. (2004), "Q-ball imaging.," Magnetic resonance in medicine : official journal of the Society of Magnetic Resonance in Medicine / Society of Magnetic Resonance in Medicine, vol. 52, pp. 1358-72.