# Diffusion reconstruction by combining Spherical Harmonics and Generalized Q-Sampling Imaging

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## Introduction

Advanced diffusion reconstruction algorithms can be used to probe the complex micro-structure of white matter tissue in the human brain. One of the popular methods to resolve fiber crossings is constrained spherical deconvolution[4] (CSD) which can be used for single shell (constant b-value) image acquisitions. Generalized Q-sampling Imaging[1] (GQI) is used for Diffusion Spectrum Imaging[3] (DSI) and Multi-shell image acquisitions. We propose a new reconstruction method that combines CSD and GQI to estimate spherical harmonics (SH) coefficients for fiber Oriented Distribution Function (fODF). This method enables the advantages of CSD reconstruction[4] to be applied to DSI and multi-shell acquistions.

GQI reconstructs the diffusion oriented distribution function (dODF) from diffusion weighted images using the following equation:

$$\psi_{voxel}(\hat{u}(\theta,\varphi)) = L_\Delta \int_{\mathbb{R}^3} E_{voxel}(\vec{q}) sinc(2\,\pi\, L_\Delta\, \vec{q}\cdot\hat{u})\, d\vec{q}$$

By definition dODFs are functions defined on a unit sphere and can be represented as a linear sum of spherical harmonics[2].

$$\psi_{voxel}\big(\hat{u}(\theta,\varphi)\big) = \sum_{l=0}^{L_{max}} \sum_{m=-l}^{l} c_{lm} Y_l^m(\theta,\varphi)$$

Combining the equations above will provide an analytical expression for spherical harmonics coefficients.

$$c_j = \int_{\mathbb{R}^3} \Big(\int_{\Omega} L_\Delta\, sinc(2\,\pi\, L_\Delta\, \vec{q}\cdot\hat{u})\, Y_j(\theta,\varphi)\ d\Omega\Big) E_{voxel}(\vec{q})\, d\vec{q}\ \ , j = j(l.m) = \frac{l^2+l+2}{2} + m$$

To find coefficients $c_j$, we used the least squares method with regularization (Laplace-Beltrami operator).

## Method

A 62-year-old female subject was scanned using a 3T MRI system (TIM Trio, Siemens, Erlangen, Germany) with a 32-channel coil, using a DSI protocol[3]. The field of view was 240 mm x 240 mm, matrix size 96 x 96, slice thickness 2.4mm (no gap) with 50 slices. The number of gradient directions used for DSI was 257, maximum b-value=7000 sec/mm$^2$, and TR / TE = 9916 ms / 157 ms. Above algorithm is implemented in MALAB to reconstruct the dODF and (fODF). Multi-FACT fiber tracking[5] was performed using DSI-Studio.

## Results

The proposed reconstruction algorithm produced dODFs that have the expected advantages (over GQI) of using CSD techniques, e.g. sharper peaks and less noise (Fig1A). Tractography using fODFs produced with the proposed method yielded anatomically correct fiber tracts. In comparison to tractography using the GQI reconstruction, these tracts are more precise (note inter-hemispheric distinction in fig 1C, 1 & 2 clearly shows left and right Fornix separation). The proposed reconstruction method has the advantage that the SH parameterization of the diffusion data can be used to interpolate dODF data at subvoxel locations. There are a number of potential applications for interpolated dODFs including the high resolution estimates of diffusion direction to visualize subcortical nuclei (see 3 and 4 in fig 1D, thalamic nuclei identification only in hyper-resolution sampling) and improved tractography to visualize detailed connectivity.

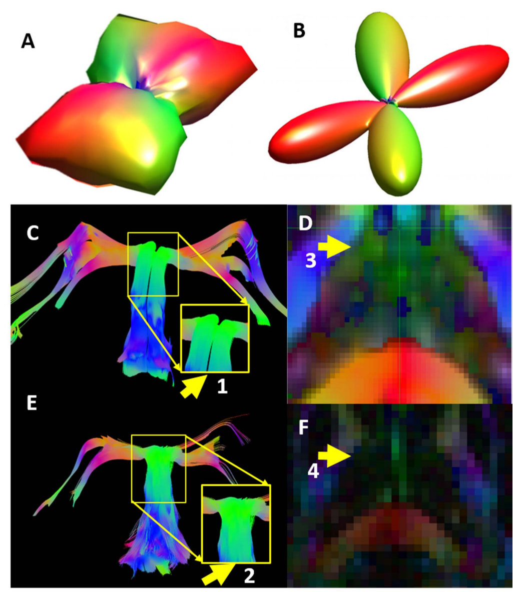


*Figure 1A) dODF using GQI B) fODF using proposed reconstruction method C) Fornix track reconstructed using proposed reconstruction algorithm D) Color encoded thalamus regions showing thalamic nucleus, hype-resolution interpolation E) Fornix track reconstructed using GQI F) Color encoded thalamus regions showing thalamic nucleus, lower-resolution using GQI*

## Conclusion

The novel diffusion MRI reconstruction algorithm presented here is derived from current CSD and GQI methods, produces improved estimates of diffusion direction, and enables CSD techniques to be applied to DSI and multi-shell data.

## References

[1] Yeh et al. 2010. [2] Maxime et al 2007. [3] Wedeen 2005. [4] Tournier et al. 2004, 2007 [5] Yeh et al 2013