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To cite this version:

HAL Id: hal-00967830
https://hal.archives-ouvertes.fr/hal-00967830
Submitted on 31 Mar 2014

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Non-Local Non-Negative Spherical Deconvolution for Single and Multiple Shell Diffusion MRI

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I. Introduction

In diffusion MRI (dMRI), Spherical Deconvolution (SD) is a category of methods which estimate the fiber Orientation Distribution Function (ODF). Existing SD methods, including the widely used Constrained SD [1], normally have two common limitations: 1) the non-negativity constraint of the ODFs is not satisfied in the continuous sphere; 2) many spurious peaks are detected, especially in the regions with low anisotropy. In [2], we proposed a novel SD method, called Non-Negative SD (NNSD), to avoid these two limitations. NNSD guarantees the non-negativity constraint of ODFs in the continuous sphere, and it is robust to the false positive peaks. In this abstract, we propose Non-Local NNSD (NLNNSD) which considers non-local spatial information and Rician noise in NNSD, and apply it to the testing data in ISBI contest.

II. Method

We represent the square root of ODF $\Phi(u)$ as a linear combination of real Spherical Harmonic (SH) basis $Y^l_m(\cdot)$ with even order, i.e., $\Phi(u) = \sum_{l=0}^{\infty} \sum_{m=-l}^{l} \epsilon_l^m \cdot \sum_{c=1}^{C} Y^l_m(u)^c$, where $u \in S^2$, and $Y^l_m(u)^c$ is the integral constant of three SHs which can be calculated from the Wigner 3-j symbol. Then based on the closed form of spherical convolution using SH basis, for a given axisymmetric fiber response function along $z$-axis $H(qu(0,0,1)) = \sum_{c=1}^{C} h_c(qy)Y^0_0(u)$, the convolved diffusion signal is

$$E(q\alpha) = \sum_{\alpha \in \Omega} \sum_{b \in \beta} \sum_{\gamma \in \gamma^c} \sum_{d \in d^c} \frac{4\pi}{2l+1} \epsilon_{l}^{m} \cdot \sum_{c=1}^{C} Y^l_m(u)^c \cdot h_c(qy)Y^0_0(u)$$

where for any fixed vector $q = qu$, $K(u)$ is a square matrix with the elements $K_{nm} = \sum_{c=1}^{C} Y^l_m(u)^c \cdot h_c(qy)Y^0_0(u)$. Then NNSD [2] is to estimate $\epsilon$ by minimizing

$$J(\epsilon) = \frac{1}{2} \sum_{i=1}^{N} [e^T \cdot K(\epsilon) \cdot e - E_i^T] + \frac{\gamma}{2} \epsilon^T C \epsilon$$

III. ISBI HARDI Reconstruction Challenge

In the ISBI reconstruction challenge, the testing data was generated based on Numerical Fibre Generation toolbox [7]. We test the proposed NLNNSD in the data with three kind of sampling schemes: 1) single shell DTI scheme with 32 directions, $b = 12000s/mm^2$; 2) single shell HARDI scheme with 64 directions, $b = 3000s/mm^2$; 3) multiple shell DSI-like scheme with 514 directions, $b \in (0, 40000s/mm^2)$. For all night datasets (three schemes with three SNR 10, 20, 30), we fixed $\ell = 8$, $\lambda_{NNSD} = 0$, and used the tensor fiber response function with FA of 0.8, mean diffusivity of 0.8. In the non-local mean of $e^i$ and $E_i^i$, we uses a $11 \times 11 \times 11$ search window, and a $3 \times 3 \times 3$ patch to define the weights, where the parameters $a$ and $h$ were tuned respectively for $e^i$ and $E_i^i$ to obtain visually good results for each dataset.

References