DTI Tractography Challenge-MICCAI 2011: A Volumetric Approach to extract Corticospinal tract in Diffusion Tensor MRI

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1 Introduction

This report presents our volumetric segmentation approach to determine the white matter connectivity, specifically in the corticospinal tract. The complete analysis is based on the work by Fletcher *et al* [1], which uses a Hamilton-Jacobi (H-J) formulation and a fast iterative method to minimize the total path cost between two seed regions. The total cost is defined as the integral of local costs obtained from the tensor information along the path. This leads to a region-to-region connectivity providing a volumetric representation of the white matter pathway between two regions.

2 DTI analysis pipeline

Once the seed regions are defined that represent two target regions of the volumetric pathway, the local cost is calculated at each point on the image using its tensor information. This is followed by a nonlinear partial differential equation which computes minimal cost from the first target region to every point in the image. Similarly, the minimal cost is computed from a second target region. The two solutions are then combined in order to produce a minimum cost path between the two regions.

As [1] quotes, given a path $c : [a, b] \rightarrow \Omega$, where Ω is an image domain, the total cost of c is defined as

$$E(c) = \int_a^b \psi(c(t), T(t))dt, \tag{1}$$

where $T(t) = \frac{c'(t)}{\|c'(t)\|}$ is the unit tangent vector of c. The local cost function, $\psi(x, v)$ gives the cost of moving in the unit direction v from point x. Following [2], a quadratic local cost function is used which is defined as

$$\psi(x, v) = v^T M^{-1}(x)v, \tag{2}$$

where $M(x)$ is a symmetric, positive-definite matrix defined at each point $x \in \Omega$.

Instead of directly choosing the tensors in place of M, they are sharpened by raising it to a power α so that the solution tends to follow the white matter pathway rather than the shortest path in the Euclidean sense. Now, if the sharpened tensor is considered to be the speed (in the H-J formulation), which gives low cost along the principal eigen directions, the cost is the inverse. Thus we have

$$M(x) = |D(x)|^{\frac{1}{3}} \left(\frac{D(x)}{|D(x)^{\frac{1}{3}}|}\right)^{\alpha}, \tag{3}$$

where $\alpha > 1$ and $|D(x)|$ denotes the determinant of $D(x)$. Let γ be the optimal path obtained using H-J formulation and ϵ be the tolerance of paths relative to the optimum. A set of all points whose constrained minimum cost is less than $(1+\epsilon)E(\gamma)$ is defined as a volumetric pathway between the two target regions. Thus the segmented voxels describe the fiber connection between them.

To solve numerically the H-J equation, the Fast Iterative Method [3] is used due to its speed. As our analysis is mainly concerned with the white matter connectivity, a white matter mask is generated to solve for the cost function. For numerical accuracy, the solution on the grid is supersampled by two from the original data.

3 Results

The DTI volumetric segmentation framework has been applied to two healthy and two neurosurgical cases. The analysis was carried out to segment the left and the right corticospinal tracts in datasets. Using the color-coded orientation map that can be calculated using the tensor volume, we outlined the terminal regions manually for these tracks. A DTI atlas by Mori [4] has been used as a guideline to define these seed regions on our colored orientation maps.

Figure 1 illustrates one example of seed regions on a healthy subject. Figure 2 illustrates results that depict the segmented corticospinal tracts on a healthy and neurosurgical case. According to the figure, these segmented regions are overlayed on T-1 weighted MR images as well as colored Eigenvector images. An α value of 3 and an ϵ value of 0.06 are chosen for all cases.

References

1. Fletcher, P.T, Tao, R., Jeong, W, Whitaker, R.T.: A Volumetric approach to Quatifying Region-to-Region white Matter Connectivity in Diffusion Tensor MRI. Proceedings of Information Processing in Medical Imaging (IPMI); (2007) pp. 346-358
2. Pichon, E., Westin, C.F., Tannenbaum, A.: A Hamilton-Jacobi-Bellman approach to high angular resolution diffusion tractography. In: MICCAI. (2005) pp. 180-187
3. Zhao, H.: A fast sweeping method for eikonal equations. Mathematics of Computation 74(2004) pp. 603-627
4. Mori, S., Wakana, S., Nagae-Poetscher, L.M., van Zijl, P.C.M.: MRI Atlas of Human White Matter. 1st Edition, Elsevier (2005), ISBN: 0-444-51741-3

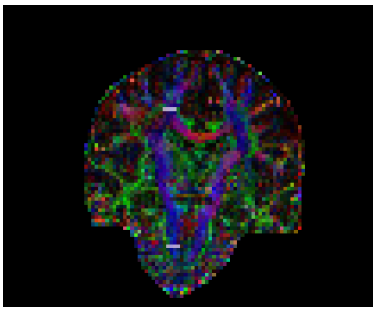
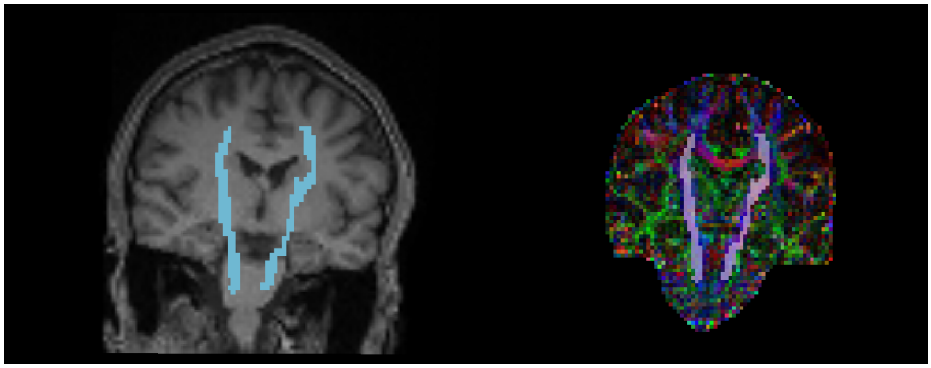
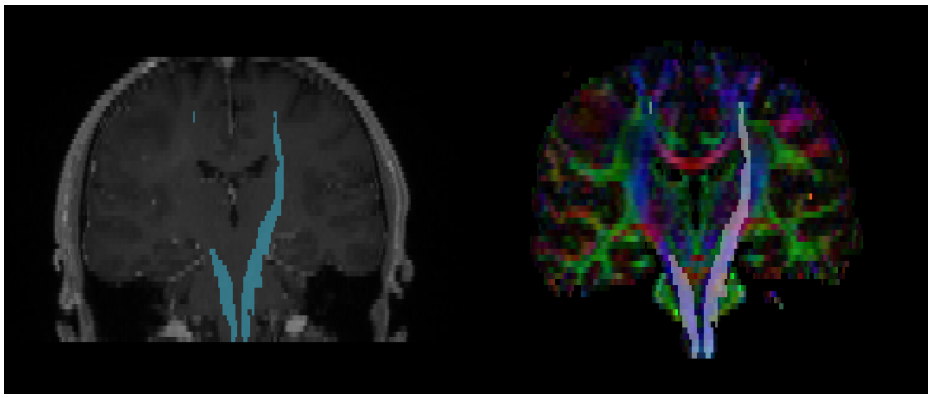


Fig. 1: White regions indicate seeds defined for Corticospinal tract on a healthy case



(a) Neurosurgical View1 (b) Neurosurgical View2



(c) Neurosurgical View1 (d) Neurosurgical View2

Fig. 2: (a) DTI volumetric segmentation results on a healthy subject T1-weighted image; (b) DTI volumetric segmentation results on colored eigen-vector image; (c) DTI volumetric segmentation results on a patient T1-weighted image; (d) DTI volumetric segmentation results on colored eigen-vector image