Diffusion Anisotropy Measure based on the Basis of Tesseral Harmonics

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Introduction. Diffusion-weighted magnetic resonance imaging (DW-MRI) is a non-invasive technique that enables the measurement of water molecular diffusion in tissues. The diffusion properties of water in the human brain are of special interest because of the wide range of the medical applications. DW-MRI provides a great deal of important information about functional coupling between the cortical regions of the brain, the characterization of neurodegenerative diseases etc. Such measures as water mean diffusivity, the direction of the main diffusivity and the degree of anisotropy within a voxel play an important role in white matter investigations. These measures are exploited in tractography techniques to segment and track white matter fibres in the human brain.

Several diffusion anisotropy indices have been calculated from the diffusion tensor model, including the fractional anisotropy (FA) and the relative anisotropy (RA) [1], the volume ratio [2], the generalized anisotropy (GA) [3] etc. FA is one of the most frequently used because of its good sensitivity and tolerance to noise. FA is computed by normalizing the variance of the three eigenvalues of the diffusion tensor. However, it produces significantly low values when there are fibres crossing within the same voxel. In the past few years there has been great interest in finding a measurement of anisotropy that does not dependent on fitting the data to a tensor model [4, 5].

We present a method for the characterization of diffusion anisotropy based on the analysis of the apparent diffusion coefficient (ADC) profile in terms of the tesseral harmonics (TH) series coefficients resulting in an anisotropy map of the brain. In the past few years, several anisotropy measures defined on the coefficients of a spherical harmonics (SH) series to describe the ADC profile have been reported [4, 5], but they are insufficient to built a robust anisotropy map. The tesseral harmonics (THs) are an alternative set of the spherical harmonics for real-valued functions and the characterization of the diffusion anisotropy based on our method is computationally simple, fast and consistent with the known fibre anatomy.

Theory (Methods).

Consider the general case of high angular resolution diffusion imaging (HARDI) of a voxel with an unknown composition of fibres. The measured ADC profile, $f(\theta,\varphi)$, can be expanded using the spherical harmonics Y_{lm} as:

$$f(\theta,\varphi)=\sum_{l=0}^{\infty}\sum_{m=-l}^{l} f_{lm}Y_{lm}(\theta,\varphi)$$

The methods for computing the expansion coefficients, f_{lm}, are described in [4, 5]. Here, we use the THs as a basis set to expand $f(\theta, \varphi)$ up to 8^{th} order; only even orders of the THs were used because of the antipodal symmetry of the ADC.

To infer the underlying diffusion process we applied the rotationally invariant anisotropy index AI:

$$AI=\sqrt{\frac{\int d\theta d\varphi \sin\theta \left| f(\theta,\varphi)-f_{00}Y_{00}\right|^2}{\int d\theta d\varphi \sin\theta \left| f(\theta,\varphi)\right|^2}}\,.$$

AI, bounded between 0 and 1, is 0 for a voxel with the completely isotropic diffusion and 1 for completely anisotropic diffusion. AI was first applied by Jespersen et al. [6] for the determination of the intra-voxel distribution of the fibre orientations while measuring the intracellular diffusion coefficient, but not the ADC.

Results and Discussion.

DW–MRI data were acquired on a 3T scanner (Tim-Trio, Siemens) from a healthy adult: TE/TR=92/10000 ms, resolution=$(1.8\ mm)^3$, FOV=230x216 mm, matrix=120x128, b-value=800 s/mm^2, 60 directions distributed over an icosahedron. The anisotropy map of a brain, created by our method, is shown in the Fig.1. For comparison, the FA map for the same slice is also shown. The images look very similar and show the same structures although we did not use diffusion tensor fitting in our calculations.

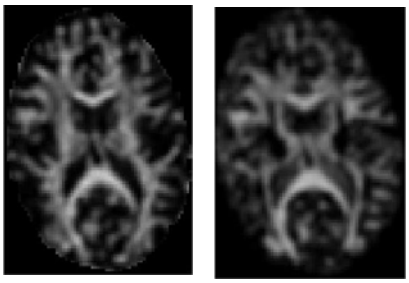

Fig. 1. Anisotropy measurements computed on a brain slice: FA (left), AI (right).

For comparison in Fig. 2, the anisotropy index AI for our model is correlated with the FA measure from the DTI fit. A statistically significant linear correlation is observed, demonstrating that the two parameters reflect the similar information. A comparison of our model with others reveals that our model may be an improvement over known methods of classification of different tissue types in DW-MRI data sets.

Conclusion.

The characterization of anisotropy using THs provides useful information about the underlying tissue microstructure in each voxel. The map of anisotropy can be used in tractography. We conclude that our approach is a useful extension of the existing methods.

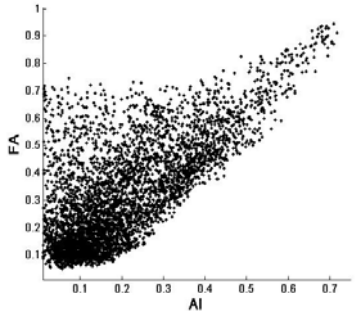

Fig. 2. Pixel-by-pixel correlations between AI and FA. Only data inside the brain were used.

References

[1] Pierpaoli C., Basser P.J.1996, Magn. Res. Med., 36: 893-906.
[2] Basser P.J.1995, NMR Biomed, 8: 333-344.
[3] Ozarslan E. et al. 2005, Magn. Res. Med., 53: 866 – 876.
[4] Frank L. R. et al. 2002, Magn. Res. Med., 47: 1083-1099.
[5] Alexander D. C. et al. 2002, Magn. Res. Med., 48: 331-340.
[6] Jespersen S. N. et al. 2007, NeuroImage, 34: 1473-1486.