Resolving Fiber Crossings: a two fiber model simulation result

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Introduction:

Tensor-based fiber-tracking has been developed over the last few years and is gradually being used as clinical tool.

Two different problems could be identified in the situation of crossings of fiber tracts. The first relates to the sub-voxel-based identification of a single- or a multi-fiber system. The second problem follows when a system is identified as a multi-fiber system: identifying the angle(s) and (confounding) volume-fraction(s) of the individual fiber tracts. In this case it is crucial to understand the errors in the final estimates of the angle, before validating the method.

In this abstract simulations have been performed, and a method using Levenberg Marquardt (LM) algorithm, [1], has been proposed. The size of the errors has been estimated as a function of the angle and relative volume fraction in the two-fiber system.

Method:

The simulation tool is based on the distribution of the Apparent Diffusion Coefficient (ADC) as a function of diffusion direction **v** [2]. The two fibers adaptation is given in reference [3]:

$$ADC(v) = \frac{1}{-b}\log\left(f\, e^{-b.v^T.D1.v} + (1-f)e^{-b.v^T.D2.v}\right) \qquad (1)$$

where b (s/mm^2) identifies the diffusion weighting strength, the unitary vector $\mathbf{v} = (v_x, v_y, v_z)^T$ indicates the direction of the diffusion gradient. The two volume fractions are f and(1 – f). The diffusion coefficients for fiber 1 and fiber 2 are summarized by the positive definite symmetric 3x3 tensors D1 and D2 [4].

In our simulations, θ is defined as the angle between the two fibers, ranging between 0° and 90°. White noise is added to these simulated ADC measurements, to match a predefined SNR of 30 and 200. In all our simulations, we used 40 equally distributed diffusion directions.

In our fitting procedure f and θ are estimated from the simulated ADC(v). We applied a LM method to this non-linear problem. The starting configuration for the fiiting algorithm was 90° and 0.5 for θ and f respectively.

In the simulations 290 different combinations of volume fraction f and angle θ were used. The b-value was set to 2500s/mm^2, f ranged from 50% to 90% while the angle θ was set between 22.5° and 90°. The absolute error $|\theta - \theta_E|$ between simulated input and fitted result was computed as a function of f and θ inputs.

Results:

In figure 1, the absolute error is shown as a function of volume fraction. It is clear that the error becomes larger than 5° when the volume fraction exceeds 82%. From figure 2, it becomes apparent that there is a large range around 45° which produce errors larger than 5°. In Figure 3, the distribution of all errors is shown for two different SNR simulations. The average error is much larger for the lower SNR of 30.

Discussions:

From Figures 1 and 2, the absolute error seems to depend in a large way on the volume fraction and the angle between fibers. Fractions larger than 85% or angles around 45° make it difficult to perform the two fiber fit.

From Figure 3, it appears that the SNR of 30 is posing a problem to resolve the individual fiber system for a large range of volume fractions and angles. Therefore, clinical measurements will need a SNR of at least 30 to allow an accurate two fiber fit.

In our simulations, we occasionnaly found irregular histograms. It is thought that these results relate to the fact that LM fitting algorithm can find solutions in local minima. It is thus sensitive to the starting values for f and θ. In the future, this could be resolved by choosing spatially smart starting values or using a global minimum search method (e.g. simulated annealing).

Conclusions:

The work of this abstract shows that simulations and fittings yield practical information on the possibility to resolve multi-fiber situations. It is also shown that a minimum SNR of around 30 is crucial to resolve fiber-crossings. We further found that the LM algorithm can be used for fiber-crossing situation, but needs better starting estimates.

Finally, we think that the simulations have shown that we will be able to resolve fiber-crossings in a large number of cases, provided that the volume fractions are not larger than 85%.

References:

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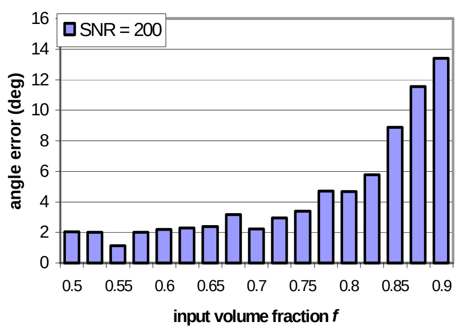

Figure 1
Results of the absolute error as a function of the volume fraction (SNR=200).

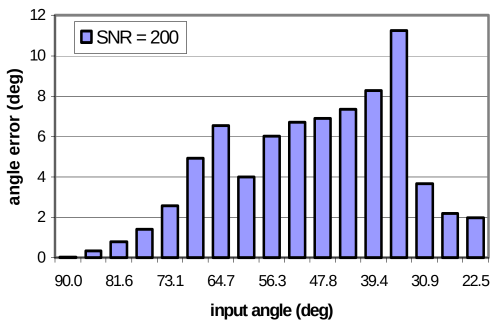

Figure 2
Results of the absolute error as a function of the angle between fibers, (SNR=200).

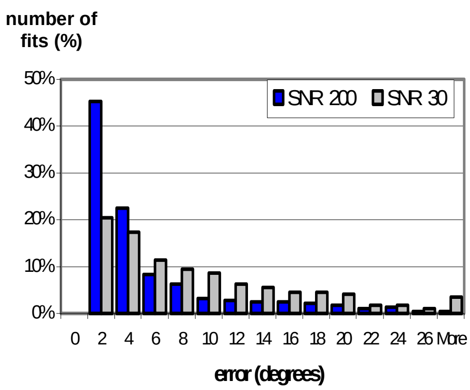

Figure 3
Histogram of the resulting error over all configurations for two different SNR values