THE DIFFUSION-ODF AS A BAND-PASS FILTER - SELECTING THE RIGHT DIFFUSION AND IMPROVING ANGULAR RESOLUTION

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TARGET AUDIENCE - This abstract is targeted for researchers and neuroscientists working with diffusion imaging.

PURPOSE – The diffusion orientation distribution function (dODF) depends on the probability of water molecules displacement and is computed directly from the diffusion propagator, displaying intrinsically smooth profiles [1]. In Diffusion Spectrum Imaging (DSI), the presence or absence of Hanning filtering in the data, or the type of interpolation to use prior to the dODF computation are critical to ensure a good angular resolution [2,3]. Despite all these advances in the processing of the dODF, there is a lack of physical interpretation on some of the parameters that are used in this reconstruction. In this study, we propose a new method of computing the dODF characterized by restricting the range of integration to displacements associated with the physical displacement of intra axonal diffusivity as if a band-pass filter is used.

METHODS – In this study we simulated 0°,15°,30°,45°,60°,75° and 90° crossing fibre configurations as the sum of two fibres with a diffusivity profile of [1.7 0.2 0.2] $x10^{-3}$ mm^2/s (no diffusional exchange), for a high resolution DSI acquisition with b-value of 8000 s/mm^2 and 11x11x11 grid yielding 515 sampling points, for a diffusion time of 50ms. Diffusion propagator was obtained using a DSI pipeline, which included zero-padding and with/without Hanning Filtering in accordance with [3]. The main objective of this study was to apply and evaluate the computation of the ODF used like a band-pass filter in order to recover only information related to the diffusion characteristics of white matter. This can be achieved by restricting the integration ranges for the dODF which are selected based on the true displacement (r) of intra axonal diffusivity fibres, rather than integrating the full range of probabilities. The mean displacement is given by $\langle r \rangle = \sqrt{6\,D\,\Delta}$, where D is the diffusivity of the tissue, and Δ is the diffusion time. Taking this information into account we can identify a band of integration which will range from a lower bound α to an upper bound β, both representing distinct physical displacements (Figure 1). In this study we used $\alpha = 2 * r_{GM}$ and $\beta = 2 * r_{WM}$ to exclude most of the slow diffusivity components like grey matter and exclude fast displacements that should not be related to intra-axonal diffusivity, respectively. To enable the generalization of the method for any given acquisition we need to calculate the maximum displacement (r_{max}) for that particular scheme and correct the integration ranges for that, as:

$$ODF(\boldsymbol{u}) = \int_{\alpha/r_{max}}^{\beta/r_{max}} P(r\boldsymbol{u})\, r^2 \; dr.$$

RESULTS AND DISCUSSION – Figure 2 displays the computation of the ODF for different crossing angles and displays both the influence of Hanning filter and the integration ranges in the final ODF reconstruction. The introduction of Hanning allows the exclusion of some artifacts in the ODF at the expense of much smoother profiles (Figure 2, upper panel). By limiting the ranges of integration we obtain improvements in angular resolution. Specifically in the absence of Hanning filter, Figure 2-bottom panel, we are able to resolve crossings down to 30°. Finally in Figure 3, it is possible to identify how the proposed method works in the presence of partial volume effects. Not only does it allow recovery of white matter features, but it also excludes the contamination coming from fast diffusion components, which cannot be dealt with by the standard way of computing the ODF, i.e., without restricting the integration range.

CONCLUSION – We have proposed a new method to better compute the orientation distribution function from DSI data or any other propagator based diffusion imaging technique. This method considers realistic physical displacements to isolate the tissues under investigation and has shown better performance than current methods with or without the use of Hanning filter. Additionally to selecting only the desired information with this band-pass approach, we are able to exclude some aliasing produced by fast diffusion components visible without Hanning filtering. This method also removes the dependence on min-max normalizations allowing for quantitative analysis to be performed on the dODF. Future studies will focus on the optimization of the integration ranges and validation of this method with real data and alternative techniques able of reconstructing the diffusion propagator [4,5].

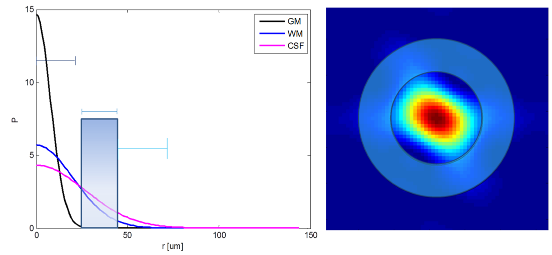

Figure 1, Left - 1D Propagator for different diffusivities species: Grey matter (GM), White Matter (WM) and Cerebrospinal Fluid (CSF), with 0.7 $x10^{-3}$ mm^2/s, 1.7 $x10^{-3}$ mm^2/s and 3 $x10^{-3}$ mm^2/s, respectively. Figure 1, Right – Pictorial representation of band pass filter in the propagator.

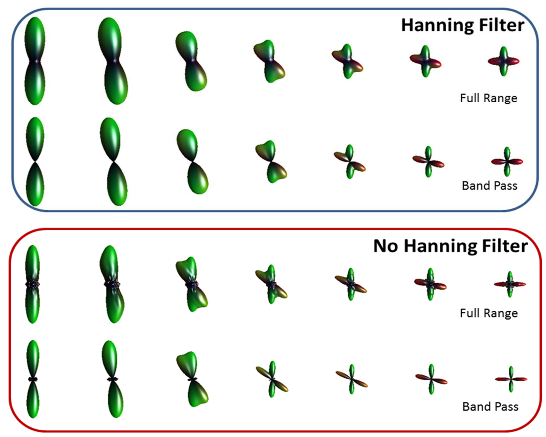

Figure 2 – Computation of the ODF on simulated data from a high resolution DSI scheme and 7 different crossing angles (0 to 90 in 15 degrees steps). For each panel, the first row displays computation with standard approach (Full Range) and bottom row shows proposed method (Band pass). Hanning filtering was applied to the propagator prior to ODF computation in top panel one (blue) and not in bottom panel (red).

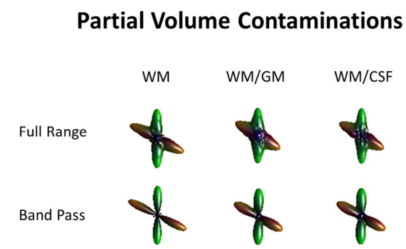

Figure 3 – Example of a 60° crossing fibre configuration with/without different partial volume contaminations and different methods of ODF computation (no Hanning filtering applied to the propagator).

[1] Wedeen, V. J. et al, MRM 2005, 54(6), 1377–86 [2] Tax, C. et al ISMRM 2014; [3] Paquette, M. Et al ISMRM 2014; [4] Özarslan, E. et al, ISMRM 2009; [5] Özarslan, E. et al, NeuroImage 2013, 78, 16–32;