Diffusion gradient orientation schemes for DTI acquisitions with unquiet subjects

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Introduction

To estimate the diffusion tensor, acquisitions must be performed for at least six non collinear spatial orientations of diffusion gradients [1]. The more spatially different the orientations are, the more accurate the estimation in each voxel is [2]. It has then been shown that an icosahedral distribution of the orientations is optimal [3]. Furthermore, increasing the number of orientations considerably improves the SNR, the diffusion-to-noise ratio [4] and consequently the information about local tissue organization is more accurate [5]. Unfortunately the acquisition time increases. Besides, it is not always possible to predict how long a subject (for example an infant) will keep quiet in the MRI magnet. Our goal was to implement orientation acquisition schemes which enable to obtain the best information, which means the best spatial distribution of the orientations, even if motion happens or if the acquisition is stopped before achievement, leading to short acquisition time.

Material and Methods

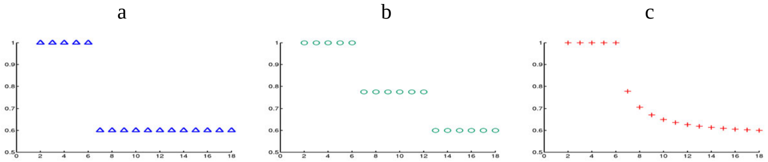

Figure 1: Interaction coefficients (α_{1j}) as function of orientation number (j), between the 1st orientation and the 17 others, for a set of 18 orientations (sub-sets of 6 orientations) with an arbitrary minimal threshold, in the three cases (a, b, c).

Schemes description and generation: In analogy to the physical model of charges distribution on a sphere, electrostatic-like interactions between the orientations were considered. The global energy of the system was minimized:

$$E = \sum_{i<j} E_{ij}$$

with E_{ij} the interaction energy between orientations i and j. The previous assumption means that both the whole set of orientations and sub-sets of orientations (acquired in reduced time) must stay spatially correct. In order to take into account that the more distant in time two orientations are, the more reduced their interaction is, different interaction weights between orientations were introduced, according to their distance during sequence acquisition:

$$E_{ij} = \alpha_{ij} E_{ij}^0$$

with α_{ij} the interaction coefficient between i and j and E_{ij}^0 their electrostatic energy. Then three different orientation schemes (involving different interaction coefficients) were considered, in order to answer different motion cases. In the first case, the acquisition is composed of different sub-sets of orientations, each of the same number (typically 6) and motion can happen at any time. Therefore each sub-set and the whole set must be correct. In our model, orientations belonging to the same sub-set fully interact while orientations of different sub-sets interact with a constant non null reduced factor (Figure 1a). In the second case, the principle is the same but motion can happen more probably at the end of acquisition (typically the patient is asleep and might wake up). Therefore a set must add further accurate spatial information to previous ones. The model is the same than in case 1 but the more distant in time the sub-sets are, the more reduced the interaction factor is (Figure 1b). In the third case, a single acquisition is performed and motion can happen at any time. Then each acquisition window of at least 6 orientations must be correct. In our model, an orientation fully interacts with its 10 closest neighbours in time and interacts less and less with an orientation as its distance in time increases, while keeping a minimal interaction (Figure 1c). Given the interaction weights defined for each scheme, the global energy of the system was minimized according to a gradient method and a simulated annealing method. The program algorithm was implemented in C++.

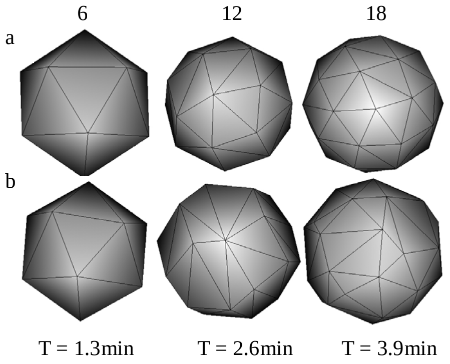

Figure 2: Sets of 6, 12, 18 orientations of spatially perfect schemes (a) and of the case 2 scheme (b) with corresponding acquisition time.

Data acquisition: To test the acquisition schemes, acquisition were performed with adults, under a protocol approved by the Institutional Ethical Committee. A DW-SE-SS-EPI technique was used on a 1.5T MRI system (Signa LX, GEMS, USA) with maximum gradients amplitude of 40mT.m^{-1}. The acquisition parameters were: 32 interleaved axial slices of 3.4mm thickness, FOV = 24cm, matrix = 128x128, b = 0 and 700s.mm^{-2}, TE = 66.5ms, TR = 12s. Diffusion gradients were applied in 18 orientations according to the three schemes described above, leading to a 3.9min acquisition time.

Data processing: After correction of the geometric distortions due to eddy currents [6], the diffusion tensor parameters were estimated using Brainvisa software [7]. Maps of apparent diffusion coefficient (ADC), fractional anisotropy (FA) and FA-weighted color-coded directionality (RGB-FA) were generated.

Results and Discussion

Spatially correct sets of orientations could be generated for the three schemes. The example of case 2 is here presented. Figure 2 shows the orientation distributions of the whole set of 18 orientations and its sub-sets (of 6 and 12 orientations) (b), in comparison with the spatially perfect distributions (a). All distributions of this scheme are not so different from the perfect ones, which is highlighted when global energies are compared. Moreover, this scheme presents the advantage that the acquisition can be stopped at any time in case of motion (sets of 6 and 12 are correct). As presented in Figure 3, the tensor maps obtained on volunteer for this scheme (b) were very similar with the ones obtained with conventional schemes (a) either if the whole set (18 orientations) or only a sub-set (6 or 12 orientations) is acquired.

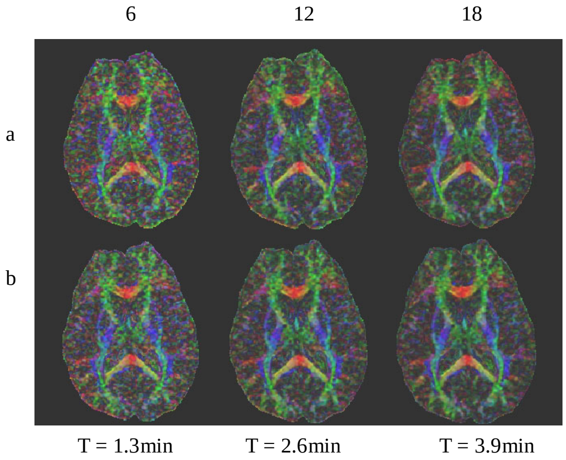

Figure 3: RGB-FA maps obtained using 6, 12 and 18 orientations of spatially perfect schemes (a) and of the case 2 scheme (b) with corresponding acquisition time.

Conclusion

The three orientation distribution schemes presented aimed at responding to particular situations for which subjects might not keep quiet during acquisition. These cases can not be directly compared since their goal is not the same. The tensor maps obtained either if the whole orientation set or only a sub-set is acquired are equivalent with the ones obtained using conventional schemes during the same acquisition time. Then, using the proposed approach, it is possible not to lose the whole data set whether motion happens before the end of acquisition. Of course, direct comparison between subjects for which the number of orientations acquired is not the same is not directly achievable.

References

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