Real-time Rician noise correction applied to real-time HARDI and HYDI

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Introduction

Real-time diffusion-weighted (DW) Magnetic Resonance Imaging (rt-dMRI), introduced by [1], performs diffusion tensor (DTI) and High Angular Resolution Diffusion (HARDI) imaging during the ongoing acquisition. This technique is fully dedicated to clinical applications, where scan duration is a limiting factor, and produces in real-time all maps stemming from any HARDI or Hybrid Diffusion (HYDI) model (such as the General Fractional Anisotropy (GFA), the Orientation Distribution Function (ODF) and the Fiber Orientation Distribution (FOD)). Further progress was made about optimizing the orientation set [1-2] and detecting on-line motion [3]. But, a common problem of dMRI is the contamination of the signal with noise, especially at high b-values. Assuming a Rician noise, which is the noise model for a single-channel acquisition [4], we have developed a real-time correction dedicated to real-time HARDI and HYDI [5]. The proposed technique relies on the Linear Minimum Mean Square Error Estimator (LMMSE) [6] and the Kalman Filter (KF) [1], embedded with a feedback loop.

Material & Methods

Noise correction - First, the corrected DW signal $\hat{S}(\mathbf{v},\mathbf{o})$, at voxel position **v** and along the diffusion direction **o**, is obtained from the measure $S_m(\mathbf{v},\mathbf{o})$, using the LMMSE and an estimation of the noise standard deviation computed from the background of the image. The result is injected in the KF that returns the coefficients $\hat{\mathbf{C}}_{\mathbf{v}}^{DWI}$ of the decomposition of the ratio $R=\hat{S}(\mathbf{v},\mathbf{o})/\hat{S}_0(\mathbf{v})$ on a modified Spherical Harmonics (SH) basis (fig. 1). As expected, the LMMSE alone causes a smoothing effect in corrected images, due to averages performed isotropically with local neighborhoods. To reduce this effect, a further feedback loop is added to the algorithm, stemming from the current local estimate $\hat{\mathbf{C}}_{\mathbf{v}}^{DWI}$, in order to provide a dual spatial and structural anisotropic weighting:

$$w(\mathbf{v},\mathbf{v'}) = \underbrace{\exp\left(\frac{-(\mathbf{v'}-\mathbf{v})^2}{2\alpha^2}\right)}_{w_{SPATIAL}} \underbrace{\exp\left(\frac{-\sum_{j=1}^{N}\left(C_{\mathbf{v'}}^{DWI}(j)-C_{\mathbf{v}}^{DWI}(j)\right)^2}{2\beta^2}\right)}_{w_{STRUCTURAL}}$$

$w_{SPATIAL}$ weighs the influence of a neighbor from a Gaussian model using its distance to the central voxel; while $w_{STRUCTURAL}$ gives more influence to the neighbors sharing similar underlying structural organization. The 2 weights involve two α and β parameters to be tuned to reach optimal results. α was set to 1.5, providing a good trade-off between accuracy and smoothing. β was optimized using various simulations of crossing fiber bundles built using a Gaussian mixture model with Rician noise addition, and β was obtained equal to 0.15. We applied the real-time Rician noise correction method on multiple-shell data with the following parameters: maximum SH order=6, 5x5x5 neighborhood, (α,β)=(1.5, 0.15).

Acquisitions – axial 2D single shot twice refocused DW Spin Echo EPI acquisitions were performed on a 3T Tim Trio (Siemens, Erlangen) with following parameters: 64 diffusion directions, b=0/3000/6000s/mm², matrix 96x96, 60 slices, FOV=19.2cm, slice thickness=2mm, , T_E/T_R=117ms/11.5s, GRAPPA factor=2, partial Fourier 5/8, RBW=1410Hz/pixel.

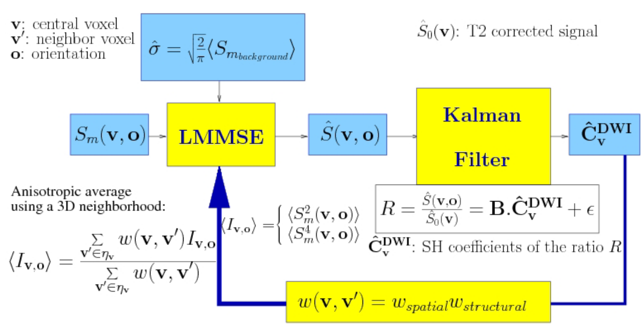

Figure 1: The Rician noise correction algorithm.

Results & Discussion

After correction, GFA maps yielded improved contrasts, with details emerging better from the images and ODF maps gained in coherence (fig. 2-3). The raw ODF shown on fig. 2 indicates 3 orientations, among which is a putative spurious peak due to noise. It disappears after correction, whereas the 2 others remain with bigger lobes, providing more angular accuracy from a neighborhood point of view. Fig. 3 shows similar effects at a very high b-value, on a voxel belonging to the corpus callosum known to be unidirectional. Thus, noise was decreased, while the good angular resolution was kept.

The Rician noise correction method was made available for real-time use, thanks to a parallelization and a distribution on a cluster of 60 CPUs that lead to a huge reduction of the processing time per volume: from 37s on a workstation to 0.8s with the cluster, thus far below the repetition time of 11.5s.

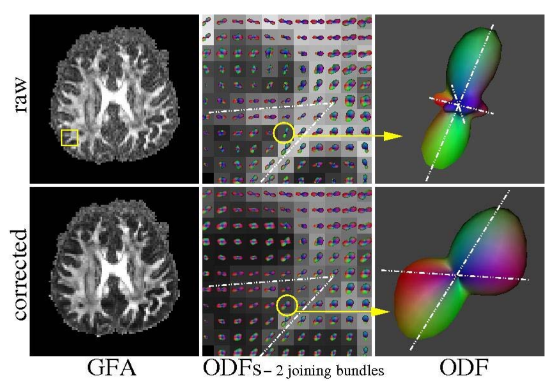

Figure 3: Results at b=3000s/mm²

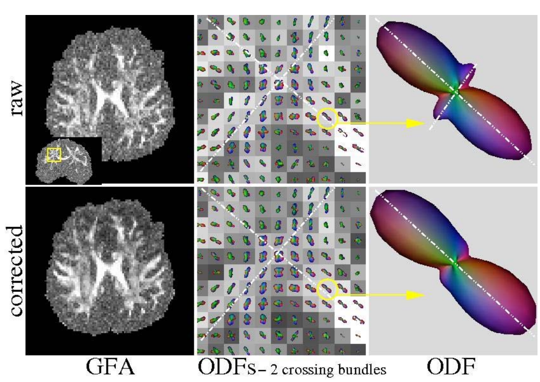

Figure 3: Results at b=6000s/mm²

Conclusion

We have developed a real-time Rician noise correction method, compatible with the real-time environment of [1] and appropriate to a wide range of b-values, including high b-values such as 6000s/mm² where the signal to noise ratio is very low, thus allowing the use of very high b-values for diffusion acquisitions at 3T.

References

[1] Poupon *et al.*, Med. Image Analysis 2008; 12:527-534 [2] Deriche *et al.*, Med. Image Analysis 2009; 13:564-579 [3] Caruyer *et al.*, ISBI 2010, 812-815
[4] Constantinides *et al*, MRM. 1997; 38(5):852-857 [5] Brion *et al*, MICCAI 2010 [6] Aja-Fernández *et al.*, IEEE Trans. on Med. Imaging 2008; 27:1389-1403