Notes on HARDI data preprocessing: Effect on tensor fit

Scott Trinkle

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These notes describe the effect of data denoising on the resulting tensor fit, using the principal diffusion direction (PDD) and fractional anisotropy (FA) as comparison metrics.

Tensor fitting was performed using the FSL dtifit tool on the raw data, as well as on the data denoised with sliding windows of $5 \times 5 \times 5$, $7 \times 7 \times 7$, and $9 \times 9 \times 9$. For this comparison, the volumes were not registered before computing the tensor fit.

Figure 1 shows histograms of the percent difference in FA between the raw and denoised volumes for each window size, calculated as

$$\Delta\text{FA} = \frac{\text{FA}_{\text{denoised}} - \text{FA}_{\text{raw}}}{\text{FA}_{\text{raw}}} \times 100. \tag{1}$$

A binary mask was created for the brain using the FSL BET tool on the averaged $\bar{b}_0$ volume from the $7 \times 7 \times 7$ denoised volume. All comparisons were restricted to this mask.

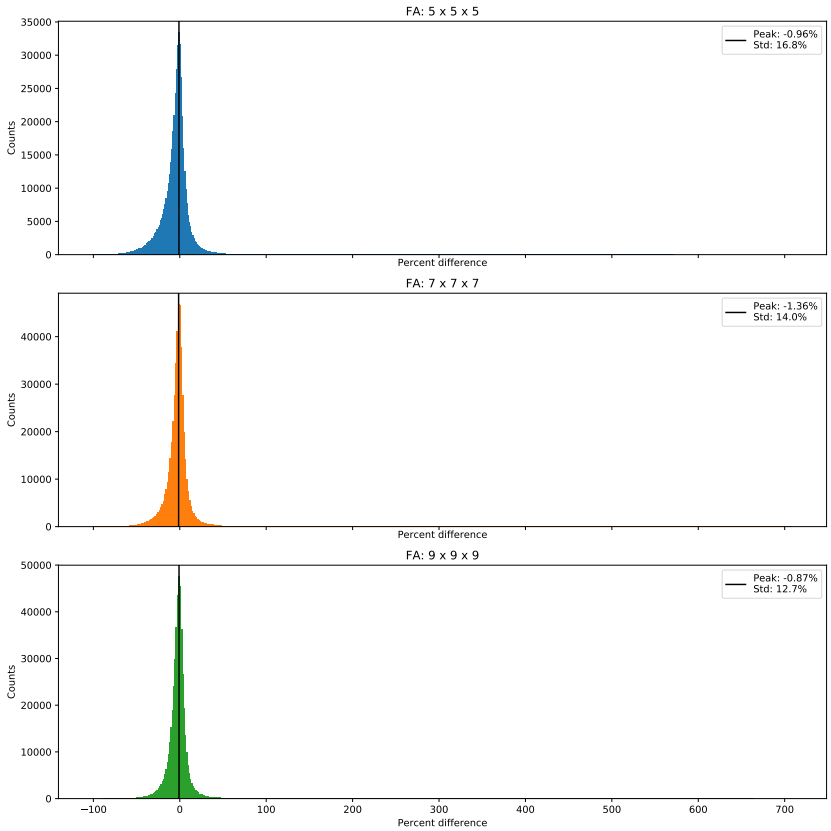

Figure 1: Difference in FA between raw tensor fit and the denoised tensor fits with different window sizes. The bold line indicates the peak of the distribution. Comparisons were restricted to voxels within the brain.

Overall, FA differences for all of the denoised volumes were around 1%. The anomolous counts (up to 600-700%) resulted from background voxels being included in the brain mask. Generally, the distributions get wider with smaller window sizes.

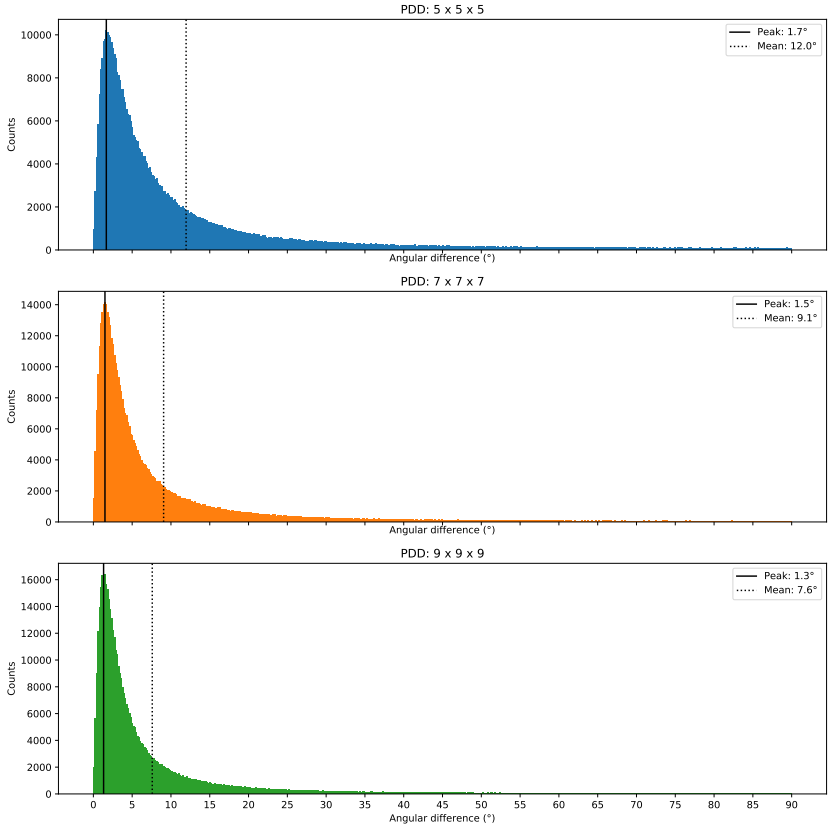

Figure 2: Angular difference in PDD between raw tensor fit and the denoised tensor fits with different window sizes. The bold line indicates the mean of the distribution, while the dotted line indicates the mean. The Comparisons were restricted to voxels within the brain. Note that the PDD at each voxel is unique within a minus sign, so angular differences are restricted to [0°, 90°].

Figure 2 shows histograms of the angular difference in PDD between the raw and denoised volumes for each window size. Note that the PDDs are unique within a minus sign, so the angular differences are restricted to [0°, 90°]. The distributions have similar peaks of about 1.5° for each window size, with means increasing from 7.6°—12.0° as the window sizes decrease. Figure 3 restricts the PDD comparisons to voxels with FA>0.7. Here, we see similar trends with a much lower spread in the distributions, indicating that denoising has less of an effect on PDD for high FA voxels (presumably white matter).

Figure 4 shows spatial maps of PDD angular difference, b_0 intensity, and FA difference (from left to right, respectively). These images confirm the potential trend from comparisons of Figures 2 and 3: regions with low angular differences correspond to regions of high FA and vice versa. In other words: the highest angular differences generally occur in either gray matter or in the ventricles (where diffusion is more isotropic), while the lowest differences occur in the white matter, with more oriented structure.

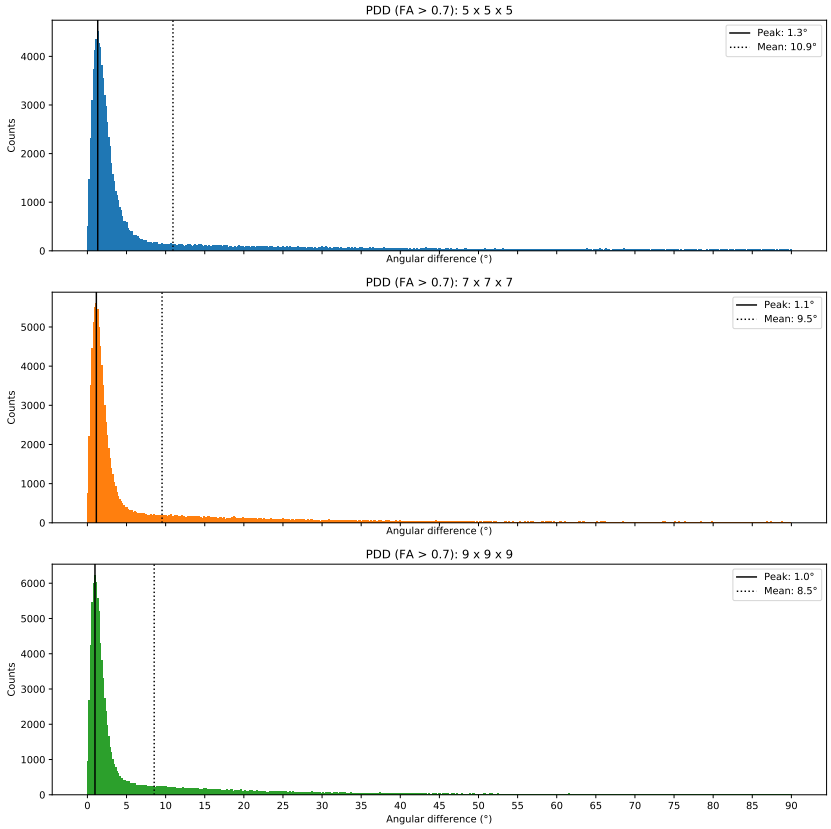

Figure 3: Angular difference in PDD between raw tensor fit and the denoised tensor fits with different window sizes. Here, comparisons were restricted to voxels in the brain with an FA > 0.7. The bold line indicates the mean of the distribution, while the dotted line indicates the mean.

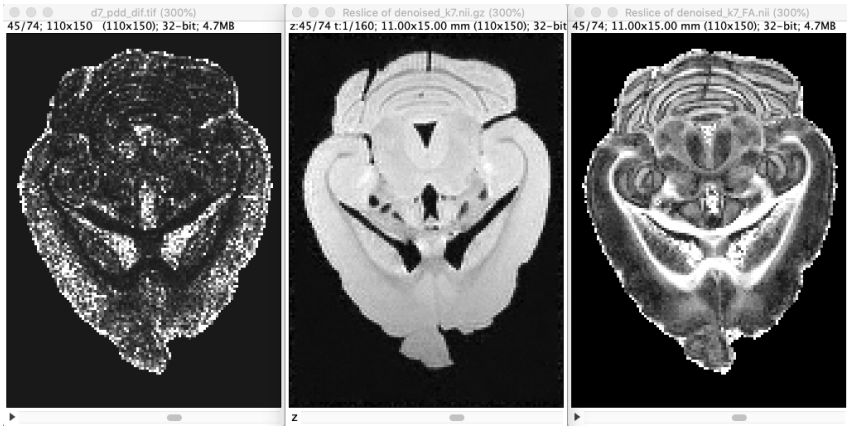

Figure 4: From left to right: PDD difference image, b_0 image, and FA image of the same slice. Note that areas of low PDD difference are in high FA regions, while areas of high PDD difference are in low FA areas (including the ventricles).

Conclusion

These results demonstrate that denoising the raw data results in a measureable effect on the tensor fit. It is not clear how to conclude which denoising window size is "best" at this point. Generally, the differences between denoised and raw fits is much greater than the differences between fits calculated with windows.

Next, I will look at a constrained spherical deconvolution ODF reconstruction and see how it changes with window size. I expect to see similar results — that the reconstruction does not seem dramatically sensitive to the window choice. In this case, I plan to follow the paper's recommendation of choosing $N > M$ (N: voxels in the window, M: diffusion directions), and use the $7 \times 7 \times 7$ window to start looking into distributions / locations of crossing fiber populations in the sample. We can use these reconstructions to plan out where and how to section the sample before microCT imaging if we end up needing to do that.

Once we have the microCT ground truth ODFs, we can use those as a benchmark to evaluate all of the parameters involved in diffusion MRI processing — denoising, registration, the various tunable parameters in different ODF reconstruction algorithms, etc.