Effect of non-local means denoising on cortical segmentation accuracy with FACE

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Introduction

Cortical thickness measurements based on MRI have the potential to accurately detect changes in the cortical gray matter. During the last decade, several methods have been developed to estimate cortical thickness using surface based reconstruction (Dale 1999, Kim 2005, Eskildsen 2006). Due to the high sensitivity of reconstruction methods to acquisition artifacts, noise in MRI signal may directly affect the obtained measurements. Usually, this noise is reduced using various smoothing filters. Recently, the non-local means (NLM) filter has demonstrated very high denoising performance compared to these traditional filters (Coupe 2008). In this study, we investigated the sensitivity to noise of cortical surface reconstruction and the ability of the NLM filter to reduce the effect of noise.

Methods

Sixteen repeated T1-weighted scans with isotropic 1mm voxels of the same subject were acquired over a short period of time (Holmes 1998) and were used to create an average image with very high signal-to-noise ratio. The 16 scans were bias field corrected (Sled 1998), intensity normalized, registered to ICBM space and aligned using rigid transformations (Collins 1994) before computing a voxel-by-voxel intensity average dataset with greatly reduced noise (reference image). In order to simulate several levels of noise, the reference image was added Rician noise (1-10%). The optimized blockwise NLM filter (Coupe 2008) was then applied to the 10 simulated noisy images as well as the 16 original scans.

FACE (fast accurate cortex extraction, Eskildsen 2006) was applied to the reference image, the simulated noisy scans with and without NLM filtering, and the original 16 images with and without NLM filtering to generate cortical surfaces delineating the WM/GM and the GM/CSF boundary. Cortical surfaces extracted from the reference image were considered as the reference during comparison.

To measure the cortical segmentation error, the root mean square (RMS) of the distances from the vertices of the test surface to the reference surface was calculated for both WM and GM surfaces. Furthermore, the surfaces were voxelated onto a 1mm isotropic voxel grid to enable calculation of the Dice coefficient (DC) (Dice 1945). The WM, GM, and CSF classifications (fuzzy c-means), which are a part of the cortical extraction process, were also evaluated by DC.

Results

Fig. 1 shows input images, tissue classification images, and images with cortical surfaces overlaid for the reference image built on the 16 repeated scans, the reference image with 9% of added Rician noise before and after NLM filtering. Note that the GM surface has difficulties capturing the GM/CSF boundary in the noisy image, while after denoising the delineation is improved. This improvement can be seen on Fig. 2 and 3, where the segmentation accuracy on denoised images is better for all the noise levels in terms of DCs and RMS distances. The mean noise level over the 16 repeated scans was estimated at 4.8±0.3% using the noise estimation proposed in (Coupe 2010). This level is indicated on the charts in Fig. 2 and 3. Fig. 4 shows the effect of denoising the 16 original scans on the segmentation accuracy compared to the reference image. Denoising improved the accuracy significantly ($p<0.001$, paired t-test) for both WM and GM surfaces.

Conclusions

The results demonstrate that applying NLM filtering to the MRI scans improves the accuracy of cortical surfaces extracted using FACE. For the experiments with synthetic noise, the RMS distance to the reference was below 0.5mm for noise levels up to 10%, which covers the realistic range of noise present in MRI scans. Segmentation accuracy of the original scans was also improved by denoising, which resulted in RMS distances of 0.44±0.03mm and 0.42±0.03mm for GM surfaces and WM surfaces compared to 0.49±0.03mm and 0.52±0.06mm for the unfiltered scans. The RMS distances obtained are lower than previous experiments using another cortical reconstruction method on the same data (Kim 2005).

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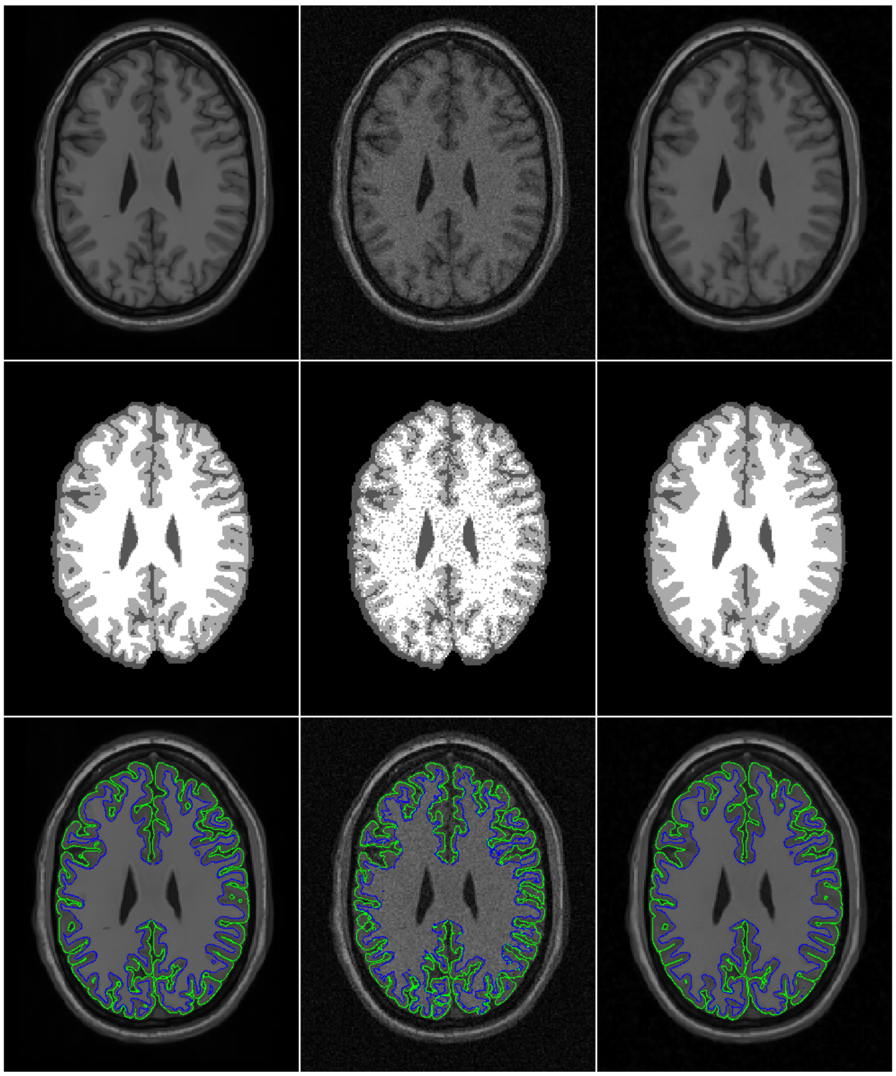
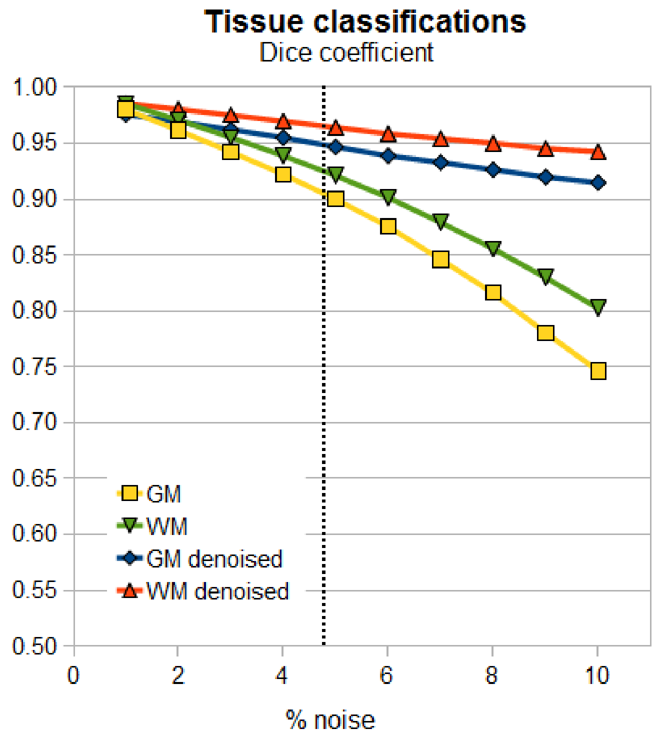


Figure 1: Rows: Unprocessed image, tissue classifications, and image with surfaces overlaid. Columns: Reference, 9% noise, and 9% noise + NLM denoising.



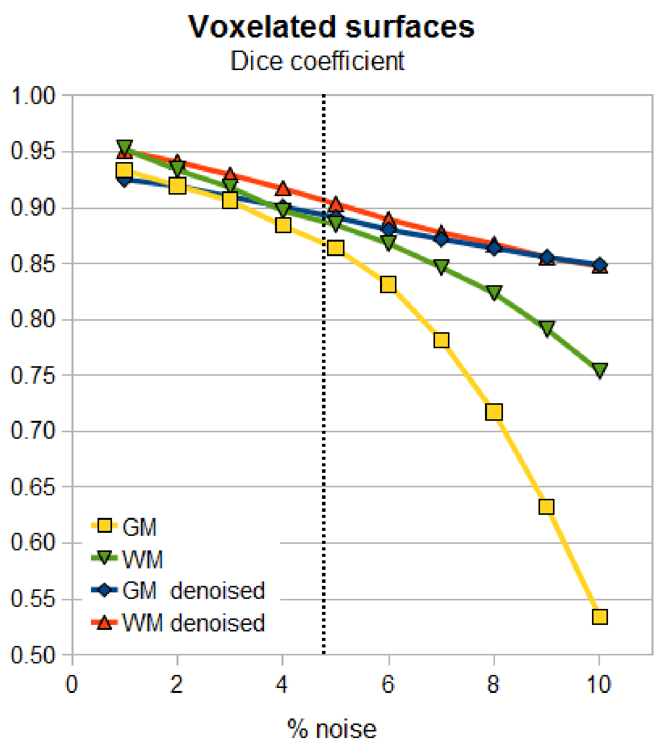


Figure 2: Dice coefficent of tissue classifications and voxelated surfaces with increasing levels of noise with and without NLM denoising.

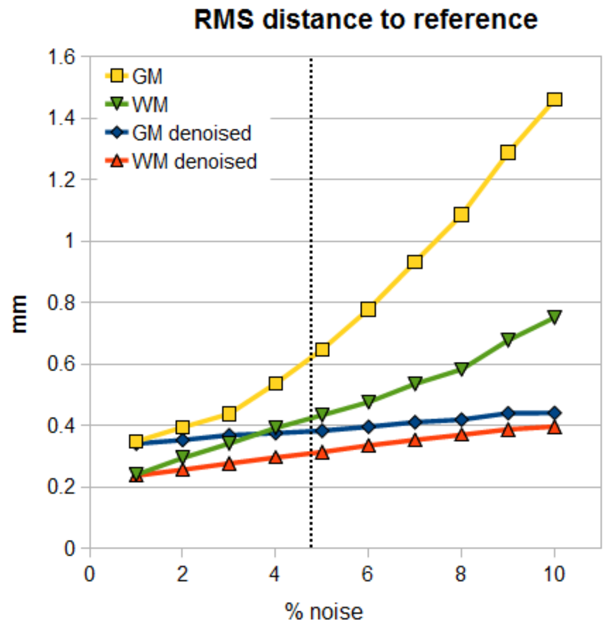


Figure 3: Surface RMS distance to reference for increasing levels of noise with and without NLM denoising.

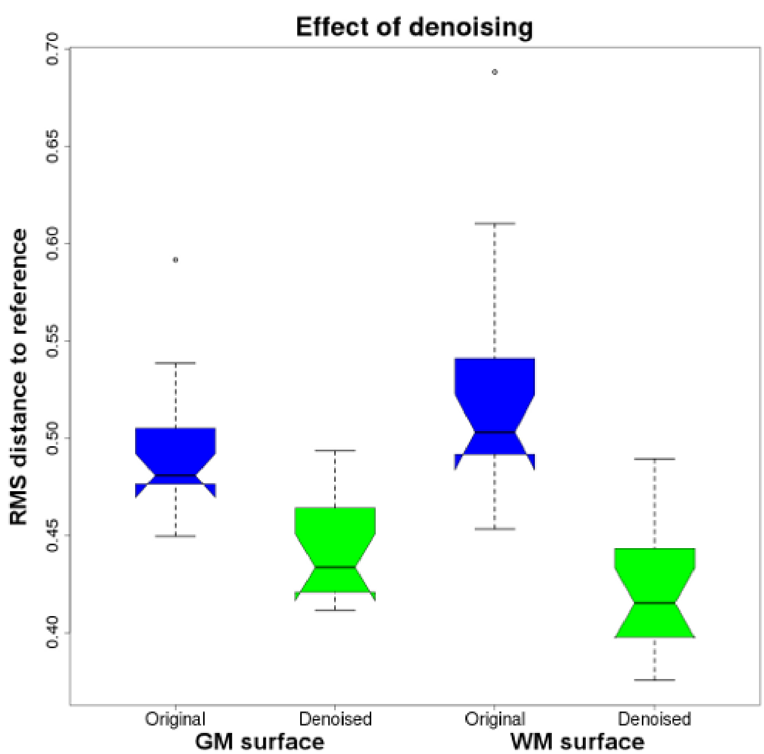


Figure 4: RMS surface distances for the 16 repeated scans to the reference before and after NLM denoising.