

3D Inhomogeneity Correction for MRI

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Introduction: High field magnetic resonance imaging (MRI) can give us beautiful images of the brain but even the best images suffer from intensity inhomogeneity. This is generally the result of the sensitivity of the receiver coils (a global issue) but also from differences in magnetic susceptibility between brain areas (a local issue). Neuroscientists face the difficult problem of correcting for intensity inhomogeneity when identifying white matter from grey matter. This delineation is required to mathematically flatten or inflate a model of the brain cortex for further analysis. Salvado et al (2006) compared 3 forms of 2D inhomogeneity correction on neck slices and demonstrated that their method, local entropy minimization with spline support (LEMS), reduced intensity inhomogeneity from global coil based inhomogeneity and from local susceptibility issues. Here we report that this process can now be done in 3D on full brain images.

Methods: We first filter the 3D image (Y) as described in Black et al (1998). The foreground/background threshold which is required by this procedure is automatically determined as the first post-max valley in the smoothed intensity histogram (e.g. between 50 to 100 in Fig. 1A). We then convolve a sparse, uniformly spaced sample (every other element is each direction) with a 21mm full width half maximum 3D Gaussian kernel to initialize a bias field estimate (B0). This estimate is then expanded and linearly interpolated to match the size of the original image. The mean value of B0 is scaled to match the mean value of the original image. This initial bias estimate is used to form a cubic spline model of the actual bias field (B), which is iteratively modified so as to minimize the entropy of the intensity-corrected image. Analysis points, or knot centers are evenly spaced across the 3D image and the volume of each knot is defined by the centers of its neighbors. Knots are analyzed in descending order of their SNR. The value within each knot is optimized to minimize the entropy of the corrected image (X; where $X=Y/B$) as described in Salvado et al (2006). This process is both iterative and cumulative so that with the last knot, the entire image is used in the entropy calculation. For intersubject normalization the last major peak in the intensity histogram is assumed to be the white matter and is scaled to a fixed value.

Results: This method was performed on 40 full brain images (T1 weighted; 1mm isovoxel; 256x256x176 voxels). Figure 1 shows the intensity histograms for the 40 brains at 4 key steps in the LEMS3D procedure. Fig 1A shows the original data. Fig 1B shows the effect of the 3D anisotropic diffusion (Black et al 1998). Fig 1C shows the results of the LEMS3D procedure. Notice the scattered but clearly separable grey and white matter peaks in each histogram. Fig 1D shows the intersubject normalization. Now all subjects have a similar and clear white matter peak. Figure 2 shows the intensity based white matter selection done in BrainVoyager QX 1.9. Figure 2A clearly shows missed white matter in the anterior and lateral sections. This is greatly reduced in the "after" image (Fig. 2B) on the right without falsely including the posterior grey matter.

Discussion: There are several advantages to the LEMS3D method. 1) It has true 3D correction, not slice-by-slice. 2) It addresses local as well as global inhomogeneity. 3) One can "set-it-and-forget-it" in that it requires no a priori tissue classification and automatically finds the background masking thresholds. This reduces 'user' time and increases reliability. 4) Though this process may be computationally demanding, it can be completed on a Pentium 4 class desktop computer running Matlab in just over an hour for a 256x256x176 voxel image. 5) Lastly, this new technique is able to normalize across subjects for an automated white matter selection.

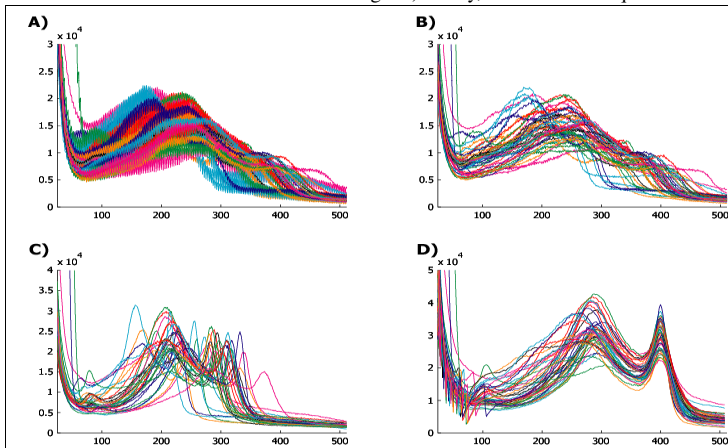


Fig 1: Intensity histograms for 40 brains. A) shows the original histogram from the raw data; B) shows the same histograms after filtering using robust anisotropic diffusion; C) after LEMS3D processing the histograms present clear peaks corresponding to the tissues; D) after our final intensity normalization steps all the histogram peaks overlap allowing easier segmentation and image analysis.

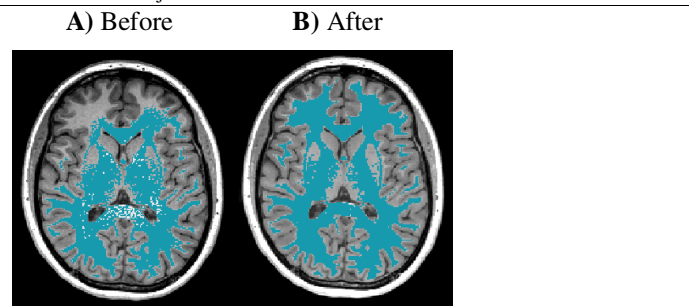


Fig2: Example of intensity based white matter selection. The blue denotes the voxels selected as white matter using Brain Voyager QX. A) Data was manually loaded in to BrainVoyager QX and adjusted for intensity. B) Data was run through LEMS3D and automatically loaded in to Brain Voyager QX.

References:

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- Salvado O., Hillenbrand C., Zhang S, Wilson, D L. (2006) Method to Correct Intensity Inhomogeneity in MR Images for Atherosclerosis Characterization IEEE Trans. On Medical Imaging. 25(5).