Background Field Removal at the Boundary

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Target audience: Those interested in improving background field removal at the boundary.

Purpose: Background field removal is an essential step in generating a high-quality QSM image. Current techniques perform better within the ROI than at the boundary. Some methods are corrupted by overfitting errors (PDF[1]), while others avoid the issue either by eroding the ROI (SHARP[2]) or by setting the boundary conditions to an approximation (LBV[3]). Obtaining more reliable local field information at the boundary could improve QSM in the cortical gray matter, and is therefore of clinical interest. As an initial step towards this goal, we report improved background field removal at the boundary using the newly-developed iterative PDF method (iPDF).

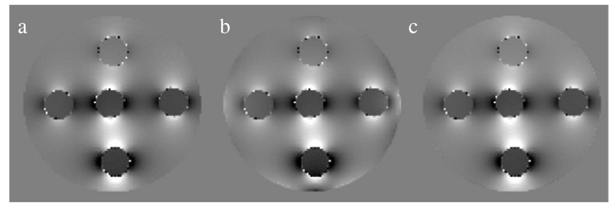

Figure 1: Local field maps of (a) true local field, (b) PDF, (c) iPDF.

Theory: The Projection onto Dipole Fields (PDF) [1] method estimates the background field by placing dipoles outside the ROI in an attempt to best fit the total field:

$\chi_B(r) = argmin_{\chi_B(r)} \left\| w(r)(b_T(r) - d(r) * \chi_B(r)) \right\|_2^2$ where $\chi_B(r)$ is the susceptibility map outside the ROI, $d(r)$ is the dipole kernel, and $b_T(r)$ is the total field. This method works well in the interior of the ROI but at the boundary, background dipoles are placed just outside the boundary to explain local fields just inside the boundary, thus generating errors.

iPDF is motivated by the hypothesis that any local field values at the boundary unexplainable by susceptibility sources inside the ROI are likely corrupted by PDF boundary over-fitting errors and should be re-estimated. iPDF first runs PDF to generate a first guess of the local field. Parts of the local field that MEDI [2] is unable to invert are discarded. This refined field estimate is then multiplied by a binary mask (w_2) to remove low SNR voxels and subtracted from the total field $b_T(r)$. PDF is then applied on this difference field in an attempt to improve the background field estimation. Since a portion of the local field has been removed, the orthogonality of the (remaining) local and background fields may be better met. The concrete steps are thus:

1. $\chi_B(r) = argmin_{\chi_B(r)} \left\| w(r)(b_T(r) - d(r) * \chi_B(r)) \right\|_2^2$
2. $b_{L,1}(r) = b_{total}(r) - d(r) * \chi_b(r)$
3. $\chi_L(r) = argmin_{\chi_L} \left\| w(r)(b_{L,1}(r) - d * \chi_L(r)) \right\|_2^2 + \lambda ||\mathfrak{M}\nabla\chi||_1$
4. $b_{L,2}(r) = d(r) * \chi_L(r)$
5. $b_B(r) = b_T(r) - w_2(r)(b_{L,2}(r))$
6. $\Delta\chi_B(r) = argmin_{\Delta\chi_B(r)} \left\| w(r)(b_B(r) - d(r) * \Delta\chi_B(r)) \right\|_2^2$
7. $b_{L,3}(r) = b_T(r) - d(r) * \Delta\chi_B(r) + w_2(r)(b_{L,2}(r))$

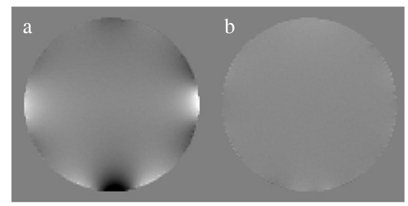

Figure 2: Error maps. (a) PDF, (b) iPDF. Errors at the boundary in PDF are reduced in iPDF.

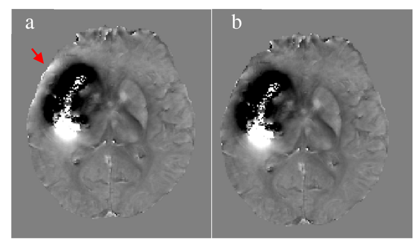

Figure 3: Local field of *in vivo* intracranial hemorrhage. PDF-generated local field (a) introduces errors between the bleed and the boundary (red arrow). iPDF local field (b) reduces this error.

Methods: A cylindrical water phantom with vials containing varying concentrations of Gadolinium solution was scanned using a multi-echo GRE pulse sequence on a 1.5T scanner (GE Healthcare, Waukesha, WI) Matrix size: 108x108x86, Voxel size: 1x1x1mm, 4 echoes, ΔTE=0.5ms. The measured magnetic field without the vials was defined as the “true” background field. The difference between the measured field with and without the vials was defined as the “true” local field. The local field was then estimated using the PDF and iPDF methods. Relative error over the ROI was calculated for each method. The PDF and iPDF methods were also applied to a case of intracranial hemorrhage.

Results: Figure 1 shows the local field maps generated by the PDF and iPDF methods. The difference between these methods and the truth are displayed in Figure 2. iPDF showed improvement at the boundary of the ROI, where it removed overfitting errors introduced by PDF. The relative error over the ROI was 0.33 and 0.16 for PDF and iPDF respectively. In Figure 3, the method is tested on a case of intracranial hemorrhage. The iPDF error at the boundary is reduced compared to PDF, although the interpretation is more difficult given the lack of ground truth.

Conclusion: Our phantom studies show that iPDF improves local field estimation at the boundary compared to PDF alone. We observe similar patterns *in vivo.*

References:

[1] Liu T, et al., NMR in biomedicine 2011;24(9):1129 -1136. [2] Schweser, F., et al. (2011) *NeuroImage* 2012; 59(3):2789-2807. [3] Zhou D, et al. NMR Biomed 2013;submitted. [4] Liu J, et al., Neuroimage 2012;59(3):2560-2568.