Guided Multi-channel Blind Deconvolution Coil Intensity Correction for Improved Uniformity and Contrast Fidelity

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Introduction: Image-based intensity correction techniques for MR phased-array receivers typically act like high pass filters, relying on the assumption that the corrupting bias field exists in the low-frequency content of an image, and the anatomy remains primarily in the high-frequency components. If the boundary between the bias field and the anatomy is not well defined, a reduction in image contrast or insufficient intensity correction can result. An alternative approach, based on multi-channel blind deconvolution (MBD) [1-2], attempts to derive sensitivity profiles of the coils by comparing the differences in the signal from each element in the array. While MBD can produce accurate sensitivity maps for enclosed arrays [3-4], for less symmetric coil geometries, MBD intensity correction breaks down. An illustrative example is the extreme case encountered with single sided (e.g. spine) arrays. Here, as the distance from the array increases, each element becomes less unique and SNR is reduced, resulting in incorrect sensitivity estimates in the direction perpendicular to the plane of the array. To compensate for this lack of information, we propose adding a homomorphic filtering step in an iterative implementation of MBD.

Materials and Methods: Multi-channel blind deconvolution is accomplished by minimizing the following energy function: $E = \sum_{i=1}^{N} \|\rho b_i - y_i\|^2 + \alpha \|A\vec{b}\|^2$, where ρ is the intensity corrected "truth" image, b_i and y_i are the sensitivity profile and acquired image from coil i, α is a constant balancing the two terms, **A** is a matrix composed of pairwise comparisons of each image in the array [1], and $\vec{b}$ is a vector containing $\{b_1, b_2, ..., b_N\}$. After an initial estimate for the truth image (typically a sum-of-squares image), the energy function is minimized iteratively, with the sensitivity profiles refined in each iteration. The derived sensitivity profiles are then used to find an improved truth image and the process repeats to convergence. Due to the ill-posed nature of the problem, the solution is not unique and can be guided with additional information, namely a homomorphic filtering step added after each refinement of the truth image (Fig. 1) to drive the optimization to a more uniform solution in the direction normal to the array surface. Images of the lumbar spine, head, and torso were acquired on a 3.0T MR750 (GE Heal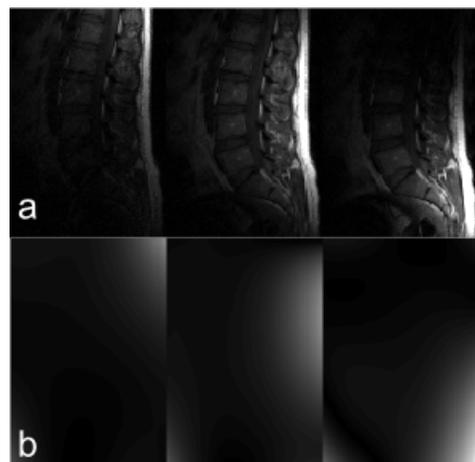thcare, Waukesha, WI) with 8-channel spine and head arrays (GE Coils, Cleveland, OH) and 32-channel cardiac array (In Vivo, Gainesville, FL). Reference images using the body coil were also acquired for comparison.

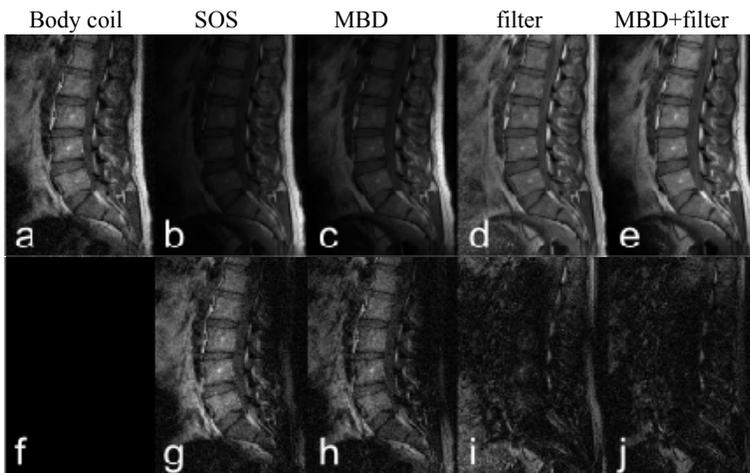| Body coil	SOS	MBD	filter	MBD+filter

Fig 2. Sagittal image of lumbar spine acquired with the body coil (a), and spine array (b-e). Reconstruction by sum-of-squares (b), MBD (c), homomorphic filtering (d), and iterative MBD with homomorphic filtering step (e). Images (a-e) were normalized to their maximum intensity and are displayed with the same window and level. (f-j) Difference images using the body coil image as a reference.
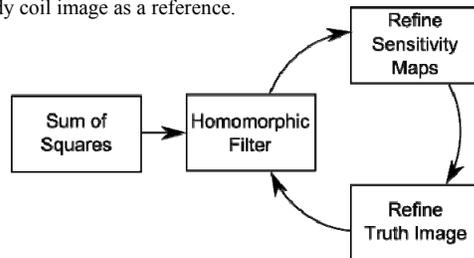

Fig 1. Diagram of the iterative MBD algorithm with a homomorphic filtering step.

Results: Spine images acquired with 6 channels of the spine array show marginal improvement in uniformity in the A/P direction when reconstructed with MBD alone (Fig 2c). Using the homomorphic filter only (Fig. 2d), a ~20% reduction in contrast is observed (e.g. between discs and vertebrae) when compared to the body coil. Incorporating the homomorphic filter into the iterative MBD optimization restores uniformity in the A/P direction without a significant loss of contrast (Fig 2e). Comparing the derived sensitivity maps to the coil images (Fig 3) demonstrates good visual agreement of the estimates. Head and torso images also showed (less dramatic) improvements.

Discussion and Conclusion: Multi-channel blind deconvolution is promising as a technique for image-based coil intensity correction. Adding a homomorphic filtering step in the iterative reconstruction can increase the accuracy and robustness of the method substantially, extending the technique to asymmetric geometries where the lack of information far from the coil surface would traditionally cause inaccuracies in the sensitivity estimates. Additionally, the technique is relatively insensitive with respect to the choice of weighting constant α and the cutoff frequency for the homomorphic filter. For a given slice, the algorithm generally converges within 10 iterations taking around 2 seconds in Matlab (Mathworks, Natick, MA) on a dual core 2.4 GHz laptop.

Fig 3. Images from 3 coils in the spine array (a) and corresponding MBD-derived sensitivity maps (b).

References: [1] Harikumar G et al. IEEE Trans. Image Proc. 1999:8:202-219. [2] Šroubek F et al. IEEE Trans. Image Proc. 2007:16:2322-2332. [3] Morrison RL et al. IEEE Int. Sypm. on Biomed. Imaging 2007. [4] She H et al. IEEE Int. Symp. on Biomed. Imaging 2010.