# Improved background field correction using effective dipole fitting

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**Introduction**: For optimal susceptibility weighting imaging (SWI) [1] and accurate quantification of susceptibility [2,3], it is necessary to isolate the field generated by local magnetic sources (such as iron) from the background field, which arises from variations in magnetic susceptibility of surrounding tissues (including air). Various background removal techniques [4-8] have been proposed. These approaches either rely on strong assumptions about the spatial and frequency dependence of the background field or suffer when the information about all of the surrounding anatomy is incomplete (when for example, the field of view is narrowly tailored to the region of interest). In this article, we propose a new background field removal technique based on effective dipole fitting. It constructs a distribution of dipoles around a given region of interest, for which the generated field inside that region of interest matches the measured field.

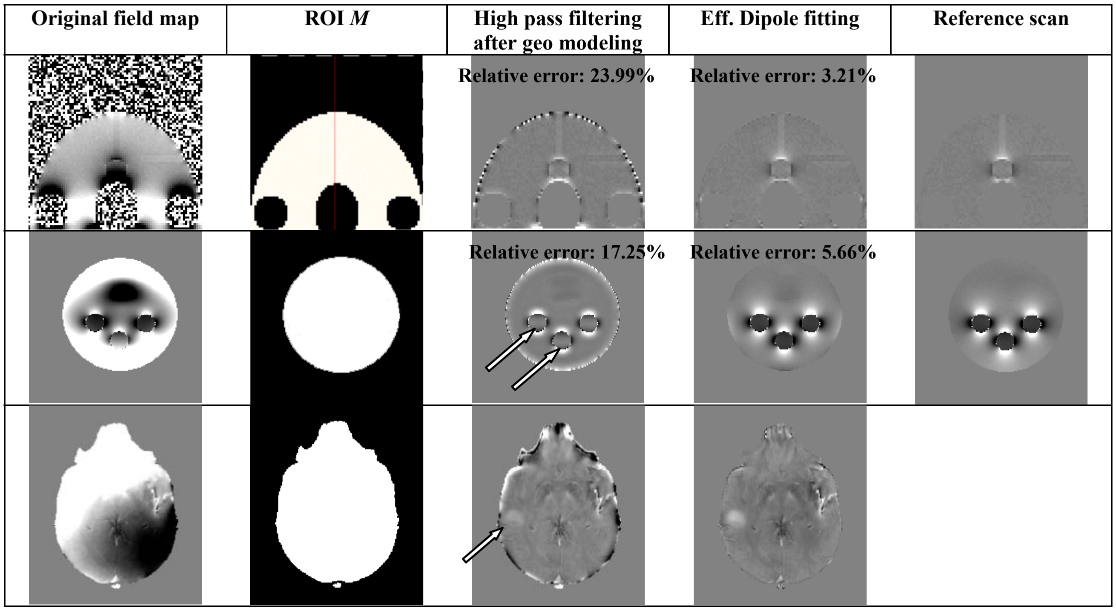
**Theory:**

In effective dipole fitting, it is assumed that sources outside a given region of interest (ROI) are responsible for the background field inside that ROI. Therefore, a susceptibility distribution outside a ROI *M* that optimally matches the field inside *M* is sought. This is expressed mathematically by minimizing the following function: $\chi^*_{r\in\overline{M}} = \arg\min \sum_{r'\in M} \left\| w(r')\times(\delta_B(r') - d\otimes\chi_{r\in\overline{M}})\right\|_2^2$ , where $\delta_B$ is the measured field map, $w(r)$ is a weighting that accounts for non-i.i.d. phase noise, *d* is the unit dipole response. The $\ell_2$ norm is minimized over all voxels within the ROI *M*. Note that nothing is assumed about the shape, position or susceptibility value of any regions outside *M*. Indeed, every voxel outside *M* is considered as an independent dipole with freely varying strength. This fitting does not attempt to give the true susceptibility distribution outside *M*, but only to model a suitable background field generated by these effective dipoles. The local effects inside *M* are obtained by subtracting the field from the fitted background: $\delta_B' = \delta_B - d\otimes\chi^*_{r\in\overline{M}}$ .

**Materials and Methods**:

Due to the size of the problem (each outside voxel is an independent unknown), an iterative conjugate gradient (CG) method was used to compute the effective dipole distribution. The proposed effective dipole fitting was compared with high pass filtering after geometrical modeling [8] in a numerical phantom, a Gadolinium phantom, and human brain scans (n=7). To provide the ground truth, a reference scan (same object without internal structures) was simulated or acquired when possible. Relative errors were calculated in the ROI by taking the Euclidean norm of the difference between the fitted and the known background field, normalized by the Euclidean norm of the known background field (using the reference scan). All data were processed using Matlab on a standard PC.

**Results and Discussion**: The effective dipole fitting method for each experiment took less than 3 minutes and 45 iterations. For all cases, effective dipole fitting was able to remove the slowly varying background field while preserving the local fields, and the resultant field map has high resemblance to the one from a reference scan. High pass filtering was able to remove the slowly varying background field to a large extent, but also filtered out some of the internal effects as shown by the arrows, where Gd tubes and brain lesion provided less phase contrast to the surrounding tissues compared to effective dipole fitting. Quantitatively, the kernel-dependent high pass filtering underestimates phase contrasts, as was suggested by different experiments [6, 7].



In the proposed effective dipole fitting method, each voxel is treated as an independent dipole. Though the number of unknown variable is large, computation can be executed efficiently. The major computational cost is 3D-FFT for evaluating the unit dipole convolution in Fourier space. Optimization of MATLAB code with C code and parallelization may substantially reduce the computation time. The number of iterations is only dependent on the relative error chosen to stop conjugate gradient, and is relatively consistent regardless of matrix size.

**Conclusion:** In this study, we have proposed a novel technique that models the background field by fitting an effective dipole distribution outside the ROI. Numerical simulation, phantom experiment showed that the calculated background field closely matched the simulated or measured background field. In the *in vivo* studies, improved contrast of brain lesions with respect to normal brain tissue was observed.

**Ref**: [1] Haacke et al. MRM:52(3):612-18; [2] Liu et al. MRM:61(1):196-204; [3] de Rochefort et al. MRM:*in press*; [4] Wang et al. JMRI:12(5):661-670; [5]Marques et al. CONCEPT MAGN RESON B:25B(1):65-78;[6] Langham et al. MRM:61(3):626-33;[7] Liu et al. ISMRM 09:465.[8] Neelavalli et al. JMRI:29(4):937-48.