Cost function guided 3rd order $B_0$ shimming for MR spectroscopic imaging at 7T

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Introduction

At high field strengths, shimming becomes increasingly more difficult and important since susceptibility induced $B_0$ inhomogeneities increase. Exploiting up to 3rd order shim coils on the system, a high number of degrees of freedom are available to generate a more homogeneous $B_0$ field. In MR spectroscopy excellent shimming is an important factor for acquiring high quality data since it dictates not only spectral line width, but in many MRS methods also the quality of the spectral baseline. Especially for non-localized chemical shift imaging (CSI) where the signal is coming from a complete slice instead of a small volume, the method and quality of the shimming procedure determines the region where good spectra can be obtained. Using up to 3rd order shim coils, an improved $B_0$ homogeneity can be achieved in a small region of interest (ROI), generally at the expense of uncontrollable frequency offsets outside this ROI. Traditionally, high bandwidth suppression bands are put over these badly shimmed regions. However, at 7T, the limited $B_0$ field restricts the effective bandwidth of these pulses, and the number of these pulses is limited due to SAR restrictions.

When suppression is not used (or fails) outside the shimmed ROI, water and lipid resonances can cause baseline distortions over the whole slice, a phenomenon known as signal bleeding. In particular, if frequency offsets of more than approx. 0.6 ppm (180 Hz at 7T) arise, these artifacts appear in the region where most resonances of metabolites are located (4.1–1.9 ppm).

In this work a novel shimming method is presented which uses a cost function for finding optimal shim fields that minimize $B_0$ inhomogeneities in a ROI while confining the frequency offsets in regions outside this ROI. Experiments show that by employing the cost function guided shimming approach, high quality CSI data can be obtained without outer volume suppression (OVS) or conventional volume selection.

Material and Methods

Data acquisition was done on healthy volunteers on a Philips 7T whole body MR system. $B_0$ field map acquisition was performed using a 3D dual-echo gradient echo sequence with TR/TE/ATE $=162.5/1.0/0.3$ ms, $FA=25^\circ$, 9 slices and $3x3x3\text{mm}^3$ voxel resolution. The field map data, $\Delta B_0$, was processed offline, where regions containing brain and fat tissue were extracted (10% intensity threshold on the magnitude image) and phase unwrapped [1]. Next, a ROI, $25\times25\times15\text{mm}^3$, was manually drawn in the images. In Matlab (The Mathworks Inc., Natick, MA) a nonlinear minimization algorithm [2], constrained by the hardware shim current limits, was employed to optimize up to 3rd order shim fields according to a minimized cost function. The algorithm minimizes the standard deviation of $\Delta B_0$ in the ROI, $\sigma_{\Delta B_0}$, while simultaneously minimizing the number of voxels outside the ROI (expressed as a percentage) which deviate more than 180 Hz from the mean frequency inside the ROI (referred to as the “180Hz cost function”). For comparison, a conventional method (direct least-squares minimization) was used to minimize field inhomogeneities exclusively in the ROI (referred to as the “STD cost function”). Calculated shim terms were ported back to the scanner and used for an additional $B_0$ field map to check the applied field for both the customized and conventional method. As a control, a $B_0$ field map was acquired without shimming, i.e. all shim terms set to zero. Subsequently, a high resolution CSI measurement was performed (2D pulse-acquire, no OVS, TE/TR=1.5/1000ms, voxel size 5x5x10mm$^3$, and matrix 32x32) with water and fat suppression on the slice of interest for which the shimming was optimized.

Results and Discussion

Regions with more than 180 Hz frequency offsets are shown in red on the slice for both the control method (fig. 1a), conventional method (fig. 1b), and the proposed new method (fig. 1c). It is apparent in fig. 1b that both the control as well as the conventional method produces high frequency offsets outside the ROI, indicating potential artifacts inducing regions, while the proposed method clearly reduces these (fig. 1c) by incorporating the field inhomogeneities outside the ROI in its cost function. Fig 2. illustrates the effect of customized shimming on CSI spectra where lipid signal bleeding is significantly reduced (bottom fig. 2) when compared to the conventional shimming method (top fig. 2). More importantly, a narrow spectral line width was maintained. It is clear that when the proposed shimming method is employed, CSI with frequency selective water and fat suppression is more effective, allowing the acquisition of CSI spectra over a large area with only low-SAR suppression techniques. Alternatively, the frequency offset mapping (fig. 1) could be used to map areas where OVS would still be necessary, decreasing the number of OVS slabs to reduce SAR and hence increase the SNR per unit of time.

Conclusion

The proposed method allows for optimizing up to third order shim terms on a user-defined region of interest in a slice while restraining the field inhomogeneities in all other parts of the slice. The novel shimming method opens the possibility to do spectroscopic imaging with only frequency selective water and fat suppression instead of the traditional SAR demanding outer volume suppression.

References