Volume Parcellation for Improved Efficiency of Dynamic Shimming

M. Poole[1], R. Bowtell[1], J. Marques[1]

[1]Sir Peter Mansfield Magnetic Resonance Centre, University of Nottingham, Nottingham, Nottinghamshire, United Kingdom

Introduction

Magnetic susceptibility differences between different tissues cause localised field inhomogeneities, which become increasingly severe at high magnetic field strengths. Such inhomogeneities lead to undesirable image distortion, particularly in echo planar images, and to signal drop-out in gradient echo data. Although shimming can be used to ameliorate the effect of field inhomogeneity, with a limited number of available shim coils, it is difficult to eliminate inhomogeneity over large volumes, since cancellation of field inhomogeneity in one region leads to exacerbated field variation in another. This limitation has led to the use of dynamic shim updating [1, 2] in which the optimal set of shim currents is used for each slice in turn during a multi-slice, echo-planar image acquisition (requiring the use of shim systems in which currents can be rapidly changed and stabilised during the time between sequential slice acquisitions). The net reduction in field variation is still limited, however, by the difficulty of cancelling local fields over the large two-dimensional extent of each slice using only a limited number of shim terms. The situation can be improved if a more compact, cuboidal volume is sampled in each acquisition, since this generally allows a better representation of the field variation within each sub-volume in terms of a small number of low order shim terms. Such a volumar sampling scheme can potentially be achieved using echo-volumar imaging [3] in conjunction with two-dimensional RF selective excitation [4, 5]. To gauge the possible advantages of this approach, we have evaluated the reduction of effective field inhomogeneity that can be achieved using dynamic shim updating for different parcellations of a volume within the typical human head. In addition, the effect of varying the effective orientation of the sub-volumes has been assessed.

Methods

Two data sets were used to evaluate the effects of using different volumar parcellations. One data set (A) was generated using the head-region of the HUGO body model (Medical VR Studio, Lorrach) and literature values of the magnetic susceptibility of different tissues, by solving the magnetostatic form of Maxwell's equations for an uniform applied magnetic field of 3 T [6]. A volume of interest (VOI) of 32×32×32 voxels (2 x 2 x 2 mm^3 voxel size) was selected in the frontal portion of the brain including the difficult area to shim near to the sphenoid sinus. The second data set (B) was collected using an echo-planar based field mapping sequence (4 x 4 x 4 mm^3 voxel size) on a 3 T scanner. A VOI of 16×16×8 voxels located in roughly the same area of the brain was selected from these data. Shimming was simulated in Matlab©. A field reference matrix, **A**, was generated for each shim term up to third order using pure spherical harmonics. To homogenise the magnetic field, **b**, within each volume considered, an optimal linear combination of shim currents, **i**, needs to be found. Here, the shim currents were calculated (as in [7]) by using a least-squares norm solution to the equation $\|\mathbf{b} - \mathbf{iA}\| = 0$.

The five different sub-volume shapes considered for data set A are shown in Fig. 1a. In each case the sub-volume contained 1024 voxels, and 32 sub-volumes were used to span the total volume. All possible orientations of the sub-volumes were considered (yielding 3, 6, 6, 3 and 3 different orientations for the five different sub-volume sizes). Data-set B was similarly analysed using three different sub-volume sizes (Fig. 1 b), with the total volume spanned by 8 sub-volumes in each case. To characterise the "compactness" of the differently shaped sub-volumes, a dimensionless measure F = (surface area)$^{1/2}$×(volume)$^{-1/3}$ was used. This has a larger value for flatter, less compact volumes. Shimming of the whole VOI was also simulated for comparison. The effectiveness of each parcellation regime was evaluated using the root mean square (rms) value of the residual field variation after shimming, which gives a measure of the spread of field values. In each case the improvements obtained using all shim terms: (i) up to and including 2nd order spherical harmonics and (ii) up to and including 3rd order spherical harmonics, were evaluated.

Results

Figure 2 shows how the residual rms field deviation after 2nd and 3rd order shimming of data-sets A and B varies as a function of F. Shimming the whole VOI was found to reduce the rms field variation in data-set A from 223.3 rads^{-1} to 121.1 rads^{-1} using 1st and 2nd order shims and to 82.4 rads^{-1} when 3rd order terms were also included. For set B, the residual rms for second and third order whole VOI shimming was reduced to 34.0 rads^{-1} and 24.9 rads^{-1} respectively, from 156.6 rads^{-1}.

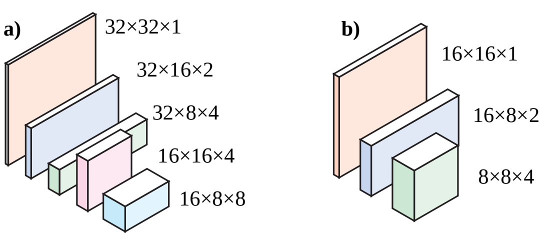

Figure 1*. Shapes of the different subvolumes for a) data set A and b) data set B.*

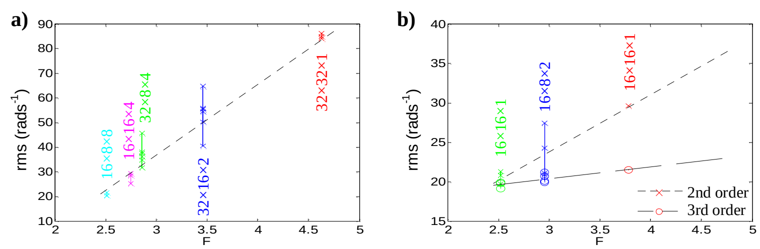

Figure 2. *Graphs of the residual rms field value after shimming a) set A and b) set B with all 2nd (and 3rd in b)) order shim terms using different parcellation regimes (colours correspond to Fig. 1).*

Discussion

The results show that the effective field inhomogeneity is reduced by dynamic shim updating in all cases. Results from both the simulated and experimentally measured data sets show an approximately linear relationship between the rms of the residual field and F, indicating that the use of more compact sub-volumes yields significantly better shimming. The relative gain in performance produced by compacting the sub-volumes is greater when shims up to 2nd order only are available. The residual rms field variation achieved after shimming varies significantly with sub-volume orientation. For the particular region chosen for analysis, coronal slice orientations (i.e. with the thinnest sub-volume dimension in the anterior-posterior direction) tend to demonstrate the worst performance. In the case where each sub-volume corresponds to a single slice, axial slice orientation yield the lowest rms field value. The residual noise in the experimentally measured field values means that the fractional improvement in rms field deviation is less for data-set B. This could be improved by using a more robust field mapping technique [9]. Limitations of the current study, which will be addressed in further work, include the use of pure spherical harmonics rather than the pattern of field variation due to real shim coils in the fitting process and the lack of inclusion of shim current limits in the fitting process.

References

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