Image quality improvement using short range finite difference in QSM reconstruction

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Target audience: Researchers who implement quantitative susceptibility mapping (QSM) algorithms

Purpose:

To show that using short finite differences to discretize gradient-based regularization energies improves the quality of QSM as compared to central finite differences. Improvements increase as resolution decreases (≥1mm).

METHODS:

The inversion problem of QSM in the morphology enabled dipole inversion (MEDI) [1, 2] can be written as $\chi(\boldsymbol{r}) = \text{argmin}_\chi \|w(b - d \star \chi)\|_2^2 + \lambda\|M\nabla\chi\|_1$, where χ is the susceptibility map, b is the local magnetic field, d is the dipole kernel, λ is the regularization parameter, M is the edge weighting matrix and w is a magnitude weighting.

One way to numerically solve this reconstruction problem is to first discretize the objective function and then solve a discrete optimization problem. Commonly, finite difference schemes are used for approximating the gradient and divergence operations. In this work we show that the choice of finite difference directly influences the image quality of the reconstruction. We compare the central difference $(x_{i+1} - x_{i-1})/(2h)$ and the short difference $(x_{i+1} - x_i)/h$. The theoretical advantage of the latter is that it is highly sensitive to undesired oscillations in the reconstructed image.

A Matlab implementation of the nonlinear MEDI method [3] was used and the regularization parameters were chosen such that the regularization cost was similar for both differences.

Healthy volunteers (n=3) were imaged with different image resolutions on 3T scanner (GE healthcare, Waukesha, WI): a low in-plane resolution (matrix size 256x256x116, voxel size 1x1x1.2mm) and a high in-plane resolution acquisition (matrix size 384x384x64, voxel size 0.6x0.6x2mm). Other parameters were TE1/ΔTE/TR=3/5/40ms with 7 echoes. Flip angle 20°, RBW=±62.5kHz, NEX=0.75.

Brain cancer patients (n=7) were scanned on 3T scanner (GE healthcare, Waukesha, WI) with voxel size 1.1x0.8x1.5mm, matrix size 320x224x116, TE1/ΔTE/TR=13/4/40ms with 7 echoes, flip angle 20°, RBW=±62.5kHz, NEX=0.75.

RESULTS:

As seen in Figure 1, 2 and 3, the QSM reconstructions with forward difference showed much less check board patterns and streaking artifacts. This trend was seen in both healthy volunteers and all patient data. A Radiologist with 3 years' experience performed image quality rating on all low resolution data sets and the reconstruction with short difference was considered consistently better for all data sets ($p<.05$, signed rank Wilcoxon test).

For high in-plane resolution data on the healthy volunteers, the differences between the two finite difference implementations become subtle (data not shown).

Apart from the improved image quality, an overall 17% speed up in computation time was observed.

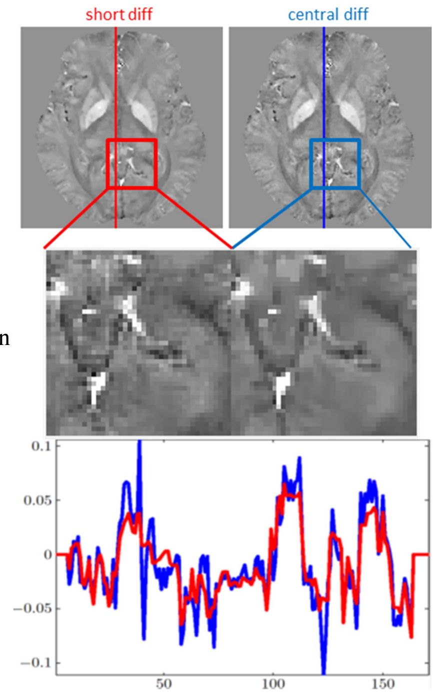

Figure 1 QSM reconstruction using short difference (left) and central difference (right with reduced checker board pattern) on healthy volunteer data.

DISCUSSIONS:

The image quality improvement is most obvious in the low in-plane resolution data sets, possibly due to the relatively lower signal-to-noise ratio associated with partial volume effect. For the short finite difference, the only function in its null space is the constant function, while for central difference, both the constant function and oscillating functions with period 2 pixels (e.g., 1,-1,1,-1,1) are in the null space. Thus short differences are more sensitive to oscillations in the reconstruction that may occur in noisy data. The central difference discretization is insensitive to these oscillations leading to checker board pattern artifacts.

CONCLUSIONS:

For low spatial resolution acquisition (≥1mm), the use of short range finite difference for gradient suppresses checker board pattern artifacts that may appear in the QSM reconstructed with central difference gradient.

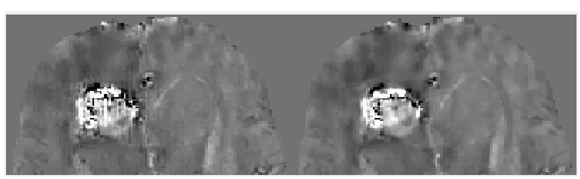

Figure 3 QSM reconstructions using central difference (left) and central difference (right, with reduced checker board pattern) on patient data.

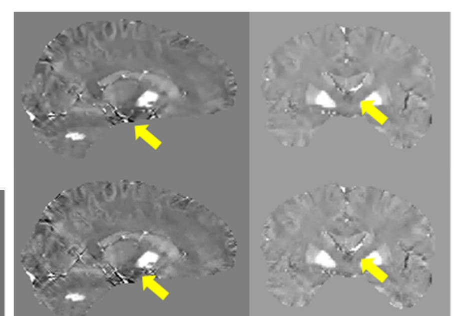

Figure 2 QSM reconstruction using short difference (top row) and central difference (bottom row) on healthy volunteer data. Differences (streaking like artifacts reduced on the rightare highlighted with yellow arrows.

REFERENCES:

[1] Liu et.al. NIMG 59, 2560, 2011 [2] de Rochefort et.al. MRM 63, 194, 2010 [3] Liu et.al. MRM 69,467,2013