Quantitative susceptibility mapping using piecewise gradient weighting

Zhiwei Zheng[1], Shuhui Cai[1], Congbo Cai[2], and Zhong Chen[1]

[1]*Department of Electronic Science, Xiamen University, Xiamen, Fujian, China,* [2]*Department of Communication Engineering, Xiamen University, Xiamen, Fujian, China*

Target Audience

Researchers interested in quantitative susceptibility mapping (QSM).

Purpose

Quantitative susceptibility mapping (QSM) is a promising MRI technique aiming to reconstruct the tissue magnetic susceptibility by solving an ill-posed problem. The calculation of susceptibility through multiple orientation sampling (COSMOS) method is an effective method for solving this problem caused by zeros in dipole kernel,[1] but it requires data acquisition at different orientation, which is impractical in clinical application. Various single orientation methods have been developed, which can be divided into two main types:[2] the first is threshold-based Fourier-space methods,[3,4] and the second is iterative regularization methods based on optimization.[5-7] The former type is fast, but the selection of threshold is often a trade-off between the level of streaking artifacts and the under-estimation of the susceptibility. The latter type usually needs to obtain a gradient weighting from additional MR images to avoid smoothness on the edges in susceptibility map, such as morphology enabled dipole inversion (MEDI), homogeneity enabled incremental dipole Inversion (HEIDI).[5,6] Because the weighting is binary, it may introduce erroneous contrast information with too many zeros in the weighting mask due to inconsistency between the true susceptibility distribution and the MR image being used and cause over-smoothing when zeros in weighting mask is not enough. In present work, we combine these two classes and propose a method to reconstruct the susceptibility map via piecewise gradient weighting from an initially estimated susceptibility map.

Method

Three-dimensional gradient echo (GRE) data from Cornell MRI Research Lab were used (http://weill.cornell.edu/mri/pages/qsmreview.html). The resolution was 0.9375 × 0.9375 × 1 mm^3 with a matrix size of 256 × 256 × 146. We performed the reconstruction in four steps: 1) obtain an initial estimate of susceptibility using a modified version of threshold-based k-space division method (mTKD);[4] 2) compute the susceptibility gradient in three directions and sort them in order of descending; 3) calculate a piecewise gradient weighting according to the susceptibility gradient as following:

$$W_{pg}=\begin{cases}1, & g_i < t_{\min}\\ \dfrac{t_{\max}-g_i}{t_{\max}-t_{\min}}, & t_{\min} < g_i < t_{\max}\\ 0, & g_i > t_{\max}\end{cases}$$

where g_i is the gradient in each voxel, $t_{\max}$ and $t_{\min}$ are thresholds for 5% maximum gradient and 50% minimal gradient obtained in the second step respectively; 4) solve the optimization problem: $\min_{\chi}\left\|W(\mathrm{F}^{-1}DF\chi-f)\right\|_2^2+\lambda\left\|W_{pg}G\chi\right\|_1$

The threshold used in mTKD was 0.2, which could adequately reduce streaking artifacts. The result was used to reconstruct the image according to the steps mentioned above with the regularization parameter λ = 0.001. The accuracy of the proposed method was evaluated via linear regression between the final result and the susceptibility map from COSMOS and a comparison with commonly used MEDI (the optimal λ was chosen to be 1/600). Here the result from COSMOS was used as a reference. Although it is not perfect, it can be a good alternative when real susceptibility in vivo cannot be measured.

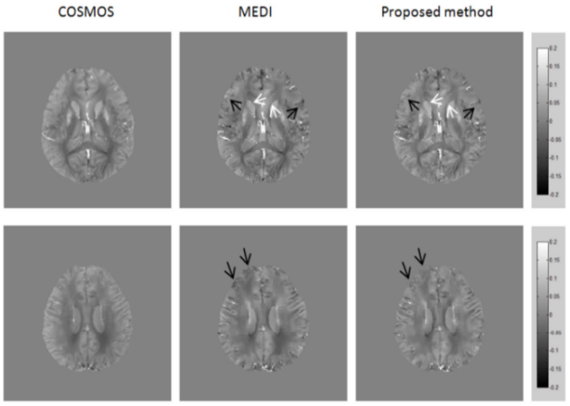

FIG. 1. Comparison of COSMOS (as an alternative reference), MEDI and proposed method. The top and bottom rows represent two different slices in axial view, respectively.

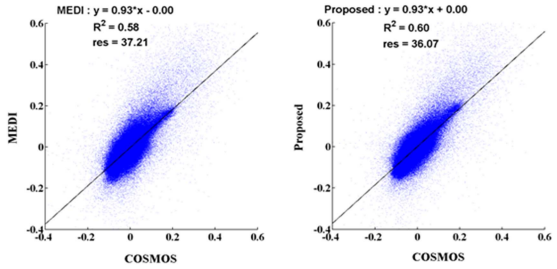

FIG. 2. Linear regression based on all single susceptibility value. R^2 is coefficient of determination, and res is norm of residuals of all points in ROI.

Results

Figure 1 shows that the images from the MEDI and the proposed method are similar in most regions. MEDI tends to give a relatively sharper contrast in interior edges (indicated by white arrows), which is in accordance with the binary weighting used in MEDI. Our method is more balanced in the entire region of interest (ROI) and has fewer artifacts in grey matter (indicated by black arrows). Figure 2 is the results of quantitative assessment by linear regression. We can see that the proposed method and MEDI both have a slope 0.93, but the proposed method has a better performance in the coefficients R^2 and res, which means that it is slightly closer to the reference.

Discussion

The proposed QSM method uses a piecewise gradient weighting from initially estimated susceptibility map instead of a binary weighting. Because the weighting varies gradually and is from susceptibility itself, it reduces the probability to introduce erroneous contrast information. However, the initial susceptibility map is often contaminated by artifacts, which may bring false gradients, so in this case we choose to use a relatively high threshold (0.2) in mTKD to fully reduce streaking artifacts. To keep a better contrast in the boundary of different cerebral regions and prevent some small false gradients caused by residual artifacts, we set W_{pg} with 5% maximum gradient to be zero and W_{pg} with 50% minimal gradient to be one. The implement of mTKD is fast, so the increasement of the total cost for reconstruction is negligible.

Conclusion

Susceptibility reconstruction using a piecewise gradient can provide a relatively balanced susceptibility map without obvious artifacts.

Acknowledgement

This work was supported by the NNSF of China under Grants 11275161, 81171331 and U1232212.

References

1. Liu T, Spincemaille P, de Rochefort L, et al. Magn Reson Med. 2009;61:196-204. 2. Wang Y, Liu T. Magn Reson Med. 2014.doi:10.1002/mrm.25358.
3. Wharton S, Schaefer A, Bowtell R. Magn Reson Med. 2010;63:1292-1304. 4. Haacke EM, Tang J, Neelavalli J, et al. J Magn Reson Imaging 2010;32:663-676.
5. Liu J, Liu T, de Rochefort L, et al. Neuroimage 2012;59:2560-2568. 6. Schweser F, Sommer K, Deistung A, et al. Neuroimage 2012;62:2083-2100.
7. Wu B, Li W, Guidon A, et al. Magn Reson Med. 2012;67:137-147.