Multi-channel data combination with linear phase baseline correction

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Introduction

Phase images from a gradient echo sequence is the key component for Susceptibility Weighted Imaging (SWI)[1] and Quantitative Susceptibility Mapping (QSM)[2]. The signal-to-noise ratio (SNR) in phase images directly determines the quality of SWI and QSM, as any noise or artifact in phase images will be propagated into the final results during data processing[1-2]. When GRAPPA is used for parallel imaging, magnitude and phase images will be reconstructed for each channel of the array coil before being combined for the final images[3]. The magnitude images are combined using root-sum-of-squares method, which guarantees the optimal SNR in the combined magnitude images[1]. However, such simple weighted averaging of the complex data may lead to a particular singularity artifact in phase images (see **Fig. 1**), attributed to the variation in the baseline phase components (φ_0) between different channels. Commonly used multi-channel phase data combination strategies include modeling the φ_0 as a constant[4] or calculating φ_0 using a reference scan or dual echo scan[5]. The former approach, i.e. constant phase offset correction, uses a reference region in the image domain to estimate φ_0 for each channel. However, the quality of the combined phase images will depend on the selected region as φ_0 is not spatially uniform even for the same channel's data. For the latter approach, even though φ_0 can be estimated accurately, extra scans/echoes are required and the data processing is time consuming. In this study, we propose an algorithm in which the coil sensitivity induced phase component is modelled as 3D linear function, and can be corrected effectively in k-space domain.

Methods

The coil-sensitivity dependent phase offset can be modeled as a 3D linear function: $\boldsymbol{\varphi_0(x,y,z)=\beta_x x+\beta_y y+\beta_z z+\varphi_c}$. For each channel, the linear gradients can be estimated from the position of the peak value ($\mathbf{k_{peak}}$) in k-space, based on the Fourier shift theorem, and subsequently corrected by shifting the k-space data. While the constant phase offset $\boldsymbol{\varphi_c}$ can be estimated as $\boldsymbol{\varphi_c=\arg(k_{peak})}$, it can be removed through complex division. In order to improve the accuracy of estimating the linear gradients, the central part of k-space was interpolated by a factor of 2, through zero-filling in image domain. After correcting the linear gradients and the constant baseline for each channel, the phase images can be combined through averaging of the complex data, weighted by the square of the magnitude. The proposed algorithm was tested using *in vivo* data collected on a 3T SIEMENS system equipped with 32-channel head coil, using a fully flow compensated double-echo sequence[6]. Imaging parameters are: TE_1=7.38, TE_2=17.6, TR=30ms, FA=15°, BW=425Hz/px, voxel size= 0.6x0.6x1.2mm^3, matrix size=512x368x144. GRAPPA acceleration factor=2. The phase images were combined using: 1. SIEMENS combination without correction of φ_0; 2. constant phase offset algorithm, in which the differences between the φ_0 in each channel and the user-defined reference channel were estimated from 32^3 central voxels in image domain; and 3. the proposed algorithm.

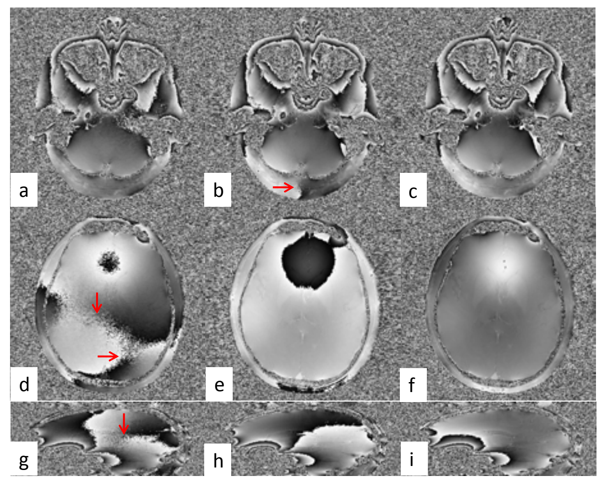

Figure 1. Phase images combined using different algorithms. **a, d, g**: SIEMENS combination. **b, e, h**: constant phase offset correction. **c, f, i**: proposed algorithm. **a** to **f**: Transverse view of two slices at TE_1=7.38ms. **g** to **i**: Sagittal view at TE_2=17.6ms. The phase singularities are indicated by the red arrows.

Results

As demonstrated in **Fig. 1**, both the constant phase offset algorithm and the proposed algorithm offered combined phase images without signal cancellation or phase singularities (arrows in **Fig 1**) in central part of the brain. However, phase singularities were observed for regions close to the edge of the head, when the constant phase offset algorithm was used, as indicated by the arrows in **Fig. 1.b**. The proposed algorithm has further eliminated any linear gradients in 3D, which leads to improved quality in the combined phase images (**Fig. 1.c, 1.f** and **1.i**).

Discussion and Conclusion

In the constant phase offset correction method, the selection of the reference channel and reference region requires *a priori* information of the channel's sensitivity. In addition, signal cancellation may still arise when the constant phase offset assumption is not satisfied. It would be ideal to estimate the coil sensitivity induced phase component purely from the raw k-space data from a single scan. In conclusion, by modeling the baseline phase variation as a 3D linear function and perform correction in k-space, multi-channel phase data can be properly combined. Future work in this direction would be to determine the shift in k-space to within a fraction of a voxel.

References

1. Haacke EM, et al. Susceptibility Weighted Imaging in MRI: Basic Concepts and Clinical Applications.; 2011. 2. Haacke, et al., MRM. 2014 doi: 10.1016/j.mri.2014.09.004. 3. Griswold MA et al. MRM. 2002 47(6):1202-10. 4. Hammond KE, et al. NeuroImage 2008;39:1682–92. 5. Robinson S et al. MRM. 2011;65:1638–48. 6. Ye et al. JMRI. 2013; 38(6):1539-48.