Optimal Combination and Filtering for 7 T – Phase Images

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Introduction:

Images based on signal phase showed superior and complementary contrast at 7 Tesla compared to magnitude images. Although the underlying contrast mechanisms are still not fully understood, several mechanisms based on tissue susceptibility [1] and water-macromolecule exchange (WME) [2] have been proposed to explain the intra-cortical gray matter (GM) contrast and the contrast between GM and white matter (WM). On the other hand, all studies using image phase rely on methods to remove the strong phase modulations induced by field inhomogeneity in order to reveal local tissue phase contrast. Currently, the most widely used method is a high-pass filter that removes the long-range low-frequency phase modulations. The situation is further complicated by the employment of phase array coils for signal reception to boost the signal-to-noise (SNR). This requires complex combination of single channel data to render proper phase images. The SENSE method, usually used for parallel imaging, can also be adapted for proper phase image reconstruction with a reduction factor R =1. However, due to the strong RF inhomogeneity at 7 T and a lack of a body coil, it is difficult to obtain sensitivity map for each individual array element. Up-to-date an optimized filter for phase image reconstruction has not been proposed. In this study, we systematically compared the effects of different filter kernel sizes (σ) on the resulting phase images using 4 different combination and filtering methods. Different aspects of resulting image quality were evaluated on a five point scale.

Theory and Methods:

One approach for image quality measurement is to use the so-called co-occurrence matrix (C_M) to determine the image contrast (Cn) and homogeneity (Hm), i.e. $\mathrm{Cn} = \sum_i \sum_j (i-j)^2 \cdot C_M(i,j)$ and $\mathrm{Hm} = \sum_i \sum_j C_M(i,j)/(1+|i-j|)$ where i and j are indexes for adjacent pixels. Phase images with subjectively high quality should have local high tissue contrast and low global inhomogeneity. In this study, the contrast and homogeneity values were calculated with varying filter kernel sizes (0.1 to 20 mm) for 4 different image reconstruction methods. The methods include: a) SENSE reconstruction with R=1 (here the filter was used to extract the sensitivity maps from the single coil data); b) adaptive reconstruction [3] followed by Gaussian filtering; c) sum of single channel phases after unwrapping, and Gaussian filtering; and d) adaptive combination including homodyne filter. The homodyne filter method was provided by Siemens AG while the other methods were in-house implementations in MATLAB. The data were acquired on a Siemens MAGNETOM 7 T scanner with a 2D gradient echo sequence (TE = 18 ms, 0.25 mm in plane resolution, 2 mm slice thickness). In order to evaluate the image qualities for clinical applications, 6 radiologists scored a total of 19 data sets processed by the 4 different methods with 5 different kernel sizes σ (FWHM: 1, 1.5, 2, 2.5, 3 mm) based on the criteria i) overall impression; ii) contrast; iii) homogeneity; iv) SNR; v) comprehensiveness on a scale from 1 (worst) to 5 (best).

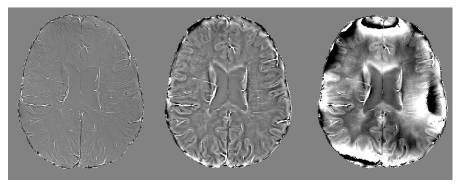

Fig. 1: phase images with Gaussian filter size of 0,5mm (left), 2,6mm (center) and 10mm (right).

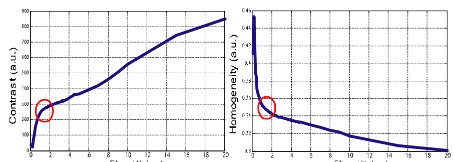

Fig. 2: The dependency of Cn (left) and Hm (right) on Gaussian filter size σ. A transition between 1 and 2.5 mm was observed in both values.

Results and Discussion:

Fig. 2 shows the dependency of Cn and Hm on different filter kernel sizes σ for the SENSE reconstruction method. Cn increased with larger σ values while Hm decreased with large σ. A clear transition between 1 and 2.5 mm was observed in both graphs. Based on this, 1.5 mm seemed to be good compromise for phase images with good contrast and homogeneity. The group averaged results of radiological readings of phase images with different σ and reconstruction method are shown in Fig. 3. Images with SENSE reconstruction (a) and Gaussian filtered adaptive combination (b) showed superior image quality compared to the other two methods in all the 5 categories. Images based on combined, unwrapped, Gaussian filtered single channel data (c) showed inferior image quality compared to methods (a) and (b). Images constructed with homodyne filter (d) showed comparable quality for the categories Homogeneity (iii) and SNR (iv), and slightly lower quality in the other three categories. Overall the radiological readings suggested that a filter kernel size between 2 and 3 mm produces the best phase image quality. This value is about 0.5 – 1 mm higher than the estimation from the Cn and Hm calculation using the co-occurrence matrix. A possible explication is that the co-occurrence matrix only considers the nearest neighbors of pixels and thus only considers a small scale.

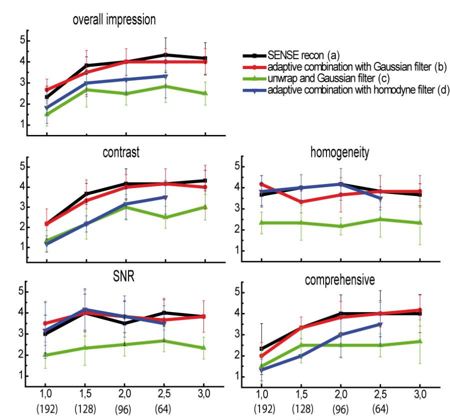

Fig. 3: Radiological readings of the 4 methods: (a) SENSE recon (black); (b) adaptive combine with Gaussian filter (red); (c) unwrap and Gaussian filter (green); (d) adaptive combine with homodyne filter (blue). Horizontal axis is the filter width (1-3 mm from left to right for methods a-c; 192-64 pixels (kspace) for method d). The best image quality were methods (a) and (b) with a filter between 2-3 mm.

Conclusion:

This study suggests that phase data combined by means of an un-accelerated SENSE algorithm and with a filter size between 2 and 3 mm result in the highest image quality. These parameters result in optimized phase image quality at 7 T even for other resolution settings (data not shown).

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Reference:

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