Reconstruction of Phase Images for GRAPPA based Susceptibility Weighted Imaging (SWI)

C. Ros[1], S. Witoszynskyj[1], K-H. Herrmann[1], and J. R. Reichenbach[1]

[1]IDIR, Medical Physics Group, Friedrich-Schiller-University, Jena, Germany

Introduction

Susceptibility Weighted Imaging (SWI) is an MR method that employs both magnitude and phase information [1]. The increasing use of phased array coils due to the improved SNR and the desire to reduce acquisition times by parallel imaging techniques such as GRAPPA [2] calls for methods for combining the phase images of the coil elements of a phased array.

In case of SWI a common technique for the combination of the phase images is to employ homodyne detection [3] which corrects phase images for phase variations with low spatial frequencies, such as those caused by the inhomogeneous coil sensitivities, and to combine the resulting phase images using a weighted sum [4]. However, homodyne filtering may cause artifacts in areas of strong field inhomogeneities. These artifacts can be avoided if a combination of phase unwrapping and correction for phase variations of low spatial frequencies is used [5,6]. In this case the phase images have to be combined correctly before unwrapping. Incorrectly combined phase images can be affected by singularities in areas of sufficient signal. Such singularities impede phase unwrapping.

On Siemens scanners the combined phase image is either calculated using Adaptive Combine [7] or a complex summation. Both can result in incorrect phase images affected by singularities.

Methods

We implemented a uniform sensitivity reconstruction [8] as a functor in the Siemens ICE framework. This functor was integrated into the standard reconstruction functor pipeline after the GRAPPA decorator. The functor relies on sensitivity maps which are automatically computed from a low resolution prescan using the body coil and one with the respective phased array. The maps are computed according to a method proposed by Pruessmann *et al* [9]. For the prescan a 2D gradient echo sequence with the following parameter set was used: TE=3.6ms, TR=7.4ms, α=25, slice thickness=5mm, matrix=64x64x22. The acquisition time required for both prescans was less than 30s. The subsequent SWI scan was a 3D fully flow compensated gradient echo scan [1] with TE=20ms, TR=35ms, α=25, FoV=220x220mm^2, matrix=384x384x72, slice thickness=1.5mm, GRAPPA factor=2. After testing the method on phantom data, measurements on subjects were performed. For comparison images were also computed with the Adaptive Combine and the "Complex Combination" reconstruction methods provided by the scanner's software from the same raw data sets. Images obtained with the body coil were used as a reference.

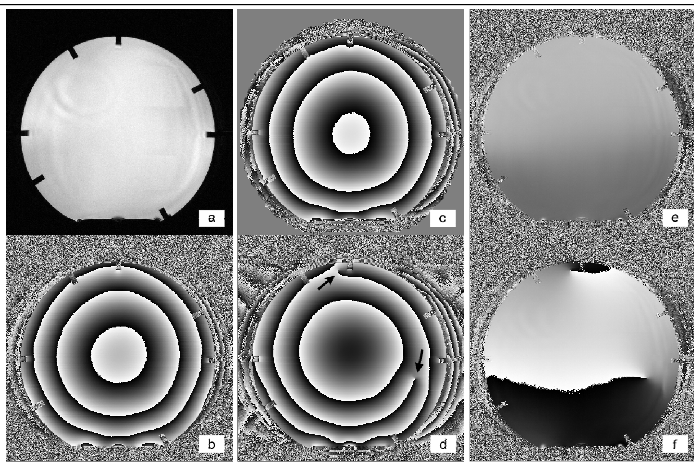

Fig. 1: Magnitude (a) and phase (b) image measured with the body coil. Phase image computed with the proposed method (c) and Adaptive Combine (d). Respective phase difference to the phase measured with the body coil (e,f). Singularities caused by Adaptive Combine are indicated by the arrows.

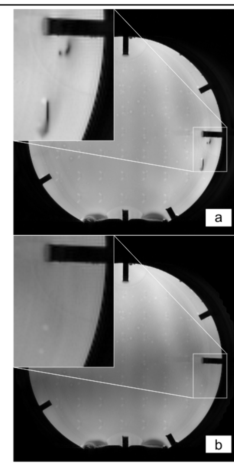

Fig. 2: Adaptive Combine leads to artifacts in magnitude images (a) that do not occur by using the proposed method (b).

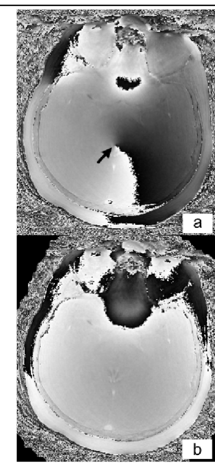

Fig. 3: Phase image of a subject reconstructed with Adaptive Combine (a) and the proposed method (b).

Results

The phase images computed with the proposed method (fig. 1c) were in very good agreement with the reference images obtained with the body coil (fig. 1b). The phase difference between the two images was almost constant (fig. 1e). The phase images reconstructed from the same data set by using Adaptive Combine were affected by singularities (fig. 1d, see arrows) in several cases. Furthermore, Adaptive Combine led to artifacts in the magnitude images in some cases. These artifacts were areas of signal drop outs in homogeneous areas. Although in general the artifacts in the magnitude images corresponded to singularities in the phase image, not all singularities led to artifacts in the magnitude images. Fig. 2a shows a magnitude image reconstructed by Adaptive Combine that exhibits such an artifact. The magnitude image computed by our method is shown in fig. 2b for comparison. Fig. 3 shows an example of a subject's phase image reconstructed incorrectly with Adaptive Combine (a) and the same image computed by our method (b).

Conclusions

By using the proposed method we were able to reconstruct phase images that were in excellent agreement with the reference images. Using GRAPPA the acquisition time of the SWI scan was reduced from 15min to 8.5min. Compared to this reduction the additional time required for the prescan was insignificant. A more surprising result of our study was that the default reconstruction method provided by the vendor, Adaptive Combine, did not only fail to reconstruct phase images reliably, it also led to severe artifacts in magnitude images. Whether those artifacts might have a clinical relevance must be investigated in future studies.

Acknowledgements

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