Improved Phase Processing in Susceptibility Weighted Imaging

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Introduction:

Susceptibility weighted imaging (SWI) [1] is a gradient echo method that uses long echo times together with high spatial resolution. The high spatial resolution reduces the sequence's sensitivity towards background inhomogeneities of the static magnetic field while maintaining or even increasing sensitivity towards partial volume effects induced by small venous vessels or small structures having different magnetic susceptibility compared to their surroundings. Instead of or in addition to inhomogeneities the field within a voxel may also experience a simple offset due to constant and homogeneous tissue susceptibility. The sensitivity towards such offsets is maintained by incorporating the phase information. Since the phase is only defined in the range of $[-\pi,\pi)$, phase wraps occur. These are reduced by homodyne filtering [2] or eliminated by phase unwrapping in image space [3,4]. Phase unwrapping eliminates phase wraps better than homodyne filtering but requires subsequent high pass filtering. This filtering may lead to artifacts, particularly at the surface of the brain, due to the sometimes steep transitions between the unwrapped phase within the brain and the surrounding areas. We present a method that combines elements of homodyne filtering and phase unwrapping to obtain improved phase images for SWI.

Methods:

Flow compensated 3D gradient echo images [1] were acquired on a 1.5 T system (Siemens Magnetom Vision): TR=57 ms, TE = 40 ms, α=25°, Matrix = 512 x 256 x 36, FOV=25.6 x 19.2 x 7.2 cm³. Unwrapped and high pass filtered phase images were reconstructed using the two standard methods (homodyne filtering, phase unwrapping + high pass filtering) and the proposed hybrid method. For homodyne filtering a low pass filtered copy of k-space is created by multiplying k-space with a hamming window. After FFT the original image is divided by the low pass filtered image and the arc tan is computed. The result is a high pass filtered and partly unwrapped phase image, where small structures, such as venous vessels are highlighted and effects from background field inhomogeneities are suppressed. Alternatively, the reconstructed phase image is unwrapped using a region growing phase unwrapping algorithm and then high pass filtered [3,4]. In the method proposed herein, the region growing algorithm is applied to both the original and the low pass filtered complex image. The unwrapped low pass filtered phase image is then subtracted form the original unwrapped phase image, resulting in a high pass filtered phase image. This phase image is converted into a phase mask and multiplied with the corresponding magnitude, resulting in the susceptibility weighted image.

Results:

The conventional method (Fig 1. left) leads to imperfect high pass filtering at the surface of the brain (arrow heads), whereas with the novel approach the surface is better delineated (Fig. 1 b). Since the different dynamic ranges in Figs. 1 a and b prohibit direct comparison with respect to anatomic details, minimum intensity projections through 10 mm of the 3D phase data in a ROI at the center of the brain are shown in Figs. 1 c and d. Both images excellently show anatomy such as veins or areas with different iron contents that lead to phase offsets (e.g. the basal ganglia), but the novel approach produces slightly sharper images. Fig. 2 shows the final venograms computed from the susceptibility weighted data sets. With conventional processing (left image) the surface of the brain is not visualized correctly (arrows), whereas with the novel method signal reduction at the surface of the brain is reduced.

Discussion:

The proposed method avoids the problems associated with high pass filtering of phase images, while maintaining the advantage of reliable phase unwrapping with region growing. Future work will investigate different settings of the low pass filter, especially with respect to applications at higher field strengths, and further validate the approach with phantom data and simulations.

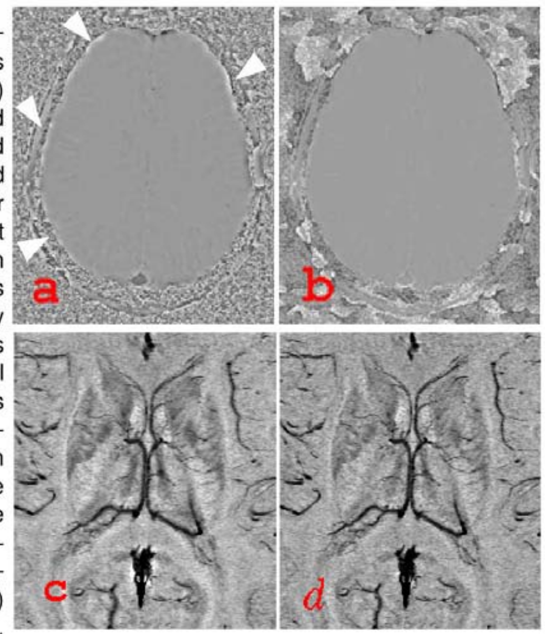

Fig. 1: Conventionally unwrapped and high pass filtered phase image (a) and high pass filtered phase image computed with the proposed method (b). The high pass filter produces bright areas at the surface of the brain (arrow heads). These areas will not be treated correctly when the phase mask is computed. With the novel method, this problem does not arise (b). Minimum intensity projections through a 10 mm stack of phase images in a ROI at the center of the brain are displayed in (c) for the conventional method and (d) for the proposed method. Both phase images present excellent susceptibility contrast.

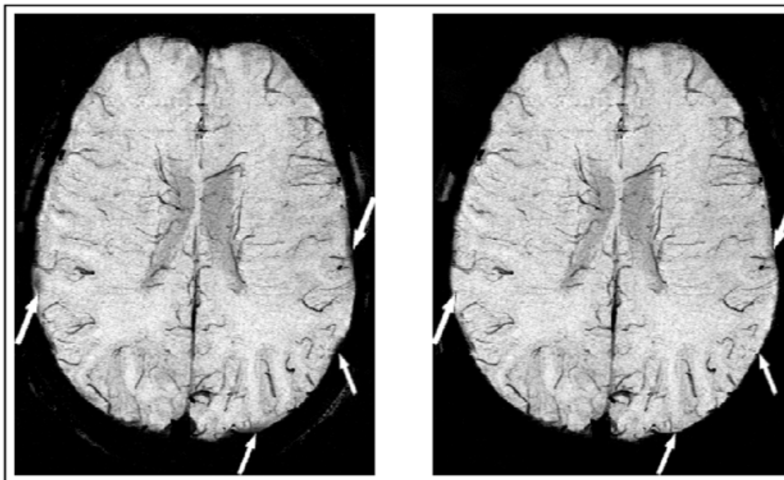

Fig. 2: Conventional (left) and new SWI (right). Delineation of the brain's surface is improved with the novel approach (arrows).

References: **[1]** Reichenbach, J. R. et al. NMR Biomed, Nov-Dec 2001. 14(7-8):453-46 **[2]** Noll D.C. et al. IEEE Trans Med Imaging, 1991, 10, 154-163 **[3]** Rauscher et al., J. Magn. Reson. Imaging 2003, 18, 175-180 **[4]** Witoszynskyj, S., et al. In Proc Intl Soc Magn Reson Med 13 . 2005 page 2249.7.