Evalutation of methods for removal for background field inhomogenities in susceptibility weighted phase imaging

F. Schweser[1], A. Deistung[1], B. W. Lehr[1], and J. R. Reichenbach[1]

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

Introduction

Susceptibility weighted phase images (SWI) provide anatomical contrast complementary to the magnitude [1, 2] by directly reflecting local magnetic field changes induced by the distribution of magnetic susceptibilities of the measured object. Therefore, phase images can be adducted as marker for deposits of iron [3] which was used to estimate brain iron levels in vivo as a function of age [4]. However, phase images are only defined in the range $[-\pi,\pi]$ which produces ambiguities (phase wraps) and thus requires correction of these 2π-wraps. In SWI two methods have been established for phase correction: homodyne filtering [5] and phase unwrapping [6]. In contrast to homodyne filtering phase unwrapping preserves all spatial frequencies and reduces the number of phase wraps especially in the vicinity of air/tissue boundaries. However, unwrapped phase images are superposed with a low spatially varying magnetic field due to background field inhomogeneities. Accurate removing of these background field inhomogeneities from unwrapped phase images is required for quantification of phase images or magnetic susceptibility. Typically, these background fields are estimated by low pass filtering using a Gaussian [7] or box kernel [8], as well as polynomial fitting [2]. In this work, we compare these methods for background field removal with a technique based on spherical mean value estimation (SMVE) [9].

Materials and Methods

Volunteer data were acquired with a high-resolution 3D fully flow compensated gradient-echo sequence (TE/TR/FA = 20ms/30ms/15°, voxel size = 0.6×0.6×0.6mm³, 75% partial Fourier along phase and slice encoding direction) on a 3T MR-scanner (Tim Trio, Siemens Medical Solutions) using a 12-channel head-matrix coil. The multi-channel phase images were combined using uniform sensitivity reconstruction [10]. Phase wraps were eliminated using homodyne filtering and phase unwrapping using the Phun-package [6] resulting in two sets of corrected images. Three sets of images were obtained from the set of phase-unwrapped images by further correcting them with respect to background field inhomogeneity using low pass filtering (Gaussian kernel), fitting by 2nd order polynomials, and SMVE, respectively. Gaussian filtering was performed with kernel widths ranging from 0.3 to 15 FOV^{-1} and SMVE was evaluated for sphere radii ranging from 0.6 to 30mm. The resulting images were analyzed with respect to maintenance of absolute phase differences within adjacent regions of the image and inhomogeneity suppression performance. Examination of absolute phase differences was motivated by the assumption that a slowly varying additive background field has a small impact on the difference between adjacent pixel values. Thus, it was assumed that a modification of the gradient map is an appropriate measure of the quality of the background field suppression. As a quality measure for phase differences the RMSE of the corrected images and the original phase-unwrapped image were calculated and normalized with the RMS of the original image. The amount of inhomogeneity suppression was measured by averaging pixel values of two ROIs in a region of high and low background field magnitude, respectively. The difference of these values was assumed to be closed to zero in case of proper inhomogeneity correction.

Results and Discussion

Fig. 1 depicts the homogenization measure over the normalized RMSE for all methods and filter parameters. Low homogenization measure and low normalized RMSE means well inhomogeneity suppression and low error in absolute phase differences, respectively. The original image is depicted by a pale blue star at zero RMSE. The SMVE seems to clearly outperform the other approaches for a certain range of sphere radii (3.6 to 10.8 voxels). This is actually misleading as the standard deviations of the ROIs were in the dimension of 10^{-1} for these images. The elimination of the background field in these images was performed equally well. Furthermore, it is striking that no images could be extracted that have both proper background field elimination and an RMSE below 0.1. This border likely results from the small background field component that is still present in the gradient field. The region of well reconstructed phase images is highlighted in green. These values were achieved by polynomial fitting, low pass filtering (kernel width of 7 to 9 FOV^{-1}), and SMVE (radius of sphere 6 to 18mm). However, the results of low pass filtering and SMVE depended on the chosen filter parameters. The homodyne filter sufficiently removed the background inhomogeneities but significantly modified the absolute phase differences in all cases. The measured phase map containing both phase wraps and background field inhomogeneity is shown in Fig. 2a. A homodyne filtered image and the phase unwrapped image are shown in Fig 2b and c, respectively. Background field inhomogeneities are directly removed using homodyne filtering while inhomogeneities are still depicted in the phase unwrapped image. Significant artefacts at the edges of the phase maps in Gaussian and SMVE may be attributed to incomplete removal of localized inhomogeneities and incomplete averaging at the edges, respectively.
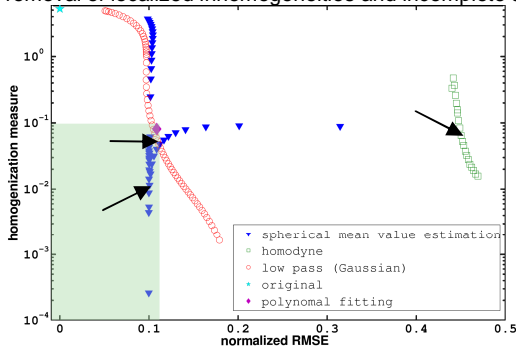

Fig. 1. Homogenization measure (logarithmic scale) over normalized RMSE. The area of best possible values is highlighted in green. The data points corresponding to Fig. 2c,2d, and 2f are marked by arrows.
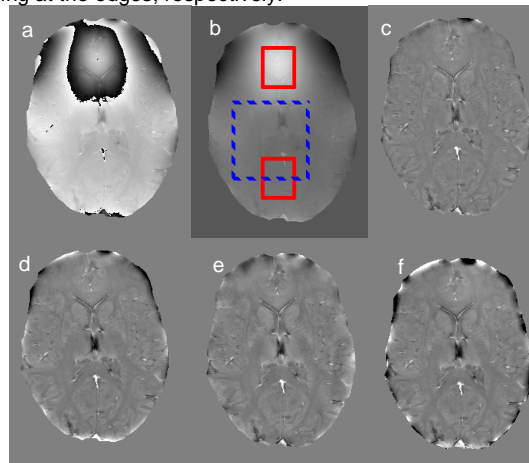

Fig. 2. Original phase map (a), phase map resulting from phase unwrapping (b), homodyne filtering (c), low pass filtering (d), polynomial fitting (e) and SMVE (f). Scaling of (a) is $[-\pi,\pi]$, scaling of (b) is [-5,10], and scaling of (c-f) is $[-\pi/2,\pi/2]$.
The ROIs corresponding to the homogenization measure and RMSE are depicted as red and blue boxes in (b), respectively.

Conclusion

We quantitatively compared methods for phase correction and background field removal that are established in SWI. It was shown that the well established homodyne filter which eliminates background field inhomogeneity very well significantly changes phase differences. Other filters were demonstrated to maintain phase differences better and thus may be favoured applications such as susceptibility quantitation.

References

[1] Rauscher A et al. Am J Neuroradiol. 2005;26:736-42. [2] Deistung A et al. Magn Reson Med. 2008;60:1155-68. [3] Haacke et al. J Magn Reson Imaging. 2007 Aug;26(2):256-64 [4] Xu X, Wang Q, Zhang M. Neuroimage. 2008 Mar 1;40(1):35-42. [5] Noll et al. IEEE Trans Med Imaging. 1991;10(2):154-63. [6] Witoszynsky S et al. Medical Image Analysis. Epub. [7] Hammond Neuroimage 2008 [8] Rauscher et al. J Magn Reson Imaging. 2003 Aug;18(2):175-80 [9] Li L et al. Magn Reson Med. 2004;51:1077-1082. [10] Ros C et al. In Proc ISMRM 2008. (abstract 1265)