Robust phase unwrapping of MRI-data with the z-step Algorithm

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Introduction

Robust phase unwrapping is a necessary prerequisite for several MRI-techniques such as chemical shift based thermometry [1] or BOLD-contrast based venography[2]. Furthermore, phase unwrapping can play an important role in the creation of sensivity maps required for a SENSE/TSENSE reconstruction, in attempts to reconstruct half-fourier data with phase preservation and in several methods for distortion compensation of EPI images. Especially in the later applications, phase unwrapping has typically to cope with images of low resolution (compared to the spatial variation of a phase jump), low SNRs and also discontinuous data sets.

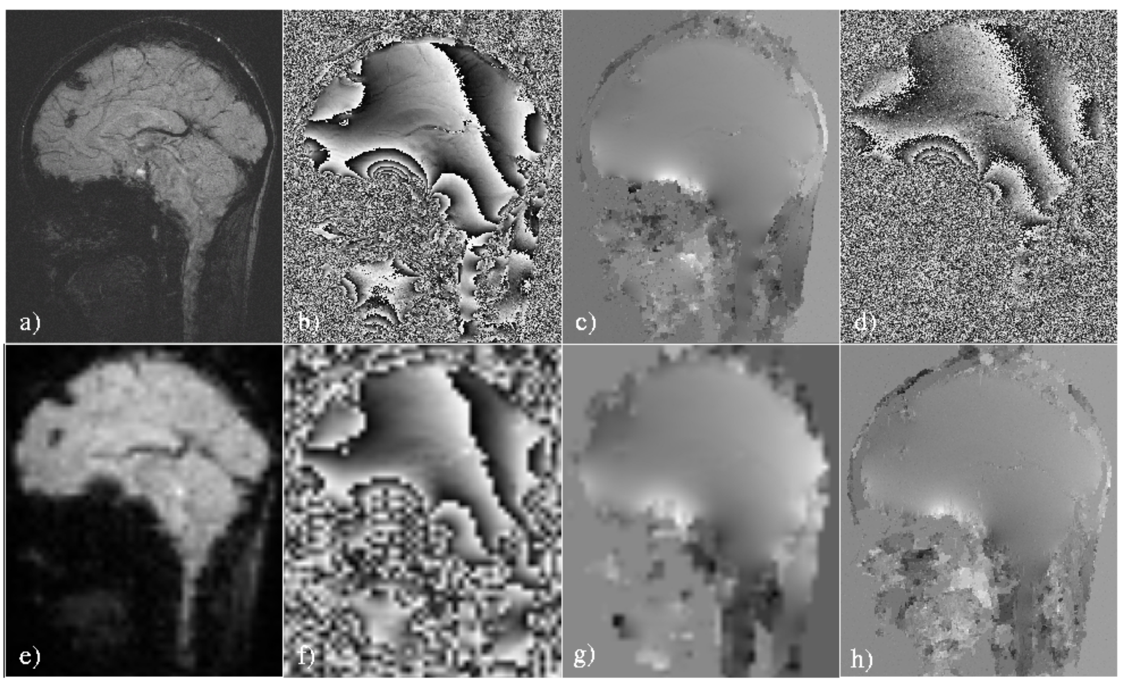
This study adopts a Bayesian approach for robust phase unwrapping. The observation statistics is 2π-periodic (it is a function of the wrapped phase) and accounts for the noise sources present in MR imaging. The a priori probability of the unwrapped phase is modeled by a compound Gauss Markov random field (CGMRF) tailored to piecewise smooth unwrapped phase images. The maximum a posteriori probability (MAP) unwrapped phase estimate is computed by a discrete optimization algorithm (Z-step), implemented by network programming techniques. The posterior density being maximized is interpretable as and L2 norm of the image phase difference constrained to be congruent with the observed wrapped phase.

Material and methods

MR-imaging: All images were obtained on a 1.5T Philips Intera system with a conventional gradient echo sequence (TE=50ms, TR=500ms, Fov=230mm, 5mm slice thickness). To investigate the influence of spatial undersampling of phase wraps on the unwrapping algorithm, the images were obtained with the following matrix sizes: 64^2, 128^2, 256^2 and 512^2. The BW/pixel was scaled according to the matrix size and the shim remained unchanged in order to reproduce the same underlying phase map for each resolution.

Phase unwrapping:

All data was reconstructed off-line and subsequently phase unwrapped with the Z-step algorithm. The quality maps depicting phase discontinuities (for example on the border of the physical object) were derived from thresholded and smoothed MR magnitude images. The robustness against low noise levels was investigated by adding additional noise to the complex data in a separate postprocessing step.



Results

Figure a) shows a sagital magnitude image of a healthy volunteer and figure b) the corresponding phase map. As shown in figure c) the z-step algorithm can reliably unwrap this phase data, even in the regions close to the eyes or the sinus cavities, that suffer severe phase distortions due to local field inhomogeneties. The robustness of the z-step algorithm to high noise levels is evidenced in image h) which represents the unwrapped phase of the low SNR image d) (SNR_{mag}=5). Furthermore, images with a low resolution like image e) (Matrix 64^2) severely undersample the phase-wraps as shown in the low resolution phase image in picture e) close to the eye cavity. Even for these cases, z-step can provide a reliable phase estimate as shown in Image g).

Conclusion

Although the majority of phase unwrapping methods lead to satisfying results on coherent MRI-datasets with large SNR and sufficient spatial resolution, they have commonly problems to cope with severely undersampled or degraded datasets which are typically obtained by fast imaging methods with long echo times. Since the later situations are not exceptional for a variety of recent imaging / reconstruction techniques, robust phase unwrapping is a valuable asset to MRI. The z-step algorithm provides a promising alternative to the established phase unwrapping approaches for these cases and a comprehensive comparison of several published phase unwrapping algorithms with respect to SNR-, undersampling- and dicontinuity-influence on the unwrapping result with the z-step algorithm is currently under way.

References

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