# Automated Phase Unwrapping of MR Images at Different Field Strengths Using Multiple Quality Maps

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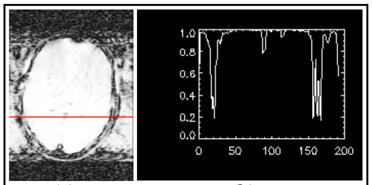
## Introduction

Data acquired by MRI sequences consists of complex values. In gradient echo MRI data, the phase of these complex images holds a lot of information on the local magnetic properties of the sample. Unfortunately, phase images contain phase ambiguities, called wraps, due to the fact that the phase is defined between 0 and $2\pi$ only. With the advent of MRI techniques that employ phase information for enhancement of anatomical and/or functional contrasts, such as susceptibility weighted imaging (SWI), the need for solving these ambiguities arises. A data quality driven 2D phase unwrapping program was developed and implemented in C based on a region growing phase unwrapping algorithm, originally developed for SAR images [1]. The original algorithm computes predictions for a pixel's unwrapped phase using the phase values (which are the only data available) both for seed finding and unwrapping. However, MRI provides complex data (magnitude and phase). In this study besides the local coherence (LC) we used the local average of the complex signal (ACS), the local average of the magnitude (AM), the local variance of the complex signal (VCS) and the local variance of the phase (VPH) as possible maps for seed finding and unwrapping. The aim of the study was to optimize the phase unwrapping algorithm presented previously [2] in terms of stability and performance by evaluating the unwrapping results to get the best combination of maps for seed finding and unwrapping**.**

## Methods

**MRI:** Data were acquired using a susceptibility weighted 3D gradient echo, first order velocity compensated sequence using the following parameters: at 1.5 T: TE=40ms, TR=67 ms, alpha = 25, FOV=256x192x64mm3, typical matrix=512x256x36; at 3T: TE=25ms, TR=40ms, alpha = 20, FOV=256x192x48mm3, typical matrix=512x384x32.




(a) (b)

**Fig. 1:** Coherence map (a) of an image with ghosts and a cut through this image along a line (b).

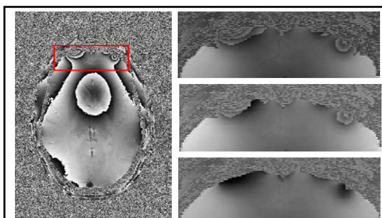
**Post-processing:** A 2D phase unwrapping program was developed and implemented in C. The algorithm computes predictions for a pixel's unwrapped phase using the phase values of neighboring pixels that have been unwrapped in earlier iterations [2]. The predictions are made using linear interpolation along one or two pixel long prediction lines. To evaluate the reliability of a predicted phase three criteria are applied: (i) The "quality" of data in a pixel, (ii) the variance of predictions of the individual lines, (iii) the difference between wrapped and unwrapped phase.

The estimation of a pixel's quality is based on a quality map of one of the following types: the local coherence (LC), the local average of the complex signal (ACS), the local average of the magnitude (AM), the local variance of the complex signal (VCS) and the local variance of the phase (VPH). These maps were implemented and their influence on unwrapping and seed finding was compared to the local coherence (LC) used in the original algorithm.

The algorithm with these different measures was implemented in an in-house developed software package. The package included an interface to IDL (RSI, USA) and a GUI for ParaVision (Bruker, Germany). It was tested on high-resolution brain data sets (512x512 matrices) acquired on 3T MedSpec (Bruker, Germany) and 1.5T Sonata (Siemens, Germany) machines.

## Results

**Unwrapping:** Using LC as quality criterion made it difficult to achieve a good separation of object and background (fig. 1). It was found that the best separation of object and background could be obtained if maps of the local average of the complex signal (ACS) or the local average of the magnitude (AM) were used (fig. 2). Using variance maps (both VCS and VCH) did not lead to any meaningful results because the variances varied too much.



(a) (b) (c) (d)

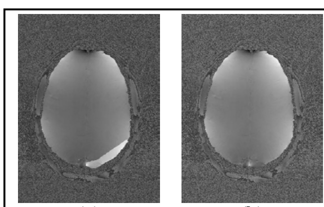
**Fig. 2:** phase image (a) unwrapped using LC (b), ACS (c) and AM (d) as quality map.

**Seed finding:** The algorithm's performance was heavily depending on the underlying map for seed finding. While the algorithm performed very well on 3T data using both AM and ACS maps, it failed on 1.5T data in several cases due to the presence of large signal intensities in areas that were loosely connected to the bulk of the brain (i.e. fatty tissue around the brain). This leads to seeds that caused unwrapping of the bulk of the brain with unreliable predictions (fig. 3a).

A solution is to use different maps for seed finding and unwrapping (fig. 3b). The best results were achieved by using LC for seed finding and AM for unwrapping.

## Discussion

The reason why LC produces suboptimal results lies in the fact that „ghosts" in MR images lead to a coherent phase even in areas with almost no signal (fig. 1). Furthermore the coherence cancels out in areas having a steep phase topology although there still is signal present. If also magnitude information is used the problem of separating the object from background can be solved. But, because some sequences lead to large signal intensities in areas that are loosely connected to the bulk of the brain a different problem arises: the algorithm's regions grow into the brain with predictions that are based on a few pixels only and thus are unreliable. The reason why this effect was observed at 1.5T but not 3T is the different relaxation times of different tissues at different field strengths. Although, this problem can, in principle, be prevented by adjusting the algorithm's parameters for each data set separately. This solution is not desirable because of a lack of robustness for day-to-day application. We found that separating maps for seed finding and unwrapping leads to a robust performance independent of sequence parameters and field strength. We obtained the best results by using LC for seed finding and AM for unwrapping. This can be justified by the fact that using LC for seed finding ensures that the algorithm starts in areas of flat phase topology. In these areas phase predictions can be made easily. On the other hand AM ensures that regions grow within areas of a well-defined signal.



(a) (b)

**Fig. 3:** image unwrapped incorrectly (a) because of large signal intensities, same image unwrapped by the modified algorithm (b).

## References

[1] W. Xu and I. Cumming, IEEE Transactions on Geoscience and Remote Sensing, 37:124–134 (1999).
[2] A. Rauscher et al., JMRI 18; 175-180 (2003).

## Acknowledgements

This work was supported by the COST action B21 (Grant No.: COST-STSM-B21-00690),
A.R. is supported by the Deutsche Forschungsgemeinschaft (DFG) (Grant No. RE 1123/7-1)