ΦUN (Φase UNwrapping) - Validation of a 2D Region-Growing Phase Unwrapping Program

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Introduction

Phase unwrapping is a non-trivial task in case of two or higher dimensional data and becomes increasingly important with the trend towards higher field strengths. Fast phase unwrapping is important in the light of online data-processing. Reliability and robustness is of special importance when phase maps are used to unwrap geometric distortions, especially in low SNR areas. This can be critical at high field strength where susceptibility gradients can be very large and lead to intravoxel dephaseing and low SNR. The aim of this study was to validate a self-developed 2D phase-unwrapping algorithm, that has been optimized for unwrapping of MR images [1], and has been implemented in C as stand alone program (ΦUN), and to compare it with PRELUDE [2] - the unwrapping tool of the FSL package (FMRIB, Oxford, UK) - in 2D and 3D mode in terms of speed and quality of the results.

Methods

Data sets of a phantom (ping-pong ball in an aqueous solution of 0.9% NaCl and 0.2mmol/l Gd-DPTA) were acquired with a fully flow-compensated 3D gradient echo sequence [3] (TR=60ms) on a 1.5T Magnetom Vision (Siemens, Germany) (fig. 1). To simulate various SNR levels the data were acquired with echo-times ranging from TE=20ms to TE=45ms and flip angles between $\alpha=2°$ and $\alpha=25°$. Additionally, two different matrix sizes (512x336x32 and 256x168x32) were used while the FoV was kept constant ($256x224x96mm^3$). In total 72 data-sets were acquired. The SNR was calculated for a region close to the inhomogeneity. Data of five healthy subjects where acquired with the same sequence (TE=40ms, TR=65ms, $\alpha=25°$, matrix=512x384x36).

Fig. 1: Cuts through the magnitude and phase image of the phantom.

Unwrapping was done by applying our self-developed 2D region-growing algorithm ΦUN as well as PRELUDE to the data. In all cases, only the default parameters were used and no optimization was done. Since by default PRELUDE uses a 2D-3D hybrid mode for high resolution data, PRELUDE was also executed in 2D mode to ensure a fair comparison. Additionally, ΦUN was also used in multi-region mode. Differences in the results between all methods were identified by subtracting the phase images from each other. Pixels that differed from 0 were investigated in the magnitude, the wrapped phase and all unwrapped phase images to obtain an understanding for the different results.
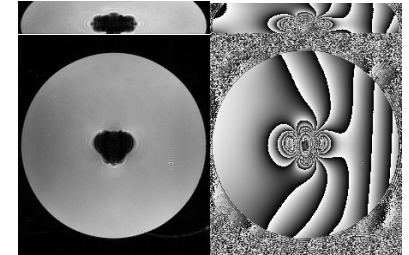
Results

Phantom data: As far as the unwrapped phase is concerned, the results of all methods (ΦUN, PRELUDE in 2D, 3D and default mode) were in excellent agreement for almost all data-sets. The only exceptions were the high-resolution data-sets with very low SNR (SNR < 8). In these cases, PRELUDE (in 2D mode) even failed to unwrap pixels in rather homogeneous regions. The number of those errors increased with decreasing SNR. In 3D mode and default mode, PRELUDE failed to unwrap these images within a 24h period and was terminated manually. In all cases, PRELUDE in 3D and default mode was considerably slower (at least by a factor 10) than the 2D region growing algorithm (fig. 3). In the best case, PRELUDE in 2D mode was just a factor 1.5 slower than the region growing algorithm in single region mode and about the same speed as the region growing algorithm in multi region mode. For PRELUDE (in all modes) the run time depended strongly on SNR, whereas it was approximately constant for ΦUN.

Subject data: For the subject data the results of all methods also were in very good agreement. Only in case of a few pixels or loosely connected areas, the results differed. Even a close inspection of those cases did not allow to judge which algorithm yielded the correct phase. As far as the time required for unwrapping is concerned, PRELUDE in 2D mode was at least a factor 10 slower than ΦUN (fig. 4). In default and PRELUDE in 3D mode was between a factor 100 and more than a factor 1000 slower resulting in run times of several hours for a single data-set.
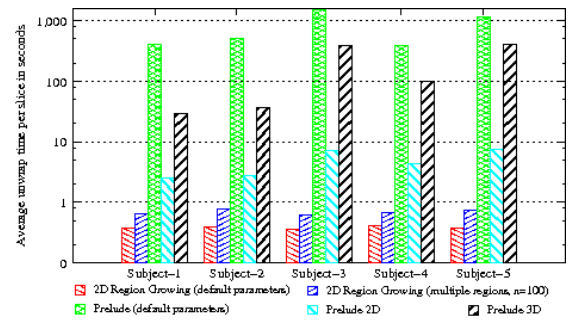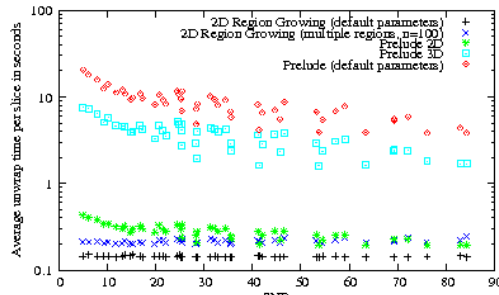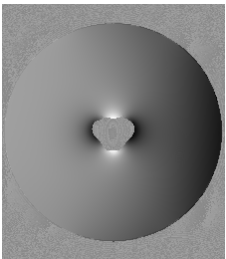

Fig. 2: Unwrapped phase of the image in fig. 1.

Fig. 3: Average unwrapping time (logarithmic scale) per slice of the low resolution data over SNR in a region near the inhomogeneity.

Fig. 4: Average time (logarithmic scale) required for unwrapping of a slice of the subject data.

Discussion and Conclusions

Both methods proved equally capable of unwrapping almost all data-sets, except for those data that had an extremely low SNR. For these data ΦUN yielded better results. Nevertheless, the unwrapping time of PRELUDE had a strong dependency on SNR. Also, the 3D modes of PRELUDE did not provide any advantage as far as the quality of the unwrapped phase was concerned, but were unacceptably slow. That the differences in speed where more pronounced in the subject data might be due to larger variations of SNR in those data-sets.

A possible point of critique of this study might be that the comparison was done without having a ground truth. Such a ground truth could only be achieved by using artificially generated phase images. We refrained from using simulated phase images because the comparison of phantom and subject data showed that the interplay between magnitude, phase, SNR and unwrapping is far more complex than what could be achieved by a simple simulation.

We conclude that reliable and fast phase unwrapping is possible using both tested algorithms. However, this is only valid if PRELUDE is used in 2D mode. Even then PRELUDE leads to 10 times longer calculation times for in vivo data sets and shows an SNR dependence.

References

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