A concomitant method to unwrap phase images with fringelines

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Target audience: Researchers working in phase imaging, SWI, and QSM.

Introduction: In MRI, phase images carry useful information and have been used in flow and temperature measurement, susceptibility-weighted imaging, and quantitative susceptibility mapping. However, the phase is usually wrapped into $[-\pi,+\pi)$ range, which needs to be unwrapped before its information can be used. A number of algorithms were proposed to unwrap phase wraps by sequentially processing each voxel [1]. In general these sequential algorithms perform well, except that they cannot unwrap fringelines, which are phase wraps that are terminated at singular poles and thus cannot be unwrapped to a continuous function. A method taking advantage of the Fourier transformation properties and trigonometric identities of the Laplacian operator [2], the Fourier method, is able to describe the fringelines as continuous functions. While the method unwraps phase wraps efficiently, the resultant unwrapped phase has low frequency deviations. In this study, we propose to combine the Fourier method and a sequential method proposed by Cusack et al. [3] by high- and low-pass filtering to unwrap wrapped raw phase with fringelines.

Materials and Methods: Magnitude and Phase images were acquired by using a standard 3D gradient-echo (GRE) acquisition on a 3T Siemens MRI system (NIH, Bethesda, MD, USA). Contrast parameters were: TR/TE/flip angle = 40 ms/25 ms/15°. Geometric parameters were: image matrix = 448×439×72, and voxel size = 0.5×0.5×2 mm^3. Parallel imaging of GRAPPA ×2, and flow compensation were employed.
The wrapped phase image was unwrapped by using the Fourier method and Cusack's method. The two unwrapped phases were high- and low-pass filtered before being summed together: $P_{proposed} = LP*P_{cusack} + HP*P_{Fourier}$. The filter was a Gaussian filter with a cutoff frequency of 0.0625 cycles/pixel.

Results: The wrapped raw phase (Fig 1A) was compared to the unwrapped phase by the Fourier method (1B) and Cusack's method (1C), as well as their combination (1D). The fringeline (yellow arrows) did not appear in the phase unwrapped by the Fourier method and in the proposed method. The unwrapped images were re-wrapped and subtracted from the raw phase. The difference images were obtained by subtracting 1 B-D from raw phase 1A, shown in Fig. 1 E-G. While the Fourier method resulted in substantial differences (1E), no difference was resulted from Cusack's method, which means the fringelines were not unwrapped. The proposed method showed "smoothed fringelines", as shown in Fig 1D. Its difference image showed the fringeline as well as three singular poles (red arrows), which could not be easily visualized in the raw phase (1A).

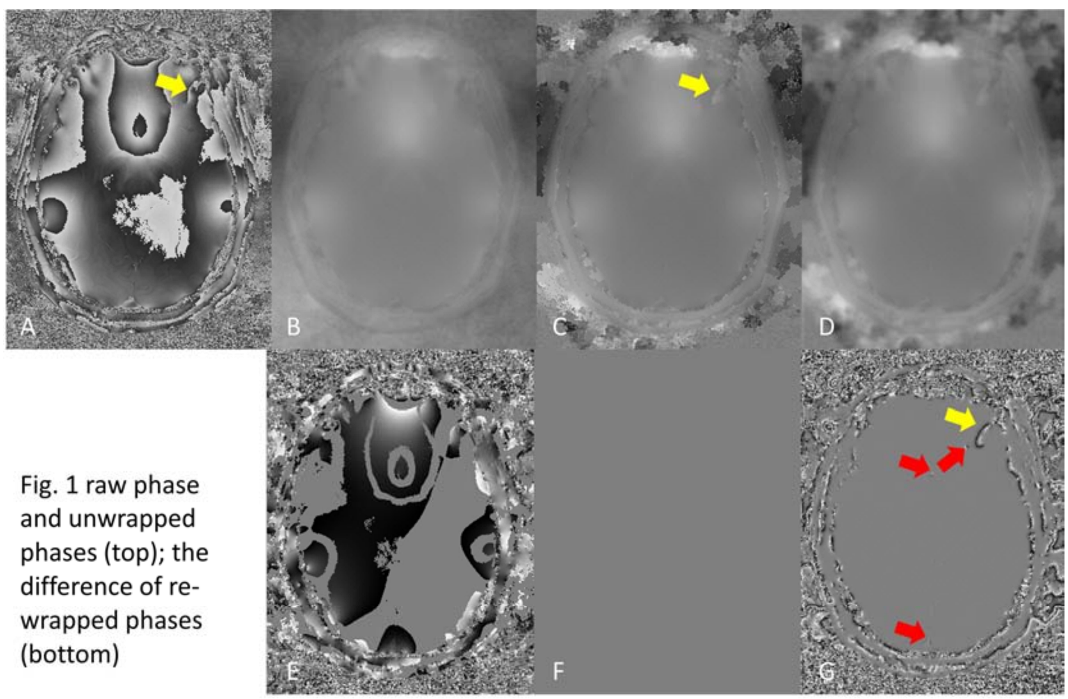

Fig. 1 raw phase and unwrapped phases (top); the difference of re-wrapped phases (bottom)

Conclusion: A simple combination of two phase unwrapping methods by applying a low- and a high-pass Gaussian filter is proposed to unwrapping raw phase images with fringlines. The resultant phase images do not have low-frequency deviations and the fringelines do not appear, which can be beneficial for SWI and QSM.

Reference: [1] Ghiglia and M. D. Pritt, Two-Dimensional Phase Unwrapping:Theory, Algorithms, and Software (Wiley, 1998). [2] Schofield and Zhu, Optics Letter 2003:28:1194-6. [3] Cusack and Papadakis., NeuroImage 2002;16:754-764.