Removing Phase Artifacts Using Fourier Transform Based Field Estimation Can Lead To Significant Improvement In Phase Unwrapping Based SWI Processing

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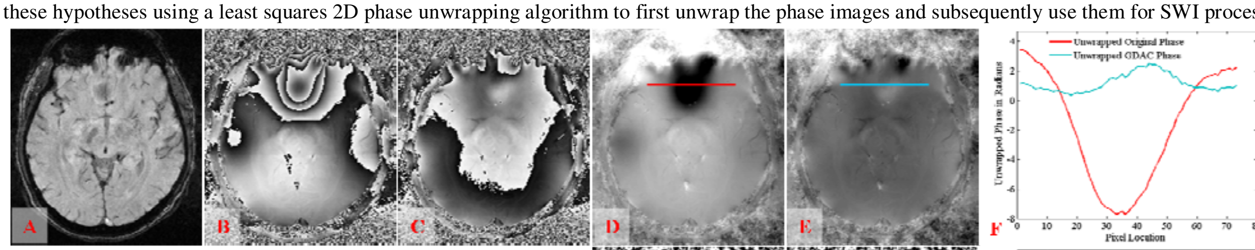
Introduction: Susceptibility weighted imaging (SWI) has become a powerful clinical tool for studying diseases like multiple sclerosis, stroke, trauma and brain tumors. However, SWI still suffers from problems caused by rapid phase changes and phase aliasing due to background magnetic field changes caused by the presence of air-tissue interface; particularly in the mid-brain and the forebrain regions near the paranasal sinuses. Since most phase changes are of low spatial frequency, a spatial high pass filtering approach has been employed so far to remove the phase aliasing [1]. Furthermore, it has been shown by Rauscher et al [2] that first unwrapping the original phase and then subjecting them to high pass filter improves the quality of the filtered phase and hence of the processed SWI images. Another approach, based on direct estimation of this phase aliasing arising from air-tissue interface geometry and subtracting out its contribution from SWI images, was proposed last year [3]. The resultant phase images, now referred to as Geometry Dependent Artifact Corrected (GDAC) phase images, have been shown to result in remarkable improvement in the resultant processed SWI images even with simple high pass filtering. A touted principal advantage of this method is that, a) the resultant GDAC phase images can work as input to any other existing phase unwrapping or phase filtering approaches and that b) it should augment the results of any of those approaches. In this abstract we test these hypotheses using a least squares 2D phase unwrapping algorithm to first unwrap the phase images and subsequently use them for SWI processing [4].



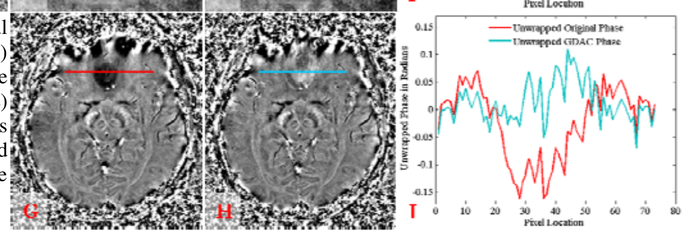


Figure 1: **A**) Original SWI magnitude; **B**) Corresponding Original SWI phase; **C**) GDAC phase; **D**) Unwrapped Original phase; **E**) Unwrapped GDAC phase; **F**) Profile plot of phase along the indicated red and blue lines on the unwrapped images (D) and (E) respectively; **G**) High pass filtered version of (D); **H**) High pass filtered version of (E); **I**) Profile plot of phase along the red and blue lines indicated on the high pass filtered unwrapped phase images (G) and (H) respectively.

Materials And Methods: One healthy volunteer was imaged at 1.5T Siemens Sonata magnet with the following parameters: 1) 3D gradient echo sequence run twice with TEs 5 and 6 ms, TR 20ms, flip angle 20°, BW 400 Hz/pixel, slices 128, matrix 256x256 and voxel size 1 x 1 x 2mm; 2) 3D SWI data with TE 40ms, TR 44ms, flip angle 20, BW 400 Hz/pixel, voxel size 1 x 1 x 2mm, matrix 256 x 256 and slices 112. Magnitude images from 5ms echo time data were used to extract the geometry of air-tissue interface using CTM algorithm [5]. Phase data from 5 and 6ms echo times was used to create phase data with effective TE of 1ms. This along with the extracted geometry was used to estimate $\Delta\chi_{air\text{-}tissue}$ and $\Delta\chi_{mastoid\text{-}tissue}$ using the method described in [3]. The quantified $\Delta\chi$ values were then used to estimate the phase at TE 40ms which was then subtracted from the collected SWI phase images to obtain the GDAC phase images. Both GDAC phase and Original phase images were used as input to a least squares 2D phase unwrapping algorithm to generate Unwrapped-GDAC and Unwrapped-Original phase. These unwrapped phase images were then high pass filtered and the results were visually compared. The high pass filtered phase images were subsequently used to generate their corresponding processed SWI magnitude images (pSWI) denoted by Unwrap-HP-GDAC-pSWI and Unwrap-HP-Original-pSWI respectively.

Results and Discussion: The values obtained for $\Delta\chi_{air\text{-}tissue}$ and $\Delta\chi_{mastoid\text{-}tissue}$ are respectively -13ppm and -7ppm. These were used for estimating the phase due to air-tissue interface at TE 40msec which is then subtracted from the original SWI phase images to obtain the GDAC phase. Figure 1B and C show the original SWI phase and the corresponding GDAC phase where most of the original phase wraps near the fore-brain region are removed. The rapid phase variation near the air tissue interface is still apparent in the unwrapped-original phase image (Fig.1D), where as it is almost completely absent in the unwrapped-GDAC phase image (see Fig 1E and profile plot in Fig1F). Consequently when these images are high pass filtered (Fig 1G and H), the resultant HPfiltered-unwrapped-Original phase (Fig.1G) still has some remnant rapid phase variation. The affect of this becomes more apparent when these phase images are used for creating the phase mask for SWI processing. Figure 2 shows the corresponding Unwrap-HP-Original-pSWI and Unwrap-GDAC-pSWI images. Due to the remnant phase variation near the air-tissue interface in the HPfiltered-unwrapped-Original phase, erroneous signal loss artifact appears in the fore-brain region (see Fig 2a). Conversely, this is completely absent in the Unwrap-HP-GDAC-pSWI (see Fig 2b). The accuracy of the quantified $\Delta\chi_{air\text{-}tissue}$ and $\Delta\chi_{mastoid\text{-}tissue}$ values depends upon how well the geometry is represented and also on the step size of $\Delta\chi$ used [6]. Better step size or a direct least-squares approach to $\Delta\chi$ quantification [6] could lead to more accurate determination of $\Delta\chi$ and hence more accurate removal of phase effects coming from air-tissue interface. However, it is encouraging that despite the possible slight error in the quantified $\Delta\chi$ values, the GDAC phase images still provide much better results compared to using original phase images.

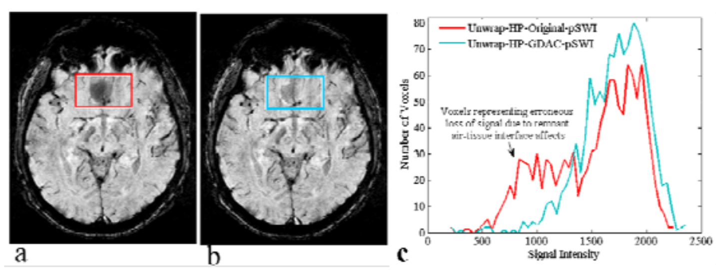


Figure 2: a) Unwrap-HP-Original-pSWI, i.e. processed SWI magnitude generated using high pass filtered unwrapped original phase image; b) Unwrap-HP-GDAC-pSWI, i.e. processed SWI magnitude generated using high pass filtered unwrapped GDAC phase; c) Difference image [(b)-(c)]; d) Histogram of the regions marked showing the # of voxels erroneously lost when original phase images are used instead of GDAC phase.

Conclusion: In conclusion, because most of the rapid phase variation near the air-tissue interface is already removed in the GDAC phase, the resultant unwrapped and subsequent high pass filtered phase images provide much better artifact free phase images. Consequently they result in artifact free processed SWI images. Thus it is shown that geometry dependent artifact removed phase images (GDAC phase) can be used as input to phase unwrapping algorithms and can help augment the results of the SWI phase processing method of using phase-unwrapping with subsequent high pass filtering.

References:1)Haacke et al., MRM, 52:612, 2004 ; 2) Rauscher A et al Proc. ISMRM 2003 p#105; 3) Neelavalli J et al Proc. ISMRM 2008 p#3499;4) Ghiglia DC et al J Opt Soc Am Optic Image Sci Vis 1994;11(1):107-117 ; 5) Pandian DS et al JMRI 2008;28(3):727-735 ; 6) Neelavalli J et al Proc. ISMRM 2008 p#3056.