Phase image artifact reduction through interpolation

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Introduction The accuracy of quantitative susceptibility mapping is dependent on the background phase removal[1–3]. When regions with unreliable phase values are included in the phase image, e.g. vessels without proper flow compensation or bones with noisy phase, a simple background phase removal may amplify phase noise or create edge artifacts. In this study, we show a method to reduce the phase artifacts that are caused by the inclusion of noisy regions with unreliable phase values, in order to improve the accuracy of QSM.

Method Usually the background phase removal consists of two steps[2,3]: phase unwrapping and filtering. The main idea is to replace the unreliable phase information in the noisy regions with interpolated phase values, prior to any filtering. This interpolation is done by solving the Laplace's equation with Dirichlet boundary condition[4]: $\Delta\varphi_{int}=0$, where Δ represents the Laplacian operator, φ_{int} is the interpolated phase. φ_{int} is equal to the unwrapped phase φ_{uw} on the boundary of the noisy regions. The Laplace's equation was solved using relaxation method[6], i.e. by iteratively updating the values in the region of interest with the local average value until the relative change between two iterations is smaller than a threshold *th*. In this study, a spherical kernel with radius 4 pixels was used to accelerate the convergence. *th* was set to be 10^{-4}. The proposed method was tested on two datasets collected for healthy volunteers on a 3T scanner using 3D flow compensated gradient echo sequence; one is focused on brain and the other on leg. For the brain data, the noisy regions are those around the middle cerebral artery, which have non-reliable phase due to the turbulent blood flow. For the leg data, the noisy regions are the bone regions where the signal is low due to little water content. Imaging parameters for the brain data: TE=14.3ms, TR=26ms, BW=121Hz/px, FA=15^o, voxel size 0.5x0.5x0.5mm^3. For the leg data: TE=7.65ms, TR=20ms, BW=248Hz/px, FA=15^o, voxel size 0.5x0.5x1mm^3. Phase images were first unwrapped using 3D path-following algorithm[5]. After interpolating the noisy regions, phase images were processed using SHARP[3] with kernel size 8 and regularization threshold 0.05. Susceptibility maps were generated using truncated k-space division[7] with threshold 0.2.

Results

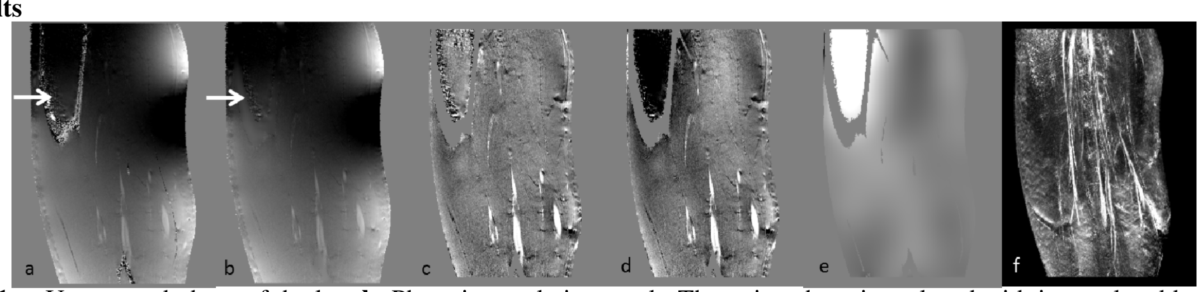

Fig. 1 a. Unwrapped phase of the leg. **b.** Phase interpolation result. The noisy phase is replaced with interpolated background phase. **c**. SHARP processed phase using (b). **d**. SHARP processed phase using (a), with zero-filling in the noisy regions. **e**. (c)-(d). **f** Maximum intensity projection of susceptibility maps generated using (c).

As shown in **Fig. 1**, replacing the noisy phase in the bone region in the leg helps to produce more homogeneous phase images (**Fig 1.c**). This leads to susceptibility maps not so affected by the noise inside the bone regions or near the edges of the bone, as shown in **Fig 1.f**. Zero-filling of the noisy region leads to low spatial frequency artifacts, as shown in **Fig 1.e.** In the brain data, the unreliable phase values near the middle cerebral artery regions leads to phase artifacts (arrow in **Fig 2.a**), which were reduced when the interpolated phase image was used (**Fig 2.b** and **c**). The non-local streaking artifacts in the susceptibility maps due to the unreliable phase were also reduced (**Fig 2.f**).

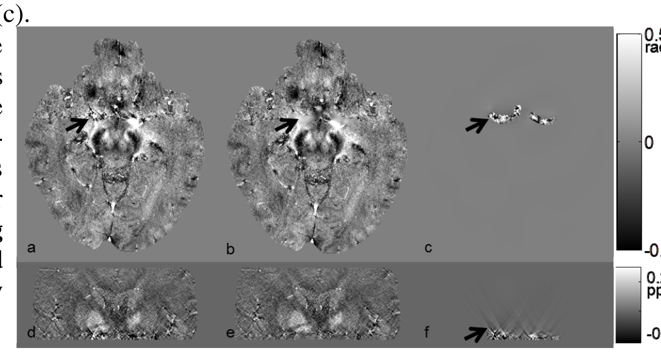

Fig. 2. **a**. Processed phase using original phase. **b**. Processed phase using interpolated phase. **c**. (a)-(b). **d**. susceptibility maps (SM) generated using (a). **e**. SM generated using (b). **f**. (d)-(e).

Discussions and Conclusions

The noisy regions in the phase images should be properly handled, prior to any background phase removal step, since any artifacts or unreliable phase in the phase images will be propagated into processed phase images and susceptibility maps. The zero-filling strategy may lead to edge artifacts due to the discontinuities in zero-filled phase images. The interpolated phase, however, is made to be smooth in 3D. Besides, it has the same property as the background phase and will be removed by the background phase removal step such as SHARP. In conclusion, the proposed method improves the QSM result, particularly for the data processing when large regions of unreliable phase are present.

Reference 1.Haacke, et al. MRM. 52, 612–618 (2004). 2.Liu, et al. NMR Biomed. 24, 1129–1136 (2011). 3. Schweser, et al. NeuroImage 54, 2789–2807 (2011). 4.Li, et al. MRM. 46, 907–916 (2001). 5.Abdul-Rahman, et al. Appl. Opt. 46, 6623–6635 (2007). 6.Hoffman. Numerical methods for engineers and scientists. (Marcel Dekker, 2001). 7. Haacke, et al. JMRI 32:663–676 (2010)