Increasing the effectiveness of the UNFOLD technique by removing phase trends

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Introduction: For dynamic studies such as functional MRI and cardiac imaging, high temporal resolution is critical in order to effectively monitor the temporal behavior of the signal. Under-sampling the k-space is a straightforward way to speed data acquisition and improve temporal resolution. However, aliasing artifacts show up because of under-sampling. In 1999, Madore *et al.* [1] reported a technique called UNFOLD, which utilize temporal information to remove aliasing artifacts associated with k-space under-sampling. UNFOLD purposely interleaves under-sampled k-space trajectories across time frames. As a result, aliasing artifacts oscillate rapidly at a specific frequency. The true signal, however, remains quite stable. Thus, they can be separated easily in the spectrum. By filtering out spectrum peaks corresponding to the oscillation of aliasing artifacts, alias-free images can be obtained. Since spectrum filtering can result in an increase in temporal coherence or a decrease in temporal resolution, it is important to keep the number of filtered-out frequency components as small as possible. However, if there is a phase drift in the signal across time frames which may be caused by scanner instability or other imperfections, it can shift or broaden aliasing peaks in the spectrum. Although filtering out more frequency components may solve the problem, it is by no means the optimal solution. In this work, we proposed a method in which both linear and quadratic phase trends are estimated and removed from the signal before the application of the UNFOLD technique. The proposed method is more effective in removing aliasing artifacts and preserving temporal resolution.

Methods: All experiments were performed on a 3T whole-body scanner (Signa, rev 12M5; GEMS, Milwaukee, WI, USA). The body coil was used for transmission and an 8-channel head coil supplied by manufacture was used for reception. To prove the effectiveness of the proposed method, a functional scan which utilizes spiral in/out sequence [2] was performed on a normal subject. High-order shim was performed before the functional scan to improve the field homogeneity. The functional scan lasted 366s with the first 6s at the beginning of the scan discarded. Other imaging parameters include TE=30ms, TR=3000ms, Flip Angle=90°, FOV=21cm and matrix size=120×120. 22 3mm slices were collected. Altogether 120 time frames were collected during the functional scan. A fully sampled k-space requires 2 spiral interleaves. However, for each time frame, only one interleaf was collected. The index of spiral interleaves alternated across time frames so that aliasing artifacts oscillated at the Nyquist frequency. The UNFOLD technique filtered out just the Nyquist frequency component to remove aliasing artifacts. To avoid the complexity caused by aliasing artifacts in the process of estimating phase trends, we combined complex images between two adjacent time frames to produce alias-free images and used those to estimate linear and quadratic phase trends. The estimation was done on a pixel by pixel basis. Later on, both trends were interpolated back into the original temporal resolution and removed from the complex images before the application of the UNFOLD technique. For comparison, the data were also processed without removing phase trends.

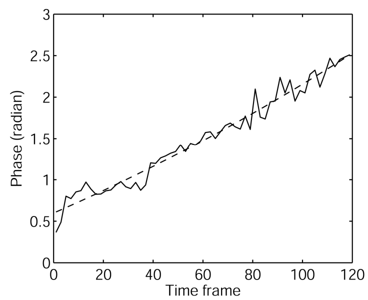

Figure 1: Phase drift across time frames (solid) and its polynomial fit up to the order of 2 (dashed) from a representative pixel.

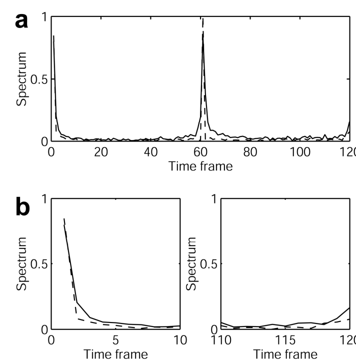

Figure 2: Spectrums (normalized) obtained from the same pixel as that in Figure 1 without (solid) and with (dashed) phase trends removal. A closer look is shown in b.

Results: Phase drift across time frames from a representative pixel ([84, 40] in spiral-in images for slice 1) is shown in Figure 1 by the solid line. It was fit by polynomials up to the order of 2, which is shown by the dotted line in Figure 1. Spectrums (normalized) were obtained from the same pixel as that in Figure 1 without and with the removal of phase trends. Results are shown in Figure 2a. A closer look of the aliasing peak can be found in Figure 2b. Representative images (spiral-in, slice 1-4) without and with the removal of phase trends are shown in Figure 3. It can be seen clearly that aliasing artifacts are greatly reduced by using the proposed method.

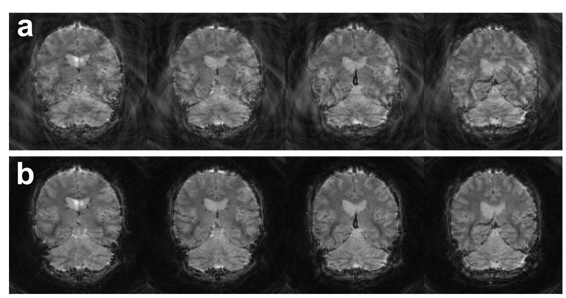

Figure 3: Representative images without (a) and with (b) the removal of phase trends before the implementation of the UNFOLD technique.

Discussion: We have proved in this study that removing phase trends before the implementation of the UNFOLD technique could help reduce aliasing artifacts and produce better images. Although our study is focused on the human brain, the same idea can also be implemented in other areas of the human body such as cardiac imaging and dynamic contrast enhanced breast imaging, where spatial resolution, spatial coverage and temporal resolution are all critical. Typically in cardiac imaging and dynamic contrast enhanced breast imaging, phase drift are more severe and may experience periodic pattern due to cardiac and respiratory activities. Therefore, it is reasonable to expect a larger improvement when the proposed method is applied into those areas, although removing higher-order phase trends might be necessary in such cases.

References:

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2. Glover GH, Law CS. Magn Reson Med 2001;46(3):515-522.