Simultaneous Nyquist ghost and Geometric distortion correction based on reversed readout strategy in EPI

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Introduction: Echo planar imaging (EPI) has been used in many applications such as fMRI and DWI. However, EPI images are prone to Nyquist ghost and geometric distortion. Nyquist ghost is caused by the inconsistency between odd and even echoes in the acquired data. Current Nyquist ghost correction methods are either reference based[1] or image based[2], which depends on whether a separate reference scan is acquired and used to calibrate the phase difference. On the other hand, B_0 inhomogeneities cause geometric distortion on EPI images. This artifact can be corrected by acquiring additional scans to measure the main magnetic field or to calculate the point-spread function (PSF)[3] for image phase correction. In this study, we proposed a new scheme based on reversed readout strategy[4] to correct both Nyquist ghost and geometric distortion artifacts on EPI images simultaneously.

Methods: Fig. 1 shows the data acquisition and reconstruction flow chart for the proposed correction method. Pulse sequence is modified based on normal EPI sequence by simply reversing the readout gradient on successive frames. Thus data at a particular phase encoded line in adjacent time-series, k(t-1) and k(t), are acquired in opposite readout direction, as shown in Fig. 1. Then k(t-1) and k(t) are combined to generate a Nyquist free image[4], which is subsequently used to calculate GRAPPA weights. Then positive echo *Ip(t)* and negative echo *In(t)* are reconstructed by GRAPPA respectively. Note that positive echoes in adjacent time frame, i.e., *Ip(t)* and *Ip(t-1)*, are acquired with a shift in *k*-space at different echo time spaced by the *ky* sampling interval. After applying a linear phase to one of them to eliminate phase ramp caused by *k*-space shift, a phase shift map $\Delta\varphi$ between two images are calculated to correct geometric distortion in *Ip(t)* by modulating the k-space data[5]. After distortion correction, the images from positive echo *Ip(t)* and negative echo *In(t)* are combined to generate the final corrected image *I(t).* All experiments were performed on a 7T horizontal-bore Bruker MRI scanner with a 4-channel surface coil. Prior to single-shot GE-EPI acquisition with the modified sequence, global shimming was performed. The image acquisition parameters are: TE/TR = 25/2000ms, readout bandwidth = 400kHz, matrix size = 128×128, NA = 1, NEX = 10, 5 slices with thickness=1.0 mm.

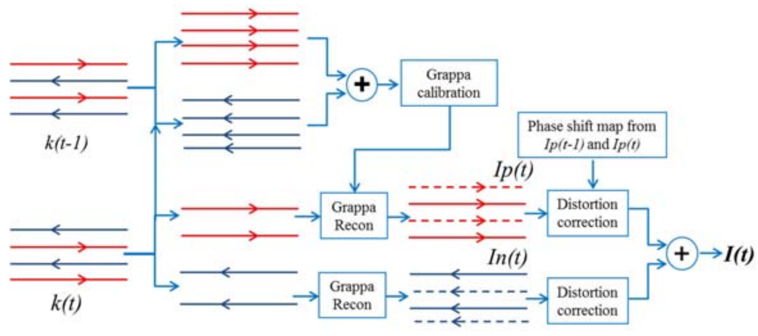

Fig. 1 Data acquisition and reconstruction flow chart

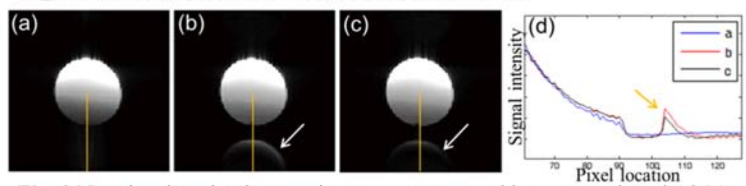

Fig. 2 Nyquist ghost in phantom images are corrected by proposed method (a), based on a reference scan (b), based on image entropy minimization (c). All images are scaled to the same level. The signal intensity of the vertical line (yellow line) from the image centre are plotted in (d). Note that all image slices (a-c) are scaled identically to the same level.

Results: Fig. 2a shows phantom image corrected by the proposed method. Images corrected based on a reference scan and based on image entropy minimization are also shown for comparison in Fig. 2b and Fig. 2c, respectively. Remaining Nyquist ghost (pointed by arrow) can be observed in Fig. 2b and Fig.2c, but is completely removed in Fig.2a. The signal intensities of the vertical line across the image centre are plotted in Fig.2d, which also proves the Nyquist ghost is fully removed by proposed method. Fig. 3 illustrates phantom images before and after geometric distortion correction, from which we can observe the distorted geometry is restored. Rat brain images before and after Nyquist ghost and geometric distortion correction are shown in Figure 4, which demonstrates the effectiveness of this method by comparison with the T2 weighted image.

Discussion and Conclusion: We have shown the proposed method based on reversed readout strategy can effectively remove Nyquist ghost without reference scan or time-consuming entropy minimization. This method allows generating phase shift map dynamically from images reconstructed from adjacent positive or negative echoes. Thus, it could potentially correct any geometric distortions that may change with time. However, the distortion can only be corrected where SNR is sufficient to ensure the accuracy of phase shift map. In conclusion, we have demonstrated the proposed method based on reversed readout strategy can effectively remove Nyquist ghost and correct geometric distortion both in phantom and rat brain. This method may be paticularly suited for dynamic EPI protocols such as fMRI and dynamic contrast-enhanced MRI applications.

References: [1] Bruder H, et al., MRM 1992;23(2):311-323. [2] Foxall DL, et al., MRM 1999;42(3):541-547. [3] Robson MD, et al., MRM 1997;38(5):733-740. [4] van der Zwaag W, et al., JMRI 2009;30(5):1171-1178. [5] Chiou JY, et al., ITMI 2003;22(2):200-205.

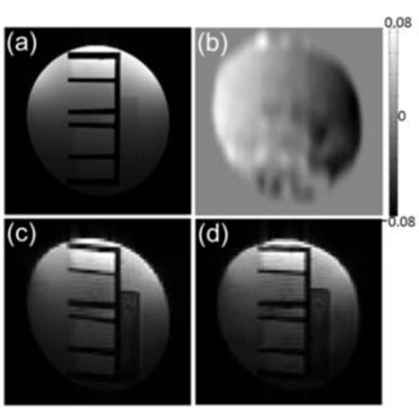

Fig. 3 images acquired from a phantom constructed with structure. (a) T2W; (b) phase shift map; (c) before distortion correction; (d) after distortion correction.

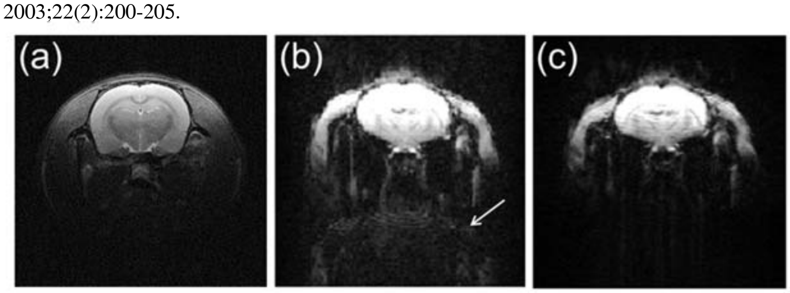

Fig. 4 Images from a rat brain. (a) T2W; (b) before Nyquist ghost and geometric distortion correction; (c) after correction, the ghost is removed and distortion in the form of tilt is corrected.