A Novel Reference-Scan-Free Method for Correction of Nyquist Ghost Artifacts in Echoplanar Brain Images

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Introduction

In echo planar imaging, sampling of data under the positive and negative lobes of the readout gradient can give rise to Nyquist artifacts. The culprit is a mismatch in sampling between odd and even data lines, usually caused by hardware imperfections and eddy currents [1]. The most commonly used remedy is the non-phase-encoded reference scan in conjunction with navigator phase correction [2], from which the phase mismatch is determined. Alternatively, image-based post-processing has been pursued since this obviates the need for a reference scan [3,4]. Here, we present a reference-scan-free approach which makes use of the approximate symmetry of the imaging object and involves computation of the second moment of hybrid x, k_y-space data from which the phase difference between odd and even samples can be derived.

Theory and Methods

The k space signals of a symmetric object are real. The method's underlying assumption is that in the axial view the brain is quasi-symmetric and thus the major object features in the images are dominated by their low-frequency and symmetric part. In this case, the phase disparities between the even and odd data lines can be identified by

$$2\theta(x) = \arg\left[E_e(x)\,E_o^*(x)\right] \qquad (1)$$

where $E_e(x) = \sum_{m=2n} S^2(x,m)$, and $E_o(x) = \sum_{m=2n+1} S^2(x,m)$

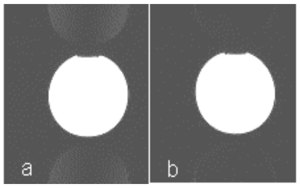
are the second moments of the even and odd echo images as calculated over the even or odd k_y lines, where x is the position in readout direction obtained after Fourier transforming along k_x, m is the index of a sample point in phase-encoding direction, and $S(x,m)$ is the signal value at location (x,m). If there is no temporal shift between odd and even data samples, $E_e(x)$ and $E_o(x)$ will have equal phase and are real after removal of the their common phase by the conjugate operation of Eq [1]. Phantom and human imaging were performed on 1.5 T whole-body scanners (Siemens Sonata and General Electric Signa™). The parameters used were: matrix size = 128×80, FOV = 24×16 cm^2, TE = 80 ms, slice thickness = 4 mm. For comparison ghost correction was also accomplished using a reference scan collected during pre-scan. Finally, the algorithm described in the following was also evaluated with synthetic images.

Results

Fig. 1a shows images of the phantom acquired using the manufacturer's two navigator echoes following the excitation pulse. The same raw data, albeit without navigator echoes, were also processed with the new method (Fig.1b). Compared with Fig. 1b, the residual ghosting in Fig.1a is still significant. One possible explanation is that the navigator echo train has only few echoes and thus is much shorter than the actual echo train. Therefore, the computed phase difference may not be accurate. One each of three series of brain images of a healthy volunteer acquired with phase encoding applied in left-right direction are shown in Fig. 2. The ghost artifacts, clearly present in Fig. 2A, have effectively been removed with the new method (Fig. 2B). The reference-scan corrected image, displayed in Fig. 2C, is comparable to that of Fig. 2B. The images in both, Figs. 1 and 2, are displayed so as to highlight the ghosts, and demonstrate the effectiveness of the method. Finally, a synthetic image with a ghost artifact is shown in Fig. 3a. Here, a stripe was added to perturb the symmetry as a means to evaluate how rigorous the requirement of symmetry is. It is noted that the algorithm almost completely removes the ghost (Fig. 3b), indicating the image to be dominated by its low frequency part.

Conclusion

The proposed method is effective in removing Nyquist ghost artifacts in spin-echo-planar images of quasi-symmetric objects such as the human head in the transverse plane, without the need for operator intervention. The method is shown to be comparable in performance to the reference-scan method for ghost suppression in axial human brain images. Anticipated applications are in spin-echo EPI, including diffusion and perfusion-weighted brain imaging.



Fig,1 Phantom spin-echo EPI after navigator echo phase correction (a), and using the proposed method (b).

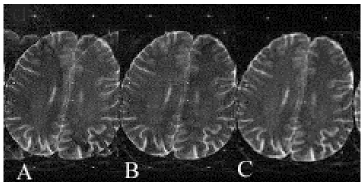


Fig. 2 Human brain image without phase correction (A); after phase correction with the proposed method (B); after correction with the reference scan method.

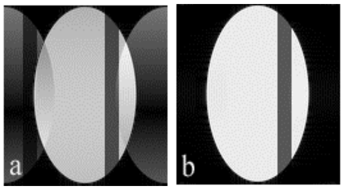


Fig. 3 a synthetic image before ghost artifact correction (a) and after the correction (b).

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