Correction for gradient-echo EPI distortions using embedded low-resolution field mapping and k-space energy spectrum analysis

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Introduction

Degradation of EPI quality by geometric distortions due to B0 field inhomogeneities is well known to the scientific community. To correct EPI distortions, the field inhomogeneities need to be first measured and then used to convert EPI data from distorted to non-distorted coordinates [1]. This approach, however, requires additional field mapping scan and may become invalid if the subject moves between field mapping scan and actual EPI scans. These two limitations were addressed in two recent methods. One method uses low-resolution estimation of field map obtained with a trajectory in which the central k-space is double acquired [2]. The high spatial frequency components of B0 field maps, however, may not be properly estimated. A second method uses k-space energy spectrum analysis to measure susceptibility field gradient maps directly from k-space data, without extra field mapping scan or sequence modification. The calculated B0 field maps, however, may have a constant offset from the actual values. Here we demonstrate an integrated approach such that the above limitations can be surpassed. The integrated technique enables accurate measurement of high-resolution Bo field inhomogeneities corresponding to every time point of dynamic EPI scans.

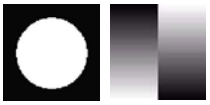
Theory

In ideal EPI data, the echo peak is located at the center of the acquisition window [1]. In the presence of susceptibility field gradient (Fig.1a), the echo peak shifts from the center of k-space (Fig.1b). The relationship between echo-shifting and susceptibility field gradient can be described by equation

$$G_{sus} = \frac{-\Delta y}{\gamma FOV_y \times (\Delta y T_{esp} + TE_{des})} \qquad (1),$$

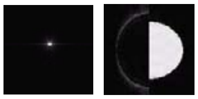
where Δy is the shift of k-space echo peak in y direction.

If one performs a k-space truncation by ky lines (from one to Ny) and uses the iterative Cuppen's partial Fourier reconstruction method [4] to reconstruct image, one finds that once the echo peak gets truncated, there is prominent signal loss of the corresponding pixels in image domain (Figs.1c &1d). By observing the signal intensity with different number of truncation pixel-wise, the location of k-space echo peak can be found, which corresponds to .the magnitude of background gradient (Fig.1e). A correction for the geometric distortion could thus be performed pixelwise using the background gradient information, with the exception of a possible constant offset B0. For this reason, an acquisition of low-resolution B0 map helps avoid offset errors during numerical integration.

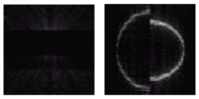


1a.96x96 phantom image and the applied B0 field map.

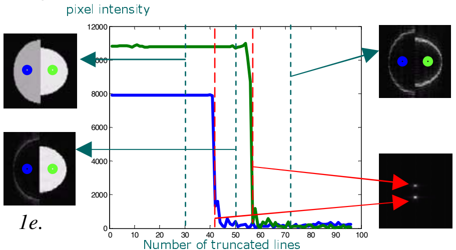
1b. distorted image and its k-space showing echo peaks shifted along the phase encoding direction.



1c. truncation of the lower half ky lines results in loss of left-side signals.



1d. truncation of lower 70 ky lines lead to signal loss for both sides.

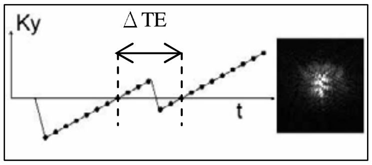


1e.

Methods

The 96x96 k-space data were acquired using single-shot EPI with trajectory shown in Fig.2a. The center k-space was double acquired by eight ky lines (Fig.2b). Two images were generated from the first and second halves of the k-space, respectively (52 ky lines each, spaced at ΔTE=6.016 ms from each other). A low resolution B0 field map can thus be estimated from the phase different $\Delta\varphi$. Subsequently, the k-space energy spectrum analysis as stated in the Theory section was used to measure the k-space peak location in a pixel-by-pixel manner, following which a high-resolution map of the background gradient could be obtained. During the process, if the k-space center shift of some pixels exited the first k-space (Ny/2+4 ky lines), the second k-space shift map was used instead to complete the computation.

The high-resolution B0 field map can be obtained by integrating the gradient map along the phase encoding direction. The initial value for the starting point of the integration along each line was taken from the low resolution B0 field map. In particular, regions where the corresponding k-space peaks did not exit the central repeated part of the k-space were anticipated to be reliable. Therefore, the starting point of the initial integration can be found from the reliable regions on the low resolution B0 field map. Initial starting point near the center part of the original image was chosen for every kx line.



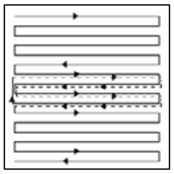
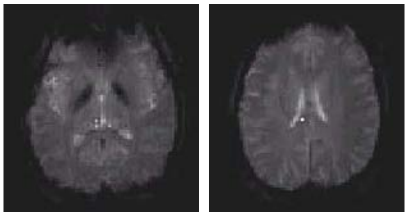


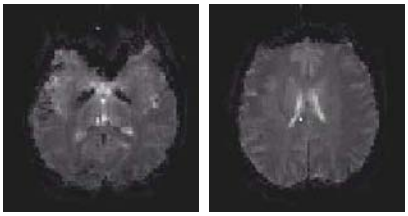
Fig.2a (up) and 2b (right). The EPI k-space trajectory of the modified sequence.

Results

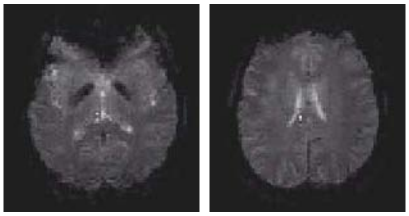
Fig.3 shows the comparison of the original 96x96 EPI images (Fig.3a), corrected images using the proposed method (TE1 = 42.3, TE2 = 48.316, Fig.3b), and the reference images obtained with corrections using an additional field map scan (Fig.3c [1]). It is seen that the majority of the geometric distortions can be corrected by the proposed technique without extra field map acquisition.



3a.The human brain EPI axial images



3b.Application of proposed method



3c.Images with additional field mapping scan [1]

Discussion and Conclusions

The proposed method combines the advantages of high spatial resolution for the k-space energy spectrum technique [3], and a reliable B0 reference provided by the double acquisition of the central k-space lines [2]. It can be applied to situations with discontinuous gap or separated parts (e.g., legs) where simple integration may fail. In addition, since the lengthening of scan time is negligible, the proposed method can be applied to dynamic study and is still valid in the presence of subject movement in different image during dynamic scanning.

References

1.Reber PJ.MRM 1998;39:328. 2. Roopchansingh RW. MRM 2003;50:839. 3. Chen NK. Neuroimage 2005;31:609. 4. Cuppen JJ. Med Phys 1986;13:248.