Correcting B0 Induced Signal Loss Using Echo Planar Imaging Reference Data

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INTRODUCTION

Spectral-spatial RF pulses [1] are widely used in MR to provide B1-insensitive fat suppression. However, the relatively narrow water excitation band (e.g., 100-150 Hz at 3T) makes these pulses quite sensitive to B0 inhomogeneity and prone to signal loss. For example, an axial scan plane at 15 cm off the scanner isocenter could experience up to 100 Hz center frequency offset due to both tissue susceptibility and inhomogeneity from the magnet itself, which could lead to more than 50% of signal loss if left untreated. This problem is particularly serious for applications involving multi-station acquisitions (e.g., whole body diffusion imaging), where large image shading can exist across both intra- and inter-station images. To compensate for such B0 induced signal loss, a B0 field map or a per-slice center frequency calibration prescan is in general needed, which can significantly prolong scan and thus may not be practical. For echo planar imaging (EPI), however, a reference scan for estimating phase correction coefficients is generally available. We propose a method to estimate and correct the per-slice B0 offset using the freely available EPI reference data. Spin echo EPI results on a phantom show that the proposed method can increase the average signal at a slice 15 cm away from isocenter from 37% to over 75% as compared to signal at the isocenter slice.

PROPOSED METHOD

Non-phase-encoded reference data is in general available before the actual EPI data acquisition to estimate phase correction coefficients [2]. By inspecting the overall phase angle across different echoes, we can also derive the B0 offset experienced by the EPI echo train from the same reference data. Note that similar idea has been used in fMRI [3,4] where navigator echoes are acquired to estimate temperature related frequency shifts for dynamically aligning the object in the temporal axis.

Details of the proposed method are as follows: Denote X as the readout axis (assumed to be in the horizontal direction), and Y as the phase encoding (i.e., echo index) axis (assumed to be vertical). We first convert EPI reference data to image domain by performing inverse Fourier transform along X. Phase angles of all even indexed echoes (or odd echoes) are taken and unwrapped along Y independently for each X using the Ahn and Cho method [5]. Then a linear fit along Y direction is done on the phase angles of even echoes to obtain the phase slope $s_n(z)$, where n is the X index and z is the slice location. The X dependent, B0 induced frequency offset $f_n(z)$ is readily available via: $f_n(z) = s_n(z)/(2\pi \cdot T_{esp})$ where T_{esp} is the echo spacing. To increase the robustness to noise (especially for slices with little tissue), we first take a projection of the magnitude data along Y, and then threshold the resulting magnitude (e.g., setting the threshold to 5% of the maximum value) to provide a mask on X. The $f_n(z)$'s that are included in the mask are averaged to provide a mean frequency offset estimate for a given slice location. Finally, polynomial fitting is performed on the frequency offsets along slice direction to ensure smooth slice-to-slice intensity transitions.

The frequency offset estimates are obtained after the reference scan but before the actual EPI scan. EPI pulse sequence reads in the frequency offsets and adjusts the center frequency for each slice. The whole process does not introduce any additional scan time.

RESULTS

Axial spin-echo diffusion-weighted EPI images with and without the proposed B0 offset correction were collected on a 3T scanner using the whole body coil for RF transmission and receiving. This sequence uses a spectral-spatial RF pulse [1] for fat suppression. An undoped silicone oil phantom (rectangular cuboid, dimension = 15cm × 15cm × 38cm) was used in this study. Diffusion weighted images on three axes were acquired along with a T2 reference (i.e. without diffusion). A total of 31 slices were acquired, which covered the space within ±15 cm in the superior-inferior direction. The remaining parameters were: b value = 1000 s/mm², TE = 76 ms, TR = 5 s, slice thickness = 1 cm, in-plane field of view = 22 cm. The top row of Fig. 1 shows three representative slices of the T2 images (diffusion weighted images are not shown for limited space, but they show similar level of signal loss and improvement) at +15 cm (superior direction), isocenter, and -15 cm (inferior direction) without B0 offset correction. Significant signal loss is apparent in slices at ±15 cm (signal is only 37% and 57% of the signal at isocenter, respectively). This is because the average center frequency offset for these slices are over 70 Hz, as evident from the frequency offset plot based on either the proposed method or a B0 field map based method (Fig. 2). The reasonably good match of the two curves in Fig. 2 indicates that the proposed method can provide faithful B0 offset estimate while avoiding the time-consuming B0 mapping. Accounting for the frequency offsets estimated by the proposed method on a per-slice basis significantly regains the signal, as can be seen in the bottom row of Fig. 1. The average signal vs. slice is shown in Fig. 3, where signal is increased to 79% for slice at +15 cm, and 89% for slice at -15 cm.

CONCLUSION

The proposed method of estimating and correcting slice dependent B0 offset is shown capable of significantly regaining signal for off center slices where increased B0 inhomogeneity is often present. As the B0 offset is based on EPI reference data, it is tailored for the scan subject and does not require additional scan time. The method can be particularly useful in B0 sensitive EPI applications (e.g., those with spectral-spatial pulses) and applications where large slice coverage is desired (e.g., whole body diffusion weighted EPI).

REFERENCES

[1] Zur, MRM, vol. 43, pp.410-420, 2000. [2] Maier et al., US Patent 5,151,656, 1992. [3] Hinks et al., US Patent 7,259,557, 2007.
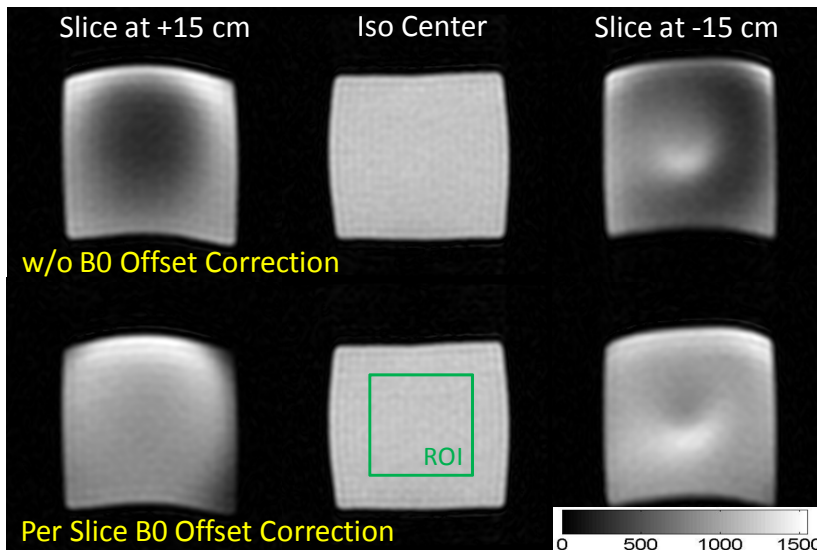[4] Xu et al., *Proc. of ISMRM*, p.5059, 2010. [5] Ahn et al., *IEEE-TMI*, vol. MI-6, pp. 32-36, 1987.

Fig. 1. Axial EPI images without (top row) and with (bottom) B0 offset correction at 3 slice locations. Signal loss due to off-center B0 offsets is significantly recovered by the proposed method.
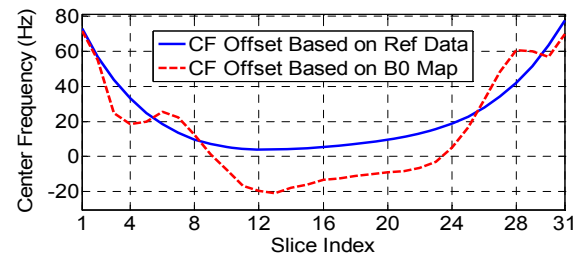

Fig. 2. Estimated frequency offset vs. slice index based on reference data (blue solid), which matches reasonably well with the results from a separately collected gradient echo based B0 field map (red dashed).
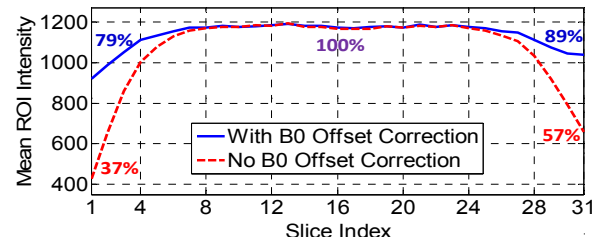

Fig. 3. Mean ROI intensity vs. slice for images with (blue solid) and without (red dashed) the proposed B0 offset correction.