Realtime B0 Inhomogeneity Correction In Multi-station Diffusion Imaging

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Target audience: Radiologists, Physicists

Purpose:

Diffusion weighted imaging (DWI) using single shot EPI routinely suffers from distortion due to B0 inhomogeneity. The degree of distortion is proportional to the B0 inhomogeneity, which increases non-linearly as the distance from iso-center increases. This causes mis-registration between stations in whole body multi-station DWI and also limits the maximum SI coverage per station. Previous studies tried to resolve this issue with slice-by-slice shimming, correction using B0 map or other anatomical scans [1, 2], but these approaches requires substantial additional prescan or acquisition times. In this study, we proposed a real-time method to detect and correct the B0 offset per slice, and it did not require additional reference scan or B0 map collections.

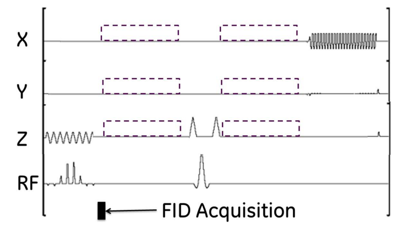

Fig 1. PSD diagram of DWI with FID acquisition after the 90º excitation for real time B0 correction. Diffusion gradient (dotted) is off during dummy acquisitions .

Theory:

In standard MR acquisition, the center frequency (CF_0) used for a station is usually measured from the center slice. The optimal center frequency (CF_N) for each slice N may be different from CF_0 due to tissue susceptibility and magnet B0 inhomogeneity. This causes geometric distortion if left untreated. The CF offset (CF_N-CF_0 for each slice translates to a phase offset in its free induction decay (FID) phase signal.By inspecting this linear phase offset, we can derive the CF offset experienced by the slice (Eq.1),

$$\Delta CF = \frac{-\Delta\phi \times BW \times 2}{2\pi} \quad \text{[Eq.1]}$$

, where ΔCF is the center frequency offset (Hz), $\Delta\phi$ is the phase offset and BW is the ±bandwidth (Hz).

Note that similar idea has been used in fMRI [3, 4] where FID signals are acquired to estimate temperature related frequency shifts for dynamically aligning the object in the temporal axis. In DWI, the FID can be collected after the 90º excitation pulse (Figure 1) during the dummy acquisition period such that it does not introduce additional scan time. Inter-slice smoothing method can be applied to the phase offset for all the slices to ensure smooth CF transitions between slices. Weighting polynomial fitting is used to place more weighting on the slices with good signal property (brain, abdomen) and less weight on those with poor signal (e.g. neck, lungs). The resulting CF offset can then be applied to each slice during actual acquisition in real-time by adjusting the excitation & receiving frequency.

Methods:

Multi-station DWI was performed on healthy volunteers on a GE 3T 60cm bore scanner (MR750) using the body transmit & receive coil. Optimized DWI parameters were: FOV:48cm(LR)x33.6cm(AP), Matrix: 96(freq) x 128(phase), TR/TE:3300ms/40.1ms, single spin echo, BW:250kHz, Slice thickness:10mm, # slices:30/station (i.e. 30cm per station), STIR, TI=245ms, b-value=0s/mm^2(2 NEX), 400s/mm^2 (6 NEX), diffusion encoding: 3-in-1, scan time: 1:13min per station. We compared the resulting distortion in 3 inter-slice fitting methods (Median filter, weighted 2nd order or 3rd order polynomial fitting). We also compared this with standard acquisition without real-time B0 correction. Distortion is assessed by sagittal reformat of the images.

Results & Discussion:

We observed good FID phase signal fidelity except in area of low SNR due to lack of tissue and/or high susceptibility (eg. neck & chest area) . In the interslice fitting method comparison (Fig 2), weighted 2nd order and 3rd order fitting performed better than median filter because it enabled the fitting to be weighted by the signal magnitude, and was therefore less influenced by noisy data with incorrect B0 estimation. In previous actual B0 map acquisition in volunteers, we observed that the slice-by-slice B0 fluctuation was better modeled by 3rd order poly fitting than 2nd order, as a result, 3rd order fitting was chosen in the final multi-station comparison. We observed improvement in both signal intensity & geometric accuracy when RTB0 was used (Figure 4).

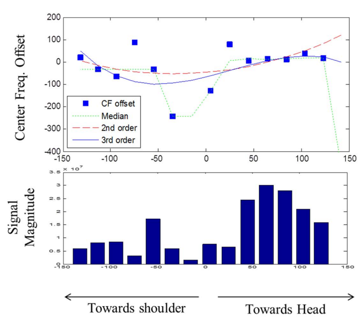

Fig 2. CF offset & the FID magnitude detected in the head station. Note the inaccurate CF offset when the magnitude was low (in the neck & shoulder area). Inter slice magnitude weighted polynomial fit helped to obtain a better CF profile, as compare to median filter.

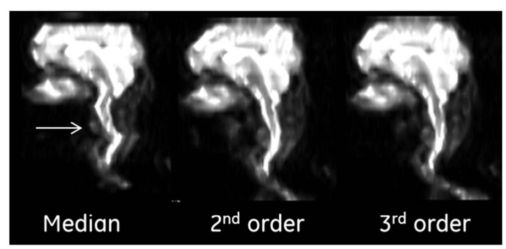

Fig 3. Comparison on various inter-slice fitting methods. 2nd order & 3rd order performed better than median filter.

Fig 4. 2 stations DWI without (Left) and with (Right) RTB0 correction (using 3rd order inter-slice fitting). Real-time center frequency offset improved the alignment and reduced shading due to off-resonance at the edge of the FOV (arrows).

Conclusion:

In this work, we demonstrated distortion reduction using the real-time B0 correction method. This technique can reduce distortion due to B0 inhomogeneity and tissue susceptibility, especially when larger SI coverage is used (increased B0 inhomogeneity). This technique does not require separate prescan or acquisition and can therefore easily be incorporated into routine clinical scanning.

References: [1] Lee et.al, JMRI. 2012; 36(4): 873–880, [2] Mori et al, Proc. Of ISMRM, p. 4718, 2010, [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.