Real-time RF Pulse Adjustment for B0 Drift Correction

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Introduction

Clinical whole-body MR scanners typically exhibit a long-term magnetic field drift of less than 0.1 ppm/hr [1]. However, short-term field variations can be significantly larger. These variations can arise from physiological fluctuations e.g. breathing but also from hardware imperfections. Here, we particularly consider heating effects of the shim irons during high duty cycle experiments that require heavy gradient switching. In EPI scans a frequency drift predominantly causes a shift of the image in phase encoding direction and algorithms have been proposed to correct for this [2–4]. However, if the frequency drift is large enough it will also influence the effect of fat saturation pulses because the fat signal frequency will gradually shift relative to the saturation pulse center frequency. Improperly suppressed fat tissue in the image can overlap with other anatomy because of the chemical shift of the fat signal, causing artifacts in the image.

We propose a method to adjust the center frequency of the RF pulses in real-time during a scan to match the scanner frequency drift thereby eliminating image shift and ensuring effective saturation pulses throughout a scan.

Methods

Imaging was done on a 1.5 T MR scanner (Siemens Avanto, Siemens Medical Solutions, Erlangen, Germany) using a custom-made 23-channel head array coil [5]. Two EPI high angular resolution diffusion imaging (HARDI) scans were performed, without and with real-time RF pulse adjustment. The imaging parameters were as follows: TR = 8.9 s, TE = 111 ms, 60 slices, matrix size 96x96, 211 mm FoV, 2.2 mm slice thickness without gap, bandwidth 1628 Hz/Px, 1 non-diffusion-weighted volume, 122 diffusion-weighted volumes with a b-value of 3000 s/mm^2, acceleration factor 2 using GRAPPA, scan time 18:25 min:s.

The frequency drift was estimated from the phase correction lines of the whole imaging volume [4] and calculated in real-time after the acquisition of the last phase correction lines of the volume. Calculation took less than 30 ms per volume (3.06 GHz Intel® Xeon™). The values found were fed back to the sequence using a real-time loop and then applied to the RF pulses (in the case of diffusion imaging: fat saturation, excitation and inversion pulses) of the next volume. To reduce short-term frequency changes due to noise a 1st order low-pass Butterworth filter was applied to the measured frequency offset values before feedback.

Results and Conclusion

The efficacy of real-time RF pulse adjustment is demonstrated in Figure 1. Without RF pulse adjustment, the fat saturation becomes less effective as the frequency offset increases over time, resulting in a prominent fat signal that partially overlaps posterior brain areas due to the chemical shift. At higher field strength, the spatial shift of the fat signal would be larger causing a more severe overlap. With RF pulse adjustment, the fat saturation stays effective over the whole scan duration. The measured frequency drift in this high duty cycle experiment is shown in Figure 2, demonstrating an overall frequency drift of ~0.8 ppm. Both scans resulted in a similar overall frequency drift. While real-time RF pulse adjustment inherently corrects for image drift, the scan without RF pulse adjustment was corrected for image drift by means of phase correction [4]. Uncorrected this would have led to an image shift in the phase encoding direction of ~3.3 pixels.

It has been shown that real-time RF pulse adjustment ensures that fat saturation pulses are continuously effective over long scan times even when using high duty cycle scans. Furthermore, this method eliminates the need for correction of image shift after acquisition. As an alternative to using phase correction lines, the frequency drift could be measured by other means e.g. an external probe. This would allow easy application of the same real-time feedback RF pulse adjustment for other sequences that currently do not include phase correction lines e.g. spectroscopy and CSI sequences.

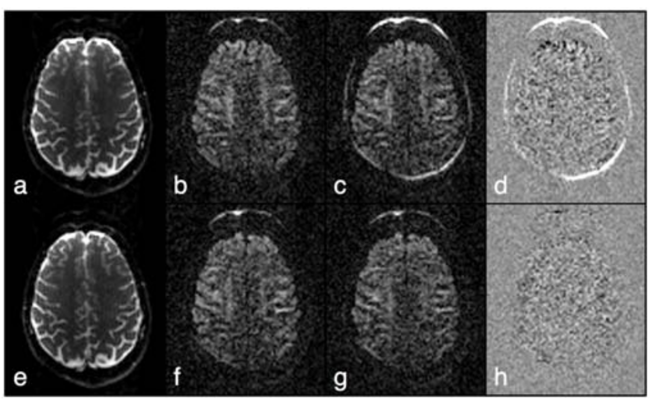

Figure 1*: Non-diffusion-weighted image (a, e), first (b, f) and last (c, g) diffusion-weighted image as well as difference of first and last diffusion-weighted images (d, h) of scans without (top row) and with (bottom row) real-time RF pulse adjustment. Without real-time RF pulse adjustment increased fat signal compared to first diffusion-weighted image can be seen (c, d). Note that the fat signal overlaps in the posterior part of the brain due to the chemical shift. With real-time RF pulse adjustment, no major difference between first and last diffusion-weighted image is observed.*

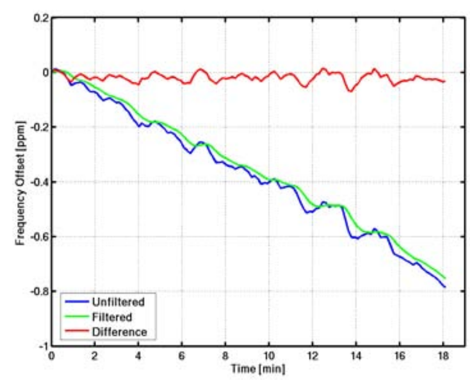

Figure 2*: Measured frequency drift (blue), filtered feedback offset frequency (green) and remaining difference (red). Overall frequency difference was found to be ~0.8 ppm i.e. about ¼ of the fat water chemical shift of 3.5 ppm. The remaining difference was -0.020 ± 0.016 ppm (mean ± standard deviation).*

Acknowledgements

This work was supported in part by The National Center for Research Resources (P41RR14075) and the Mental Illness and Neuroscience Discovery (MIND) Institute.

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