Real-time Measurement of the Drift in the B0 Field using a volumetric navigated DTI sequence

A. Alhamud[1], André J.W. van der Kouwe[2], and Ernesta M. Meintjes[1]

[1]MRC/UCT Medical Imaging Research Unit, Department of Human Biology, University of Cape Town, South Africa, [2]Massachusetts General Hospital, Charlestown, Massachusetts, United States

Target Audience: This work is of interest to anyone who wants to estimate the stability of the drift in the main magnetic (B0) field of an MRI scanner in the presence or the absence of subject motion.

Purpose: The system central frequency of an MRI scanner is adjusted before the start of MRI scanning. This may be done by acquiring a field map using for example a 3D gradient echo sequence. The estimated zero order-shim parameter of a field map reflects the offset of the scanner central frequency (or equivalently the mean offset in the B0 field) and it is added to the resonance frequency of the MRI system. During an MRI experiment such as diffusion tensor imaging (DTI), there are several sources that can change the adjusted system frequency. Changes may arise from respiration, air-tissue susceptibility differences, poor shimming, or subject motion. Furthermore, DTI acquisition may require a scan to be repeated (to increase SNR) or to be acquired with different phase encoding directions (to correct distortion). It has been reported that significantly larger B0 field fluctuations may result from heating of shim iron induced by eddy currents or mechanical vibrations[1]. In the current work we present a technique to measure in real time the drift in the central frequency during one or more DTI scans together with prospective motion correction. Furthermore, we demonstrate that real-time motion correction itself fails to recover the drift in the B0 field.

Methods: The volume navigated diffusion sequence[2] (vNavDTI) was modified to acquire an additional 3D EPI navigator with a different echo time immediately after the first navigator. A field map is created online by complex division of the images from the two navigators. The required frequency shift (zero-order shim) is calculated using a least squares fit to the 3D field map. The PACE[3] (Prospective Acquisition CorrEction) motion correction mechanism is also activated using the first of each pair of navigators to correct for motion.

All scans were performed on an Allegra 3T scanner (Siemens Healthcare, Erlangen, Germany) according to approved protocols. A water phantom was first scanned to validate the accuracy of the current technique in evaluating the drift in the B0 field. The system frequency, initially prepared by the scanner before the DTI acquisition, was manually changed as follows: a baseline scan was acquired with the initial system settings, after which the system frequency was offset in 5 different scans (1-5) by 10, 15, 20, 25 and 30 Hz, respectively. Five additional scans (a-e) were acquired on the water phantom without any manual adjustment of the scanner central frequency to determine whether the B0 field drifts due to heating of the shim iron or other sources. In these five scans PACE was used for real-time motion correction.

Two adult subjects were scanned with the modified navigated DTI sequence. Subjects were instructed to move six times during each motion scan. The navigator parameters were the same for all scans: TR/TE_1/TE_2 14/6.6/9ms, 8x8x8mm^3, matrix 32x32x28, bandwidth 3906Hz/px. The time to acquire the navigator and perform all calculations was 550 ms. DTI parameters were the same for all scans except for scans (1) to (5) of the water phantom, where fewer slices were acquired to reduce heating of the shim iron: TR/TE 10400/86 ms, 70 slices, matrix 112x112, in-plane FOV 224x224 mm^2, slice thickness 2 mm, 30 non-collinear diffusion gradient directions, b-value 1000 s/mm^2, four b=0 scans. For scans (1) – (5): TR 3200 s, 11 slices.

Results: Figure 1 shows for scans (1) – (5) acquired in a water phantom after manual adjustment of the frequency the difference between the initial system frequency and the frequency measured by the vNavDTI sequence. Figure 2 shows box-and-whisker plots of the frequency drift over the 34 DTI volumes for scans (a) to (e) acquired consecutively in a water phantom. Figure 3 shows the root mean square (RMS) motion (rotation and translation) and the drift in the system frequency across the 34 DTI volumes for the two adult subjects.

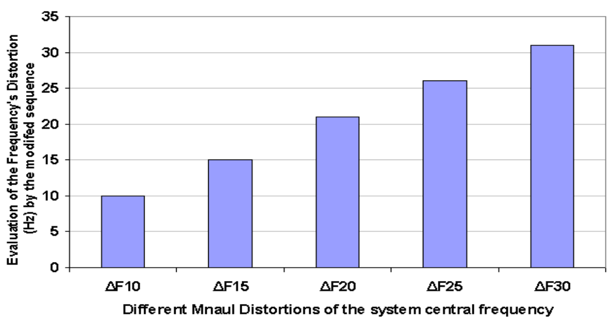

Figure 1: Frequency shifts in a water phantom as measured by the modified navigated diffusion sequence for scans (1) – (5).

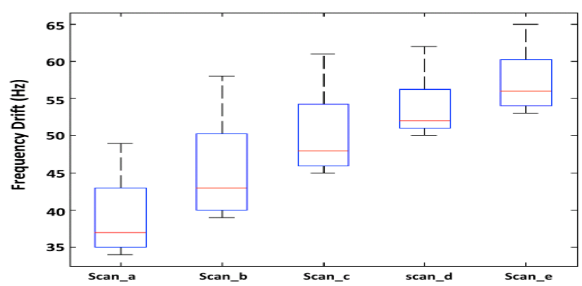

Figure 2: Box-and-whisker plots of the frequency drift over the 34 DTI volumes for scans (a) – (e).

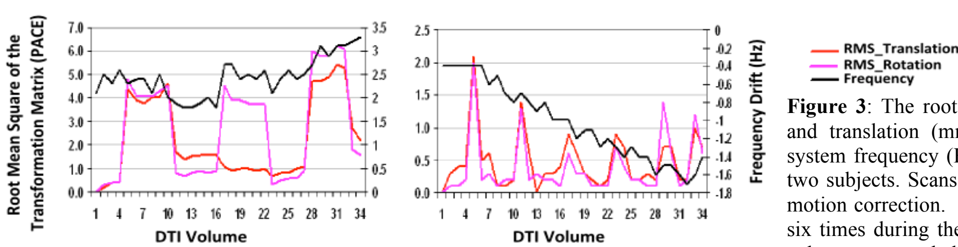

Figure 3: The root mean square (RMS) rotation (º) and translation (mm), and the drift in the central system frequency (Hz) over the 34 DTI volumes for two subjects. Scans employed PACE for prospective motion correction. Subjects were instructed to move six times during the acquisition. The frequency drift values were scaled by a factor of 10 on the plots (range 0-35Hz and 0-18Hz, respectively)

Discussion: The modified sequence accurately measures the changes in the system central frequency following manual adjusments (Fig. 1). Due to heating of the shim iron and other sources, the central system frequency may drift by as much as 25 Hz (Fig. 2) between consecutive scans. Subject motion resulted in frequency drifts more than 15 Hz and prospective motion correction alone failed to recover this drift (Fig. 3)

Conclusion: It is well known that drifts in the scanner central frequency, due to internal or external sources, can lead to apparent image shifts along the phase–encoding direction. The magnitude of this drift may differ from one scan to another or within a scan itself and increases with scan duration. Frequency drift cannot be addressed with external tracking systems. Here we proposed a technique that can measure accurately the stability of the scanner center frequency. The modified sequence is being adapted to correct the frequency drift by adjusting the frequency and the phase of all RF pulses as well as the ADCs.

References: [1] Benner et al. 2006, MRM 56 :204-209 [2] Alhamud et al. 2012, MRM 68 :1097-1108 [3] Thesen et al.2000, MRM 44 :457-465