Concurrent Field Monitoring Removes Distortions from In-Vivo DWI data

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Introduction:

In diffusion-weighted (DW) MRI, eddy current effects notoriously result in geometrical image distortions. This is problematic since variably diffusion-encoded data must be perfectly congruent to permit fitting diffusion models such as the diffusion tensor.

In modern MR systems extensive efforts are made to address this problem by optimized gradient coil and amplifier design, model-based eddy current pre-compensation, and image co-registration. However, the resulting geometric fidelity still is not always satisfactory. An emerging alternative solution is to deliberately tolerate a certain degree of field deviations in terms of eddy currents, gradient delays and field drifts and rather monitor the resulting magnetic field perturbations during each scan, using an array of NMR field probes [1,2]. Diffusion MRI is particularly challenging to monitor by such probes. This is because it typically uses long EPI trains with high maximal k values and high signal bandwidth. These properties translate into the need to obtain long-lived probe signals with very high SNR from small probe samples on the order of the targeted voxel size. In the present work it is demonstrated that these requirements can be met with recent advances in field probe design [3], enabling in-vivo DWI with concurrent field monitoring. It is shown that image reconstruction based on knowledge of the actual field evolution can remove image distortion due to eddy currents even without pre-emphasis or other hardware compensation.

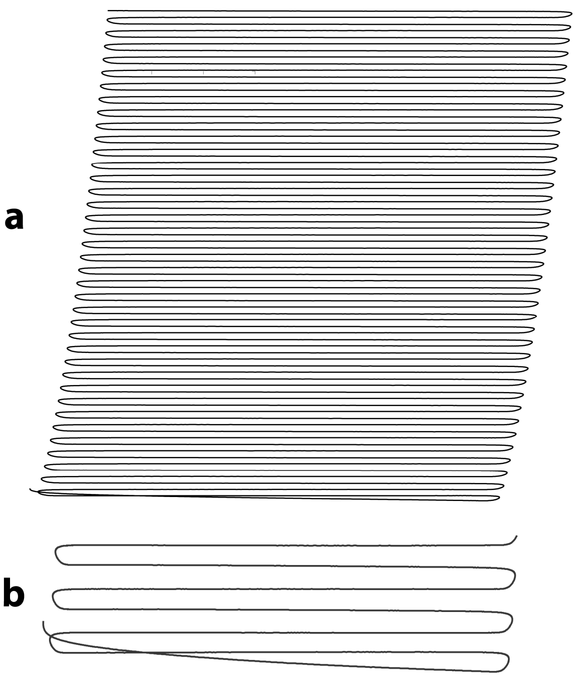

Figure 1: (a) k-space trajectory of a DW-SS-SE-EPI acquisition (b) zoomed view on the first lines of the readout

Methods:

Standard DW single-shot spin-echo EPI data (TE=79ms, TR=5000ms, 76 phase encodes, FOV=230mm) of healthy brain was acquired with an 8-channel head coil on a Philips 3T Achieva system (Philips Healthcare, Best, NL). Diffusion gradients were applied in the frequency-encoding, phase-encoding and slice directions (b=1000s/mm2). A non-DW (b=0 s/mm2) image was acquired for reference. Four RF-shielded transmit/receive NMR field probes [2] were mounted to the head-coil array, being arranged tetrahedrically around the head. After the second diffusion gradient the probes were simultaneously excited using a separate excitation RF chain [2]. During the EPI readout concurrent magnetic field monitoring was performed [3]. All eddy current compensation and correction usually performed by the system was turned off. From the NMR probes' phase evolution, a 1st-order field model was fitted, yielding the actual k-space trajectory and the evolution of global phase error, as resulting from so-called B_0 eddy currents. These results were then used as the basis of iterative gridding reconstruction [4]. For comparison all images were also reconstructed based on the nominal k-space trajectory.

Results:

The measured k-space trajectories were strongly affected by gradient eddy currents, as is to be expected in the absence of hardware compensation. For diffusion gradients applied, e.g., in the frequency-encoding direction, long-term eddy currents cause a k-space drift during the entire EPI train *(Fig.1a)*. Shorter-lived eddy currents of the phase-encoding gradient are evident in the early phase of the same readout *(Fig.1b)*. As a consequence, nominally reconstructed images exhibit substantial distortions, such as shearing and compression, relative to the non-DW image, particularly for DW within the image plane (Fig.2). As opposed to that, reconstruction based on the monitoring data yielded virtually undistorted results *(Fig.2)*.

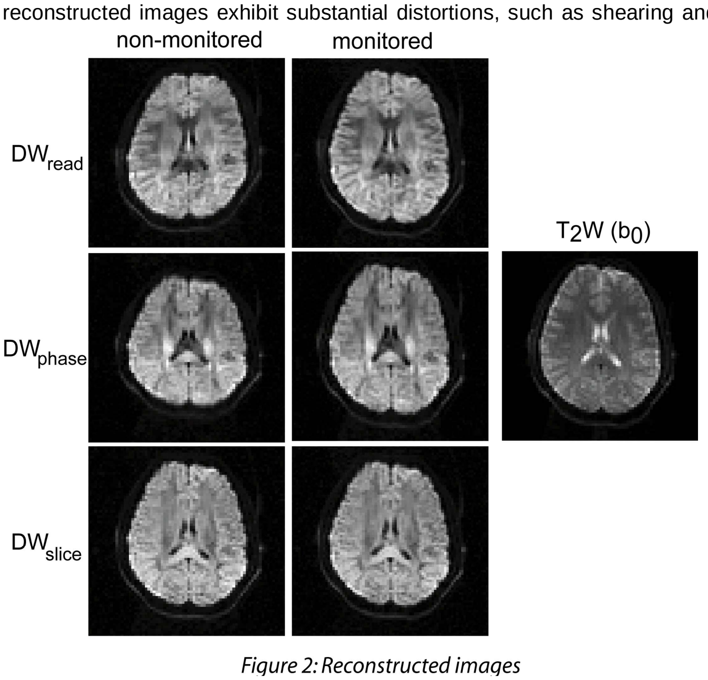

Figure 2: Reconstructed images

Conclusion:

The present work demonstrates that concurrent magnetic field monitoring of demanding EPI trains is feasible in-vivo and offers a generic way of addressing the eddy current issues of diffusion MRI. The current four probe setup is limited to monitoring of B_0 and linear gradients. However, employing more probes, the concept may readily be extended to correct for distortions caused by dynamic higher order fields. Effective distortion correction is not only necessary in DW imaging, but also for parallel imaging and B_0 inhomogeneity correction, where congruence between sensitivity/B_0 maps and the image data is required. Furthermore, segmented EPI, spiral and navigated acquisitions can profit from the information provided by this technique. Unlike previous solutions the monitoring approach requires neither predictable eddy current behavior nor run-time hardware corrections. The proposed approach thus reduces the fidelity requirements on the gradient system by leveraging RF receive channels, whose number continues to increase on commercial scanners. It may thus ultimately reduce the cost of high-performing MR systems.

References:

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