COMPARISON OF MAGNETIC FIELD MONITORING WITH ALTERNATIVE K-SPACE TRAJECTORY MEASUREMENT METHODS

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Introduction

K-space acquisition schemes, such as echo-planar imaging (EPI), spiral, rosette, etc., pose demanding requirements onto the performance of the gradient system. Fast switching gradient amplitudes induce eddy currents, which disturb spatial encoding resulting in artifacts such as blurring, ghosting or geometric distortions in the reconstructed image. In the past, several calibration methods have been proposed to deal with ΔB_0 inhomogeneities and imperfections of spatial encoding gradients (1-5). Duyn et. al (4) proposed to measure the accumulated phase information of two independent MR signals acquired at two different locations within the field of interest in order to derive the linear term of B_0 eddy currents and hence the actual k-space trajectory. Meanwhile this method has been extended and optimized to now also account for spatially-constant time-varying magnetic field variations (5). Similar to the method described by Mason et. al (3), Magnetic Field Monitoring (MFM) has recently been presented (6-8) as an alternative calibration method by deriving the actual k-space trajectory from the simultaneously measured MR signal by local magnetic field sensors.

In this work, MFM is compared to the Duyn calibration technique (DCT). It is shown that the k-space trajectory measurements obtained using MFM and DCT show differing k-space deviations and signal tracking performance. Image entropy is used as a quantitative quality metric.

Materials and Methods

Both, DCT and MFM, derive time resolved image encoding information based on the tracking the phase evolution of a subset of excited spins at different locations according to

$$\Delta\varphi(t) = \varphi_{\text{offset}} + \varphi_{\Delta B_0}(t) + k(t)r \quad [1] \qquad \text{with} \qquad \varphi_{\Delta B_0}(t) = \gamma\int_0^t \Delta B_0(t')dt' \quad [2] \qquad \text{and} \qquad k(t) = \gamma\int_0^t G_0(t')dt' \quad [3]$$

with a constant phase offset φ_{offset}. DCT excites thin orthogonal slices with a deliberately chosen distance *r* away from the gradient isocenter. The calibrations have to be performed for both gradient axes independently. In contrast, MFM derives the same image encoding information simultaneously to the acquisition. This is achieved using optimized NMR probes acting as local magnetic field sensors (6-9). In both approaches the size of the excited volumes (i.e. the slice thickness in DCT and the size of the water droplet in MFM) is bound by the desired image resolution. Additionally, the tracking period is limited by T2* induced signal decay. The comparison of the two k-space measurements techniques is demonstrated with a 2D spiral (12 arms, 4010 points) and EPI acquisition (echo train length 16, spatial resolution of 128). Both are based on a gradient echo pulse sequence and are executed on a 3T GE Signa Excite HD system (GE Helthcare, Milwaukee, WI). The resulting trajectories derived through [1-3] and the corresponding nominal trajectory (NomT) are compared by considering its reciprocal deviations, where as NomT is considered as reference. In the end, the measured trajectories are used in a fast gridding reconstruction routine (10). Image quality is assayed considering the reduction of blurring and geometric distortion artifacts using image entropy as quantitative quality metric (11).

Results

The first experiment considers a multi-shot spiral sequence (12 arms, 4010 points) with a sampling bandwidth of ±125kHz and effective resolution of 1.5mm. Fig. 1 shows a zoom of the first 100 points of the calculated nominal (blue) and the calibrated DCT (red) and MFM (green) trajectories. The interleaves have been rotated and scaled to overlay the nominal trajectory. The deviation between NomT to DCT and MFM was calculated to be 1.5% and 1.9%, respectively. Fig 2 a) to c) show the reconstructed images using a) NomT, b) DCT and c) MFM calibrated trajectories. Improved image quality could be achieved with DCT and MFM by reduction of blurring artifacts and geometric distortions. Considering image entropy of the reconstructed images within the signed ROI (red and green box), entropy of DCT equals 6.8, whereas entropy of MFM is 6.7. The reduction of streaking and ringing artifacts can be seen clearly and are highlighted within the boxes. A comparable experiment is displayed for an EPI acquisition of echo train length 16 with a sampling bandwidth of ±125kHz and effective spatial resolution of 2mm. Fig. 3 shows a zoom of the first turn of the measured trajectories. The deviation between NomT (blue) and DCT (red) and MFM (green) resulted to be 1.4% and 0.8%, respectively. Fig 4 a) to c) show the reconstructed images using a) NomT, b) DCT and c) MFM. Highly improved image quality could be achieved using DCT and MFM by reduction of ghosting artifacts, worth mentioning that no reference scan, as typically added in EPI, was executed and involved. Here as well, MFM achieves higher image quality considering its image entropy of 5.6. In comparison, entropy of DCT equals to 5.7.

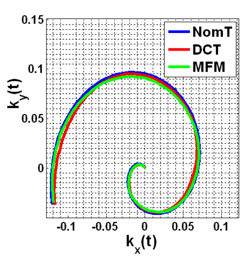

Figure 1: Zoom view of the first 100 points of one interleave of the spiral under test (12 arms, 4010 points).

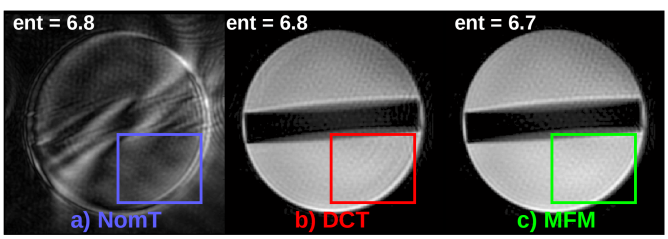

Figure 2: a)-c) show the reconstructed images using the corresponding measured trajectories. The red and green box highlights the reduction of ringing artifacts and is used for image entropy calculation.

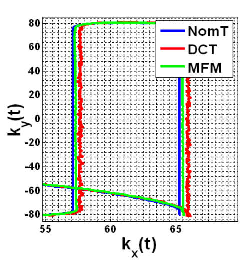

Figure 3: Zoom view of the first turn of the explained EPI scan-

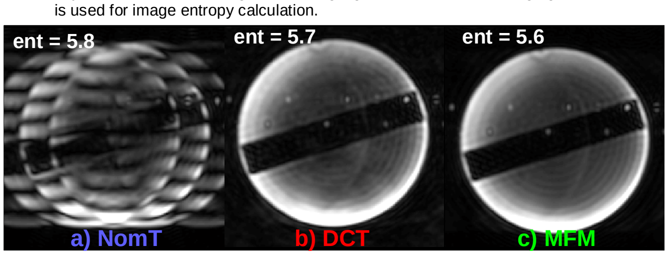

Figure 4: a)-c) show the corresponding reconstructed images. The white spots remained through coupling artifacts of MFM sensors and receiving coil.

Discussion

Especially for long gradient waveforms with a readout time greater than 30ms, both methods are sensitive to the T_2* decay of the signal. MFM prevents that by improved susceptibility matched NMR probes, where T_2* times up to 120ms can be gained. For DCT, slice thickness should be of the size of effective image resolution to result in high signal amplitude. Based on [1], *r* and maximum gradient strength are limiting factors for a correct tracking of signals phase. Beneficial of MFM is the simultaneous monitoring, which can be repeated for each scan of the examination.

References (1) Onodera et. al, J. Phys. E. Sci. Intrum. 20, p. 416 (1987), (2) Takahashi et. al, MRM 34: p. 446 (1995), (3) Mason et. al, MRM 38: p. 492 (1997), (4) Duyn et. al, JMR 132: p. 150 (1998), (5) Gurney et. al, ISMRM 2005: p. 866, (6) De Zanche et al, ISMRM 2006, p.781, (7) Pruessmann et al, MRM 46: p. 638 (2001), (8) Sipilä et. al, ISMRM 2007, p. 3277, (9) Olson et. al, Anal Chem, vol. 70, p. 645, 1998. (10) Beatty et. al, IEEE Trans Med Imaging, Vol. 24, p. 799 (2005), (11) Pluim et. al, IEEE Trans Med Imaging, Vol. 22, p. 986 (2003)