Autocalibration of Field Monitoring Arrays by Reference Tones

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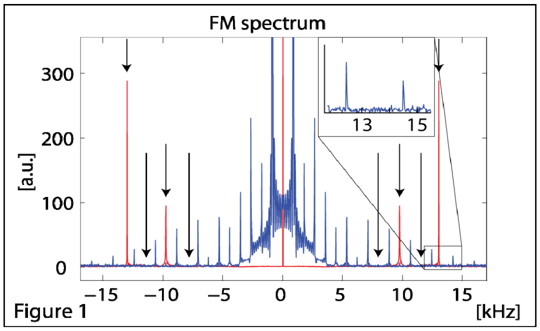
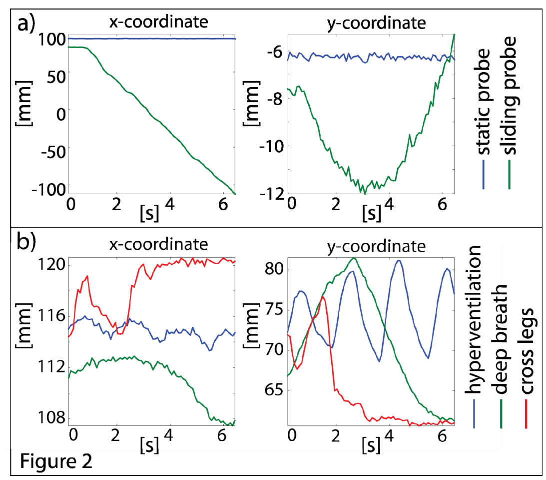
Introduction: Monitoring of gradient waveforms concurrently with MRI scans has been shown to be an effective means of correcting image reconstruction from data acquired in the presence of gradient waveform imperfections, eddy currents and field drifts [1,2]. Usually, the underlying NMR field probes are rigidly mounted in the periphery of the imaging volume. To derive the global field evolution from the signals of these probes, their positions need to be measured in a calibration step. This requirement not only extends the scan protocol but also precludes field monitoring with field probes that are subject to displacements, e.g., along with surface coil arrangements. To address this issue, in this work a reference tone method is proposed for automatic position calibration during actual field monitoring.



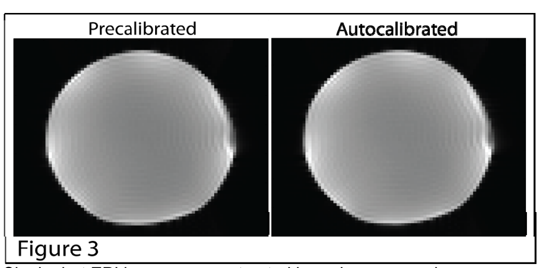
Spare bands of the gradient waveform permit the introduction of reference tones.

Method: Although the signal spectrum acquired by an NMR field probe during scanning is typically very broad, its frequency modulation (FM) spectrum reflecting the dynamics of the local magnetic field is rather narrow band and usually sparsely occupied. This is shown in Fig. 1 by the blue plot, representing the FM spectrum measured by a field probe during a single-shot EPI scan. As indicated by the arrows, there are bands within that spectrum that are essentially unoccupied by the gradient waveform. The principle underlying the proposed method is to use such spare frequency bands to superimpose small reference oscillations to the gradient waveform. In a field probe signal, the FM amplitude of such a reference 'tone' indicates the probe's current position along the respective gradient direction. To encode all three coordinates of a probe, three orthogonal tones can be introduced, one in each gradient chain. In order not to cause accrual of MR phase deviations, the tones should be zero mean. A convenient way of meeting all of these requirements is by simple sinusoidal tones, each in a different spare frequency band. Two such tones at 10 kHz and 13 kHz, are shown in Fig. 1 (red). Should no spare bands be available, the gradient waveform could alternatively be orthogonalized to the tones, e.g., by simple narrowband stop-band filtering at the tone frequencies, which has marginal influence on the k-space trajectory itself.

Experiments & Results: Experiments were performed in a 3T Philips Achieva system, using up to four ^{19}F field probes (hexafluorobenzene, doped with $Cr(dpm)_3$) for field monitoring. Throughout, tones at 10 kHz and 13 kHz of nominal 2 mT/m were used in the x and y gradients. The response of the gradient system at those frequencies was calibrated once with a fixed setup, which was then moved during the subsequent measurements. Figure 2a) shows probe positions tracked by 76 dynamic acquisitions of 50 ms duration and TR=80 ms. The blue plot was obtained from a static probe, demonstrating a precision in the order of 100 µm, whereas the green line shows a probe that was moved from left to right across the slightly concave scanner bed. Figure 2b) shows results from a probe attached to the chest of a volunteer performing hyperventilation (blue), one deep breath (green) and crossing his legs during the dynamic series. To demonstrate the suitability of such position information for monitoring autocalibration, single-shot gradient-echo EPI (FOV = 230 mm, resolution = 3 mm) of a water phantom was performed in the presence of the tones and with concurrent monitoring by four field probes. The tones perturbed the original k-space trajectory by less than 1/10 of the Nyquist sampling interval in standard deviation, thus not impairing image encoding. Figure 3 shows resulting images reconstructed based on the monitored k-space trajectories. The left image was obtained using reference values of the probe positions taken by a separate calibration scan. The right image was reconstructed with autocalibration, i.e. based on probe coordinates obtained from the tone signals only.



Tracking of field probes by reference gradient tones.



Singl- shot EPI images reconstructed based on pre- and autocalibrated monitoring data.

Discussion: It has been shown that field monitoring can be autocalibrated by reference tones, thus removing the need for separate calibration scans. This approach is especially useful if the monitoring probes cannot be rigidly mounted. In particular, it enables field monitoring with probes mounted on surface coils or flexible arrays, e.g., for abdominal and cardiac imaging. Since eddy currents and gradient fields respond linearly to the gradient waveform, the spectral separation of trajectory and tone is also sustained in the presence of eddy current confounds. Most other field perturbations such as drifts and physiologically generated fields are of much lower frequency and thus also orthogonal to the tones. The latter are of very small bandwidth and small amplitude and can therefore be generated very reproducibly. Importantly, the trajectory perturbations caused by the tones are monitored along with the original field evolution and thus do not impair image reconstruction as long as they are small. Potential confounding effects are imperfect spatial linearity of the gradient fields, which could in fact partly be caused by steady-state eddy currents induced by the tones, as well as non-linear gain of the gradient amplifiers. However, by careful system characterization at the tone frequencies, these effects can be eliminated such as to derive a strict bijection of individual modulation amplitudes and spatial coordinates.

References : [1] Barmet C et al.MRM 60(1), 2008, [2] Barmet C. ISMRM 2010 p.216