

Motion Characterisation using FID navigators and Spatial Pattern of MRI Coil Arrays

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Introduction: Following the early work of Ehman¹, several motion detection and correction strategies have been developed to deal with motion in MRI²⁻⁶. However, motion still presents a frequent challenge in structural MRI acquisitions and MRI scans with transient contrast modulations, i.e. diffusion and contrast enhanced perfusion imaging. In this work, we investigate the potential to characterise rigid-body head motion by extending a recently proposed technique for head motion detection⁷ that makes use of motion coding in free induction decay (FID) signals of head coil arrays.

Theory and Methods: In an MR experiment with a head helmet coil array⁸, 32 RF-coil elements receive signals from an object (head) with a certain spatial sensitivity. It has been shown for brain scans that object motion (translation and rotation) may introduce in some or all elements of such a coil array a measurable change in short-TE FID signals⁷. Here, we use the fact that the 32 local coil elements provide a good 3D coverage of the object. Considering the spatial information of the coil position and sensitivities, the motion-induced FID signal changes in individual coil elements characterise an inverse problem. Its solution leads to the rigid body motion parameters of subject motion. We developed a framework to make use of the motion information coded in short-TE FID signals.

All experiments were performed at 3T (Magnetom Trio a Tim System, Siemens, Germany) using a product 32-channel head coil. A FID ($t_{\text{nav}}=3.4\text{ms}$) navigator module, comprising a slab-selective 30° pulse and an FID readout ($t_{\text{acq}}=100\text{ }\mu\text{s}$), was added to a 2D EPI sequence (cf. Fig. 1). For calculation of coil sensitivity maps and estimation of the proton density distribution, $M_{0,0}$, a 3D GRE prep-scan was acquired ($64\times 64\times 48$, TR/TE/α/TA=20.0ms/1.08ms/4°/61s). The coil sensitivity maps, S_{1-32} , were low-pass filtered and extrapolated into the low-signal region. The transformation matrix to solve the inverse problem was determined through motion simulation with the GRE data (3 trans. of 1mm and 3 rot. of 1°, routines taken from [6]). By taking the sensitivity maps into account, a motion-induced FID-signal was determined for each coil element by summing over space $S_i^*M_{0,\text{mot}}$. For 6 motion parameters, this yielded a [n-channel, m-motion parameter]=[32, 6] sensitivity matrix $MS_{i,\text{mot}}=(\text{fid}_{i,0}/\text{fid}_{i,0})/(\text{fid}_{i,0})$. In subsequent experiments with the modified EPI sequence, the FID navigator signal from each coil element was compared with reference signals from the first EPI volume $\delta FID_{i,t}=(FID_{i,t}-FID_{i,0})/FID_{i,0}$. Relative signal changes δFID between repetitions translate according to $m_t=MS^{-1}*\delta FID_t$ in absolute motion parameters m_t . Additionally, simultaneous obtained EPI volumes were used to determine 6 motion parameters through registration to the reference volume³.

Phantom scans were conducted to evaluate the temporal stability of the calculated motion parameters. In addition, six healthy subjects were scanned after obtaining informed consent. During each session, 3-5 scans with 40 repetitions were performed using the modified EPI sequence. Subjects were instructed to perform free head motion (<15mm and <8°) during the delay time t_{move} (cf. Fig. 1). Data processing was then performed off-line using Matlab (The MathWorks, USA).

Results: The phantom scans showed excellent stability and erroneous introduced motion was found to be below 0.1 mm and 0.1 degree during 10 minute scans. Subject scans with “free” motion demonstrated that four (translation x,y and rotation y,z) out of six motion parameters could be calculated consistently and with good precision in all subjects. Root mean square deviation was below 1 mm and below 1 degree; sensitivity in these four motion parameters reached ± 0.2 mm and ± 0.3 degree, respectively (cf. Fig. 2). In cases of particular large motion, overestimations of its amplitude were occasionally observed (e.g. see z-rotation in fig. 2).

Discussion: The motion parameters determined by the proposed navigator-based detection approach characterise rigid body motion reasonably well. Certain motion patterns, e.g. x-axis translation, were determined with good precision of ~1 mm. On the other hand, detection of z-translation and x-rotation was not consistently achieved for all subjects (see Fig. 2). Currently, it is not understood, whether the observed limitations arise from coil geometry, imperfections in the algorithm and/or experimental design. Nevertheless, since the FID readout module could be inserted directly after an excitation pulses (e.g. slice excitation in GRE) with no or only negligible time penalty, the method has the potential to be used for real-time motion compensation in various sequences. In its most basic use, the information could be used as a motion detection module to calculate a scan quality index or to trigger a correction scheme.

References: [1] Ehman RL, Radiology 1989;173(1):255-263 [2] JG Pipe., Magn Reson Med 42(5):963-969 (1999); [3] S Thesen et al., Magn Reson Med 44(3):457-465 (2000); [4] EB Welch et al., Magn Reson Med 47(1):32-41 (2002); [5] AJW Van Der Kouwe et al., Magn Reson Med 56(5):1019-1032 (2006); [6] KJ Friston et al., Hum Brain Mapp 2:165-189 (1995); [7] Kober T et al., 2009, Magma,22(Suppl1),270-271; [8] Wiggins GC et al., Magn Reson Med 2006;56(1):216-223

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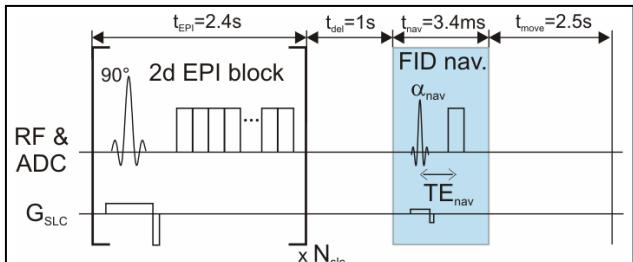


Fig. 1: Scheme of the EPI sequence: acquisition of N_{slc} slices in $t_{\text{EPI}}=2.4\text{s}$ is followed by a delay $t_{\text{del}}=1\text{s}$, a slab-selective excitation, and FID navigator acquisition (total length of navigator $t_{\text{nav}}=3.4\text{ms}$). Subjects moved during the idle time $t_{\text{move}}=2.5\text{s}$ at the end (total TR=5.9s).

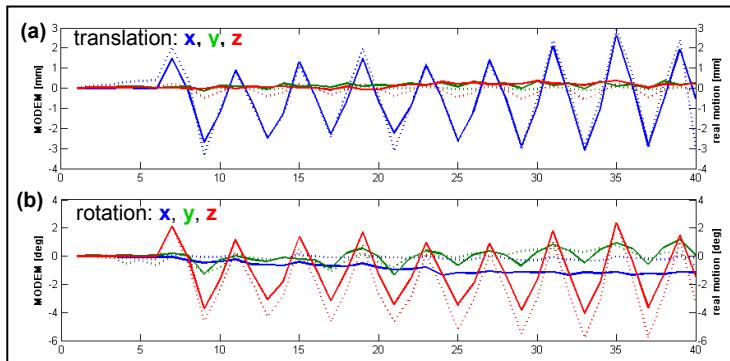


Fig. 2: Motion-parameters from a scan with “free” motion: (a) translational, (b) rotational parameters. Reference EPI motion detection values solid, parameters obtained by the presented method dashed.