Towards simultaneous measurement of head motion and B₀ field changes using FID navigators

Tess E. Wallace 1,2, Onur Afacan 1,2 Tobias Kober 3-6 and Simon K. Warfield 1,2

1. Computational Radiology Laboratory, Boston Children’s Hospital, Boston, MA, USA. 2. Harvard Medical School, Boston, MA, USA. 3. Advanced Clinical Imaging Technology, Siemens Healthcare AG, Lausanne, Switzerland. 4. Department of Radiology, University Hospital (CHUV), Lausanne, Switzerland. 5. LT5, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland.

Background

- Motion artifacts are problematic for acquiring diagnostic quality MRI in children and other uncooperative patient groups 5.
- Large motion also changes the B₀ field distribution, which is a further source of artifacts, especially with longer echo times and high magnetic field strengths 2.
- FID navigators (FIDnavs) can rapidly detect head movement 2 and have been shown to encode both rigid-body motion 4 and low-order field information 5.
- In this work, we propose an extension to our previously proposed FIDnav framework 6 to simultaneously estimate head motion and spatiotemporal variations in the B₀ field using simulation of the underlying acquisition physics and a model of the coil sensitivity profiles (CSPs) and first-order field variations.

Theory

- The FIDnav signal from the jth channel at time t may be represented as:

\[ y_j(t) = \int_0^T s_j(x) \cdot \rho(x, t) \cdot \exp(i2\pi\Delta B_0(x,t) t) \, dx \]

\( s_j(x) \) complex CSP of the jth coil
\( \rho(x,t) \) effective spin density of the object
\( \Delta B_0(x) \) field inhomogeneity at position x

- Spatiotemporal changes in the B₀ field due to the changing magnetic susceptibility distribution can be represented by a series of spherical harmonic basis functions:

\[ B_0(x,t) = \sum_j b_j(t) \phi_j(x) \]

- A forward model of the complex FIDnavs may be constructed using simulated motion and field changes. Given complex FIDnav measurements, the underlying rigid-body motion parameters (n=6) and low-order field changes (n=4) may be estimated for each TR (Fig. 1).

![Fig. 1. Schematic showing extended FIDnav motion and field measurement framework](image)

Phantom Validation

- A pineapple was scanned at 3T using a 32-channel head coil. FIDnavs were acquired while first-order shim currents were modified from -4 to 4 μTm⁻¹.
- A reference scan (TE=Tₚᵣₒᵣ) was also acquired on the surface and body coils for estimation of the CSPs and proton distribution. CSPs were extrapolated by fitting a harmonic smoothing spline to sparse points within the measured data.
- Complex FIDnavs were generated for step changes of 1 mm/°μTm⁻¹ by simulating motion of the coils and changes in the field basis functions to compute A.
- The complex inverse problem was solved via a weighted least-squares fit with a phase constraint 7 on the real-valued motion and field parameters x. 
- FIDnav field estimates achieved mean absolute errors of 0.07 ± 0.04 μm/° and 0.06 ± 0.04 mm and 0.06 ± 0.05° (Fig. 2).

![Fig. 2. Shim current changes and estimated field and motion parameters from FIDnavs](image)

In Vivo Validation

- A volunteer was scanned at 3T using a 32-channel head coil. Six sagittal FID-navigated multi-echo 3D FLASH scans were acquired, while the subject moved their head to various poses (up-down-left-right) between each scan.
- Ground-truth motion parameters were computed via co-registration of the reconstructed images.
- Ground-truth field maps were calculated in head frame of reference from the phase difference of the registered multi-echo complex data. First-order spherical harmonic functions were fit to the measured ΔB₀ maps within the brain region.

![Fig. 3. Comparison of FIDnav translational, rotational and field estimates and ground-truth motion and fitted field coefficients at each position](image)

![Fig. 4. Comparison of measured, fitted and FIDnav-based field maps for each motion](image)

Discussion

- The proposed approach can simultaneously estimate head pose and related spatiotemporal ΔB₀ field changes from complex FIDnavs with good accuracy.
- There exists a complex relationship between head pose and B₀ field inhomogeneity distribution 8. Future iterations could investigate higher-order changes or incorporate explicit modelling of predicted field changes with motion due to the changing orientation of the head relative to the main magnetic field 9.
- Higher channel-count coil arrays may facilitate estimation of second-order field changes due to the larger number of unknown parameters.
- FIDnavs can be inserted into virtually any sequence with minimal time penalty and are a promising method for retrospective correction of motion and ΔB₀ artifacts as well as real-time FOV steering and shimming.

References

8. Boegel, R. and Zaitsev M. Magn. Reson. Mater. Phys. 23, 263-273 (2010). This research was supported in part by the following NIH grant awards: R01 EB019483, R01 NS079788 and R44 MH086984.