Towards simultaneous measurement of head motion and B_0 field changes using FID navigators

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Background

- Motion artifacts are problematic for acquiring diagnostic quality MRI in children and other uncooperative patient groups[1].
- Large motion also changes the B_0 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[3] 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 B_0 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 τ may be represented as:

$$y_j(\tau) = \int_v s_j(\boldsymbol{x}) \cdot \rho(\boldsymbol{x};\tau) \cdot \exp(i2\pi\gamma\Delta B_0(\boldsymbol{x})\tau)\, d\boldsymbol{x}$$

$s_j(\boldsymbol{x})$	complex CSP of the jth coil
$\rho(\boldsymbol{x};\tau)$	effective spin density of the object
$\Delta B_0(\boldsymbol{x})$	field inhomogeneity at position $\boldsymbol{x}$

- Spatiotemporal changes in the B_0 field due to the changing magnetic susceptibility distribution can be represented by a series of spherical harmonic basis functions:

$$B_0(\boldsymbol{x},t)=\boldsymbol{\beta}(\boldsymbol{x})\boldsymbol{b}(t)$$

- 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).

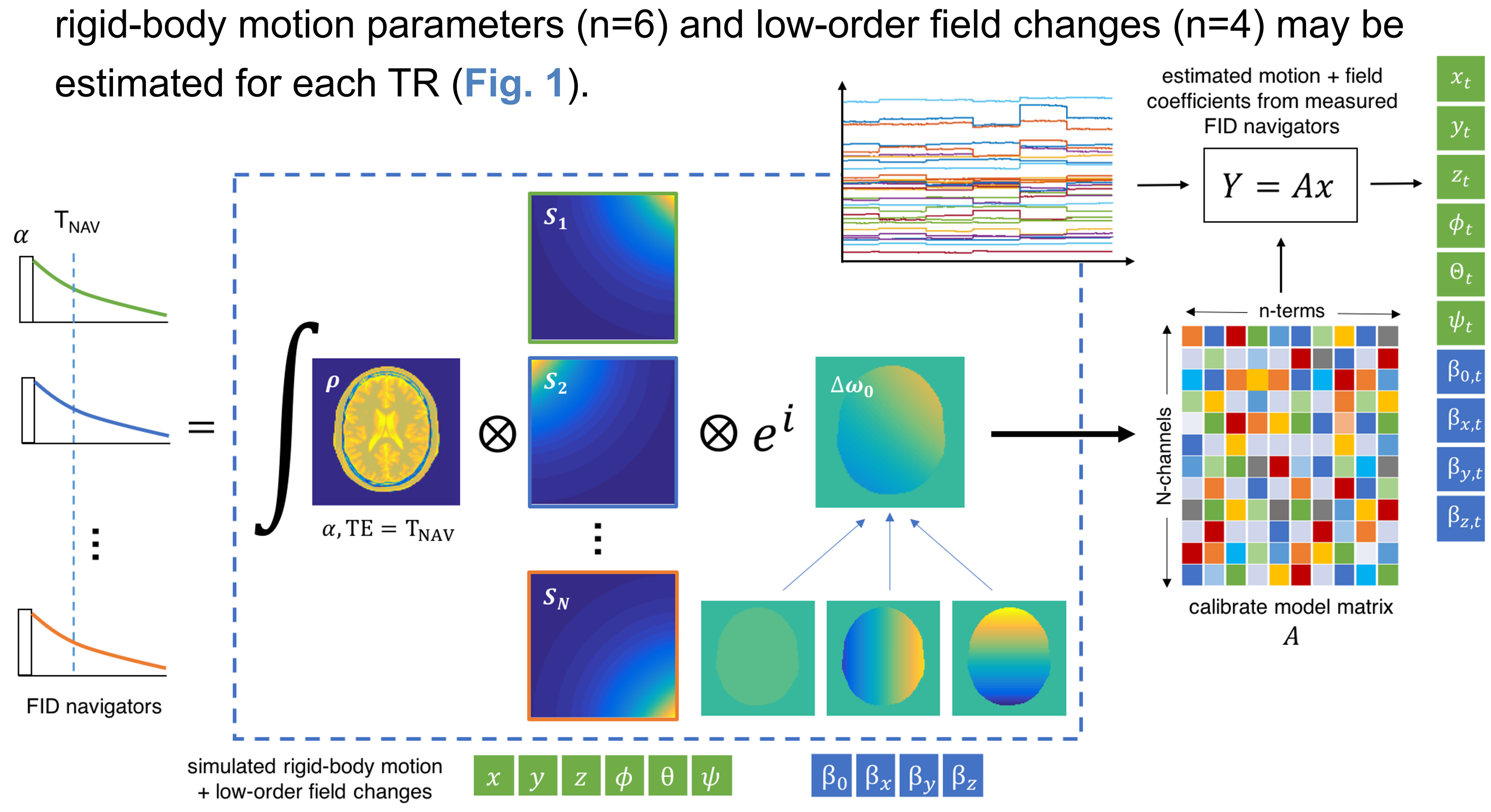

FIG 1. Schematic showing extended FIDnav motion and field measurement framework

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=T_{FID}) was also acquired on the surface and body coils for estimation of the CSPs and proton distribution. CSPs were extrapolated by fitting a biharmonic 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 $\boldsymbol{x}$.
- FIDnav field estimates achieved mean absolute errors of 0.07 ± 0.04 μTm^{-1} with motion estimation errors of 0.06 ± 0.04 mm and 0.06 ± 0.05° (Fig. 2).

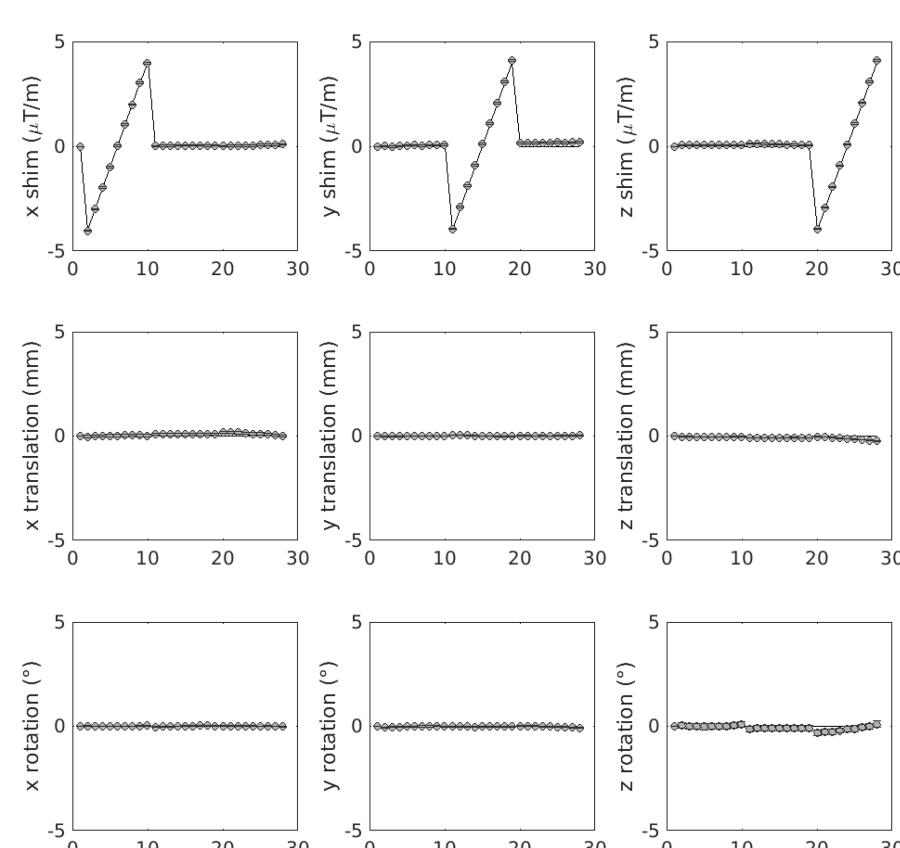

FIG 2. Shim current changes and estimated field and motion parameters from FIDnavs

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 ΔB_0 maps within the brain region.

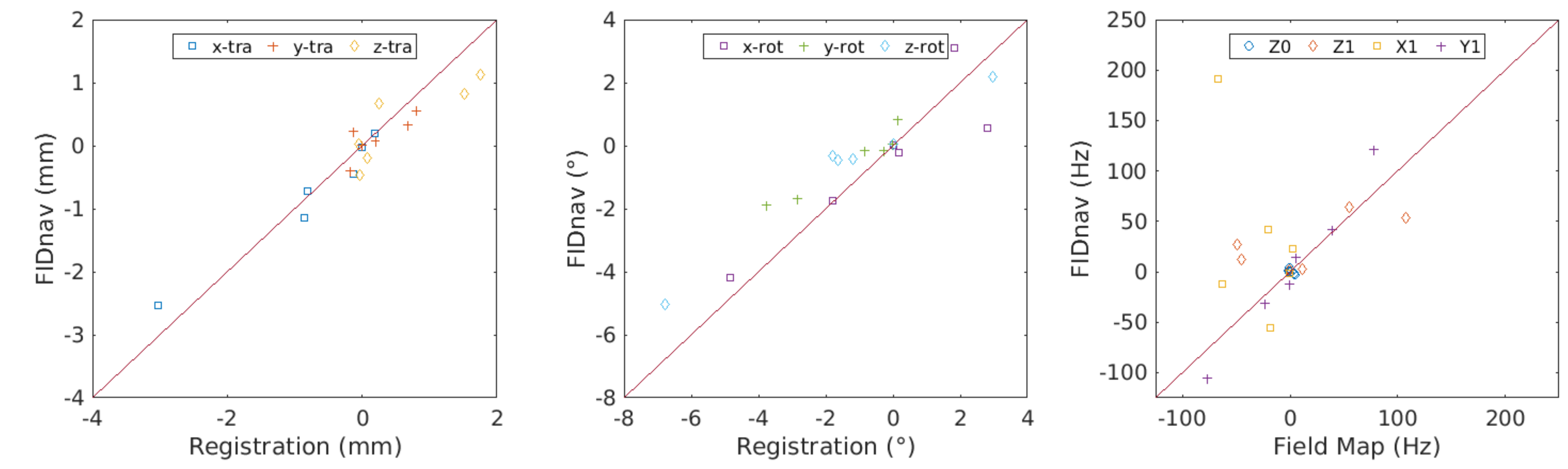

FIG 3. Comparison of FIDnav translational, rotational and field estimates and ground-truth motion and fitted field coefficients at each position

- FIDnav motion estimates achieved mean absolute errors of 0.29 ± 0.17 mm and 0.85 ± 0.65° for maximum changes of 3 mm and 7° (Fig. 3).
- ΔB_0 maps modelled using the predicted first-order field coefficients from the FIDnavs were in good agreement with the measured field maps (Fig. 4).
- NRMSE between fitted and measured field maps was 4.0% compared to 4.8% for FIDnav predictions.

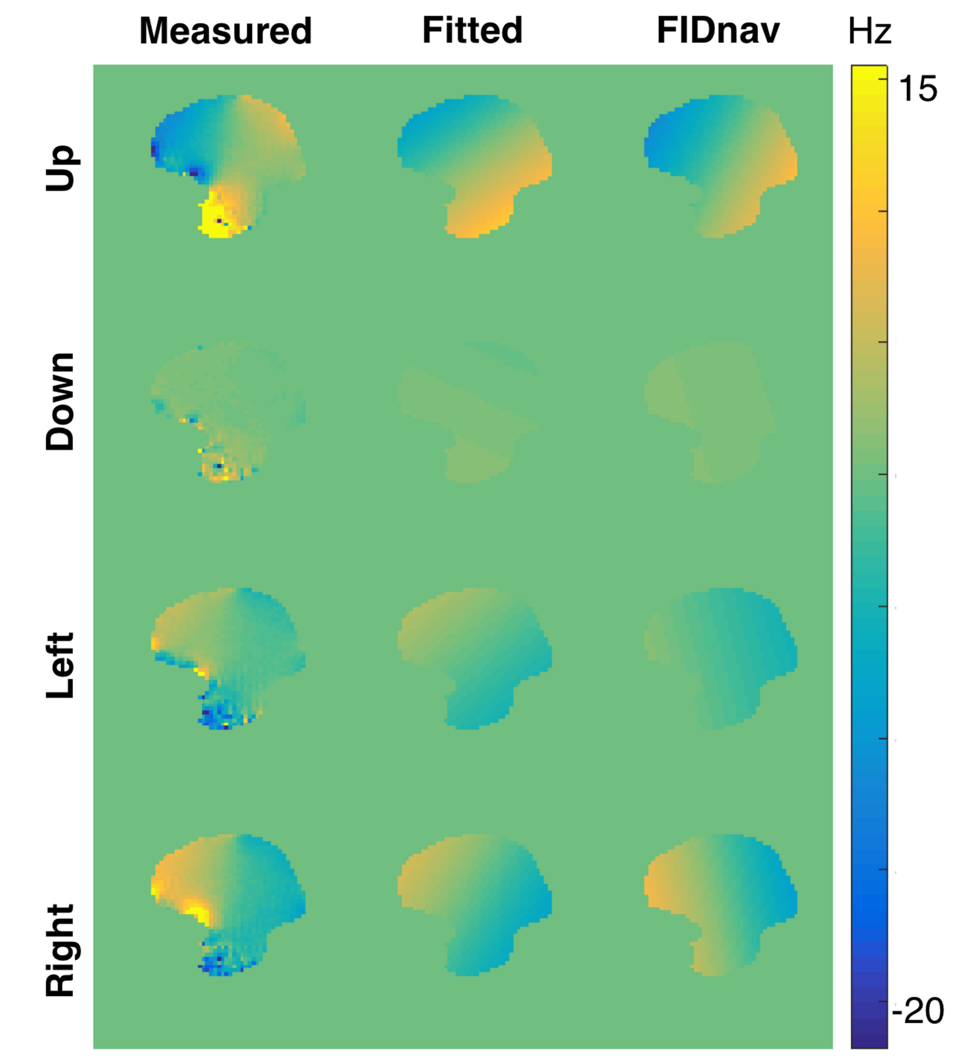

FIG 4. Comparison of measured, fitted and FIDnav-based field maps for each motion

Discussion

- The proposed approach can simultaneously estimate head pose and related spatiotemporal ΔB_0 field changes from complex FIDnavs with good accuracy.
- There exists a complex relationship between head pose and B_0 field inhomogeneity distribution[2]. 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[8].
- 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 ΔB_0 artifacts as well as real-time FOV steering and shimming.

References

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