Synopsis

A fully data-driven retrospective motion correction reconstruction for volumetric brain MRI at 7T that includes modelling of pose-dependent changes in polarising magnetic (B0) fields in the head has been developed. Building on the DISORDER framework, the use of a physics-based B0 model constrains the number of unknowns to be found, enabling motion correction based solely on data-consistency without requiring any additional probe- or navigator-data. The proposed reconstruction was validated on an in-vivo spoiled gradient echo acquisition in which the subject deliberately moved. Substantial removal of motion artefacts was achieved.

Methods

For volumetric encoding with Cartesian sampling, the DISORDER framework achieves motion correction by dividing k-space profiles (readouts) in temporal segments and allowing each segment to have a distinct motion state. This allows high (sub-second) temporal motion reconstruction as parallel imaging provides an over-determined problem to solve. However, adding a volumetric voxel-based estimation of the spatially varying B0 at every segment would make the reconstruction under-determined and a more compact B0 representation is needed. Building on prior studies, we observed that relative changes in B0 fields in the moving head frame due to motion at segment \( s \) consist of a background effects (breathing, scanner drift, etc) as well as pose-independent B0 effects (e.g. head-body orientation) as well as pose-dependent B0 effects in the head to be spatially varying and pose dependent, altering the signal acquired in MRI. Although having limited effect for small motion or clinical field strengths, these B0 drifts hamper motion correction for increased motion levels at ultra-high field (UHF) and need to be included in the forward model. Navigators and NMR probes have been used to measure pose-dependent fields but require additional hardware and/or scanning time and usually have limited temporal or spatial resolution. This work extends the DISORDER motion correction framework, which leverages optimized Cartesian sampling, by including a physics-based model to account for pose-dependent B0 fields, resulting in a fully data-driven, retrospective motion correction.

Results

Fig. 2 shows magnitude images from the different reconstructions. A clear reduction in motion corruption is observed for the proposed motion and B0 corrected reconstructions. This results in an overall increase in contrast and a recovered signal in areas close to air-tissue interfaces.
Only considering the SH does not greatly improve reconstruction (not shown), whereas the linear maps \(d(r)\) alone contribute most to the improved image reconstruction. Although motion corruption is reduced when accounting for B0 variation, the proposed reconstruction still contains residual artefacts and lower signal to noise ratio (SNR) compared to a motion-free scan. Linear maps \(d_{\text{pitch}}(r)\) and \(d_{\text{roll}}(r)\) are shown in Fig. 3 and agree with the literature\(^{6,13,14}\) and our own observations from motion-free data both in terms of dynamic ranges (up to 10Hz/degree) and spatial distributions (near air-tissue interfaces). Estimated motion parameters for the different reconstructions are shown in Fig. 4. Including the B0 model in the reconstruction results in more stable and realistic motion traces. Finally, SH coefficient traces are shown in Fig. 5 and follow the motion pattern, with fluctuations superposed, which probably come from confounding factors (e.g. respiration), as previously suggested\(^{8}\). This confirms that \(c_{n,s}\) includes pose-dependent and pose-independent effects.

**Discussion**

We have shown improved motion correction for UHF brain imaging by incorporating an explicit pose dependent B0 field term, using a compact physics-based model. Substantial reduction of motion artefacts was achieved in multiple test scans, however, as the conditioning of Equation (3) is determined by the variability of the motion parameters, simulations and in-vivo data show that the added benefit of the proposed reconstruction reduces in scans with little motion.

**Conclusion**

We have demonstrated the feasibility of fully data-driven retrospective rigid motion correction at UHF by including pose dependent B0 fields. Our method does not require any additional hardware or scanning time and once refined can be easily translated into other sequences.

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**References**


**Figures**
Figure 1: Relative B0 field changes \( \omega(r) \) in the head frame between two poses, obtained after registration, can be decomposed in lower-degree solid harmonics \((n=2)\) and localised fields that are proportional to rotation angles \( \theta_{\text{pitch}} \) and \( \theta_{\text{roll}} \) (12 and 10 degrees for this example). The linear model \( d(r) \) (not shown here) was fitted on a total of 8 motion-free scans. Data shown here is not used in further reconstructions and only served to validate our model.

Figure 2: Sagittal (left), transversal (middle) and coronal (right) view of the (A) uncorrected (B) motion-corrected and proposed motion + B0 reconstruction (C) without and (D) with considering the solid harmonics (SH). Reduced motion corruption is observed when including the pose-dependent B0 fields with the biggest contribution coming from the linear B0 model, resulting in recovered signal near air-tissue interfaces (white arrows) and improved contrast, e.g. around the ventricles. Residual improvements are obtained when including the solid harmonics (red arrows).

Figure 3: Reconstructed linear maps \( d(r) \) for (A) pitch and (B) roll rotation angles \( \theta_{\text{pitch}} \) and \( \theta_{\text{pitch}} \) overlaid on the reconstructed anatomical image. Strong linearity is observed close to air-tissue boundaries, whereas the induced fields deeper in the brain are characterized better by the lower-degree solid harmonics.
Figure 4: Translation and rotation motion traces for the (A) motion-corrected and proposed motion + B0 reconstruction (B) without and (C) with considering the solid harmonics (SH). Foot Head (FH), Anterior-Posterior (AP) and Left-Right (LR) rotations respectively represent yaw, roll and pitch rotation. More accurate motion parameters are obtained from the proposed reconstruction as the oscillatory motion traces are in discrepancy with instructions given to the volunteer. Substantial improvements come from the linear B0 model compared to the improvements of the SH.

Figure 5: Temporal coefficients of the solid harmonics $SH_{n,m}$ of degree $n$ and order $m$ B0 fields. Solid harmonics are defined so that the $SH_{1,-1}$, $SH_{1,0}$ and $SH_{1,1}$ respectively represent a linear field in the AP, FH and LR direction. Coefficients follow the motion pattern, with superposed fluctuations probably coming from the confounding factors such as respiration, as has been reported previously.5