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Motion Estimation for Brain Imaging at Ultra-High Field Using Pilot-Tone: Comparison with DISORDER Motion Compensation

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Synopsis

A ‘pilot-tone’ implementation for 7T head MRI was constructed by broadcasting RF at the appropriate frequency into the scanner room during data acquisition. This signal was demonstrated to enable motion estimation, when calibrated first by correlating measurements with motion estimates from image registration. Subsequently these estimates were compared with others obtained from the iterative DISORDER joint motion estimation & reconstruction method. These independent methods of motion estimation can potentially improve or replace other methods of motion correction at ultra-high field where motion-correction is particularly relevant.

Introduction

Motion artefacts in the head are well documented¹ and have a significant impact on high resolution image quality, particularly relevant for ultrahigh field imaging.²

DISORDER is a retrospective motion-correction method that compensates for rigid body motion during 3D acquisitions,^{3,4} essentially by simultaneously estimating intra-scan motion parameters jointly with the reconstructed images.

Pilot-tone is a motion-estimation method that uses an externally generated RF signal consisting of a single frequency chosen such that it falls outside the field of view of an image but is still sampled in the k-space data, within the over-sampled region of the frequency encoded direction.⁵ It has been demonstrated⁶ for abdominal imaging at lower field strengths, that respiration-induced loading changes of a local array receiver coil will cause temporal fluctuations in this pilot-tone signal that can then be used to infer motion information. In this work we have explored use of a similar method to create head motion estimates for brain imaging at 7T, and compare these estimates with those from the DISORDER framework.

Methods

All measurements were performed on a MAGNETOM Terra (Siemens Healthcare, Erlangen, Germany) 7T scanner in research configuration, with an 8-Tx-channel head coil (Nova Medical, Wilmington MA, USA). Human subject scanning was approved by the Institutional Research Ethics Committee (HR-18/19-8700). All scans were carried out on a single, healthy volunteer. All data analysis was carried out using MATLAB R2020b (MathWorks, Natick, MA, USA).

A pilot-tone was generated with an RF signal generator (APSIN3000, AnaPico, Glattbrugg, Switzerland) with an offset frequency in the over-sampled frequency-encoded data (adjusted per scan). The tone was piped into the scanner room through a waveguide via a monopole antenna (Figure 1), the power level set on the signal generator was -10.0dBm.

An initial set of 40 GRE “calibration” scans were acquired with the volunteer instructed to hold a different static position during each measurement, to provide positional references for the pilot tone data. GRE hold protocol: TE/TR = 5/10 ms; flip angle: 7°; 220x110x112 matrix (ROxPE1xPE2), 240x240x112 mm³ field of view (FOV); GRAPPA 2x2.

These were then followed by a DISORDER GRE scan with the volunteer instructed to provide a variety of different movements throughout.³ DISORDER protocol: TE/TR = 5/10 ms; flip angle: 7°; 220x110x112 matrix (ROxPE1xPE2), 230x230x112 mm³ FOV.⁴

A hybrid k-space⁵, containing the pilot-tone, was generated by applying a Fourier transformation to each readout line in the acquired k-space. The amplitude of the detected peak in the oversampled region was selected as the pilot-tone. Then the pilot-tone phase was referenced to the first coil and the amplitude was normalized across coils. Finally, a median filter with a 10-sample window was applied.

Motion parameters from the DISORDER reconstruction were obtained using the joint optimisation previously proposed.³

Motion parameters for the calibration data were estimated using rigid-body registration of the 40 GRE images (39 images registered to the first volume). The pilot-tone signals

$$s_x$$

\$ were assumed to relate to the registration parameters

$$s_b$$

\$ via linear model

$$sAx = b$$

\$. This model could be calibrated by estimating

$$sA$$

\$ from measurements where

$$b$$

\$ is known (via registration) computing

$$A = bx^{-1}$$

\$ using the pseudo-inverse to invert the under-determined

$$x$$

\$, aiding the estimate of motion parameters for any new pilot-tone measurement. We experimented with using either magnitude or complex data for

$$x$$

\$ and found that magnitude only data was better able to generalise to unseen measurements.

After fitting the linear model, the predicted motion parameters from the pilot-tone signal were provided to the DISORDER reconstruction. First, images were reconstructed using only pilot-tone motion estimates (no iterative motion estimation). Lastly, pilot-tone motion traces were used to guide data driven estimation of pose dependent B0-fields using a recently proposed extension of the DISORDER reconstruction⁸.

Results

Figure 2 shows the pilot-tone in hybrid k-space and plots of the extracted amplitude and phase for each coil. Figure 3 shows the calibration of the motion estimation model from pilot tone data trained from the first 20 GRE images and then tested on the second set of 20 GRE images. Figure 4 shows pilot-tone motion estimates compared with DISORDER motion estimates. Figure 5 shows DISORDER reconstructed images. The top row shows uncorrected data, the middle row data corrected with the pilot-tone motion estimates, the bottom row corrected data using the pilot-tone motion estimates to compute pose-dependent fields.

Discussion

This experiment describes first experience of using a pilot-tone to estimate head motion, at ultra-high field. Results indicate that the use of a monopole antenna with low-power pilot-tone signal at the entrance to the room is enough to generate useful motion estimates from a 32-channel receiver. Once trained, the motion model was able to accurately predict translation and rotation parameters only from the pilot-tone data.

The motion estimates were compared with others that come directly from the DISORDER joint motion estimation/reconstruction method and are in good qualitative agreement, though some differences exist.

Conclusion

We have shown that head-motion estimates can be obtained from pilot-tone measurements at ultra-high field and correlated them to motion estimation from the DISORDER method. Independent motion estimates of this type could potentially be used to augment or replace other motion correction methods. Future work would focus on an efficient method for in situ calibration.

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Figures

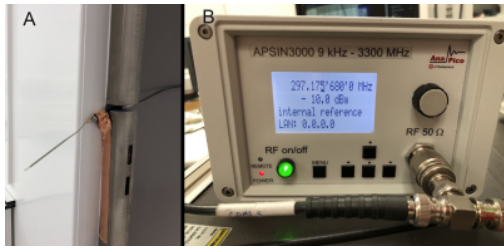


Figure 1: a) Monopole antenna passed through the custom waveguide in the scanner room door. b) The signal generator operating at 297.17568 MHz.

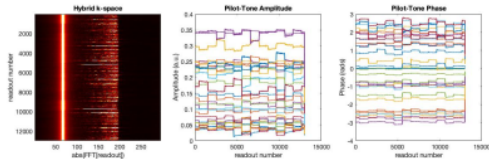


Figure 2: Hybrid k-space (left) containing pilot-tone signal and amplitude (middle) and phase (right) traces with motion encoded in each coil. Each color line is a channel. The data shown is from the DISORDER set.

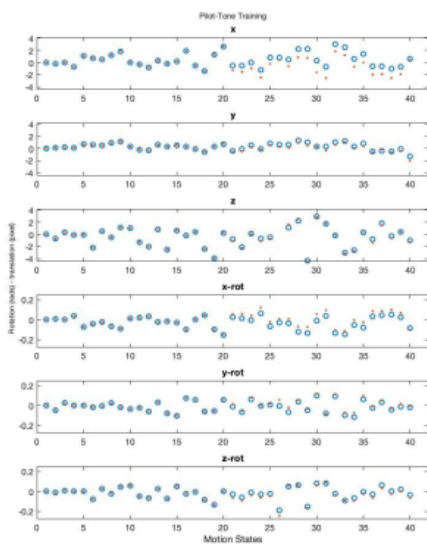


Figure 3: Results of the calibration used to determine the transformation matrix A. The first 20 motion states are used for training, taken from first 20 GRE images, and the remaining 20 motion states are test data from the second set of 20 GRE images. The open circles are the ground truth motion states, and the closed circles are the pilot-tone predicted motion states.

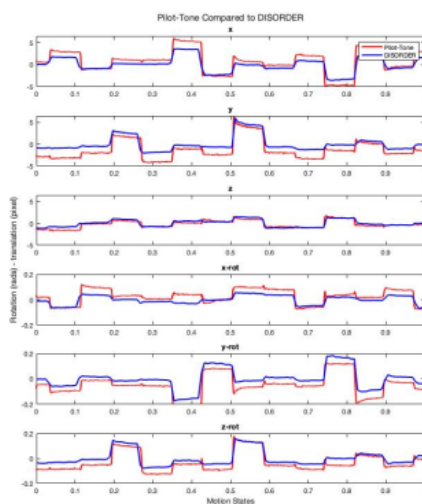


Figure 4: Pilot-tone motion traces compared to the motion traces generated by the DISORDER framework. Each axis contains 1 of the 6 directions of motion, and the red and blue curves are the pilot-tone and DISORDER displacement traces, respectively.

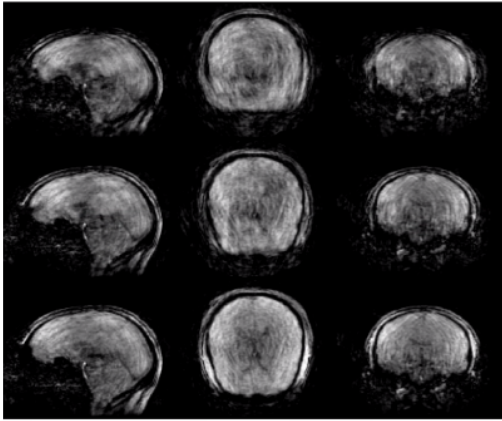


Figure 5: DISORDER reconstructed images. Top row: Un-corrected; Middle row: Pilot-tone motion corrected; Bottom row: Pilot-tone motion corrected + corrected for pose-dependent fields.