3D Estimation of Head Motion Using Three Orthogonal Navigator Echoes and Coil Sensitivity Profiles

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Introduction

Subject motion during MRI scans is a well known and serious problem that can lead to severe image degradation. Much effort has been dedicated to correction of motion artifacts either with the aid of a motion monitoring device [1, 2] or using the MRI signal itself as a navigator [3]–[5] to track motion.

In this study, a new approach is proposed to extract head position based on the sensitivity profiles of multiple receive coils in combination with three short orthogonal gradient-encoded navigator echoes (total duration about 2 ms). Experiments were performed to verify the accuracy and stability of the method in reference to co-registration results.

Motion Model

- **Assumption**: small rotational motion of the head appears as translational motion detected by a particular receive coil.
- **Navigator**: the projections (profiles) of the object in three orthogonal directions are acquired in gradient-encoded navigator echoes.
- **Model**: shift of the navigator's profile detected by a receive coil in a particular direction is the sum of the object's translation in that direction and the shifts induced by rotation around the other two orthogonal directions:

$$s_{n,c} \approx T_n + \sum_{i \neq n} \beta_{ic} R_i \qquad (1)$$

- $s_{n,c}$: the profile shift of a navigator echo recorded along direction **n** on coil *c*
- T_n: translation of the object along direction **n**
- R_i: rotation around directions orthogonal to direction **n**
- β_{ic}: the unknown coefficients in the model, translating rotation to the navigator's profile shift

Methods

- The coefficients β_{ic} in model (1) were calculated by fitting the $s_{n,c}$ of the simulated navigators to R_i following the rotation of a volumetric reference image of the subject around the three orthogonal directions individually. The reference image was acquired when the head was in its unmoved 'Neutral' position, using a 2D GRE sequence with TE=2.55 ms, TR=1.2 s, flip angle=50°, FOV of 240x180x160 mm^3 and an isotropic resolution of 2 mm.
- Head motion of the subject was estimated based on the measured, orthogonally gradient-encoded navigators in different head positions and the calculated coefficients β_{ic} in model (1). Navigators were acquired with a slab-selective excitation, TEs of 2, 2.6 and 3.3 ms in three directions, respectively, and the same TR, flip angle and FOV as the reference image.
- To evaluate the effect of resolution on the accuracy of the proposed motion estimation method, the reference image was down-sampled to the resolution of 4 mm.
- A set of volumetric GRE images were acquired in each position to determine the head position based on co-registration as a ground truth.
- Two healthy subjects were scanned on a Siemens 7 T MRI scanner with a 32-channel receive head coil (Nova).
- Head images acquired in various positions were corrected and averaged. The averaged image was used to compare the performance of the motion estimation methods.

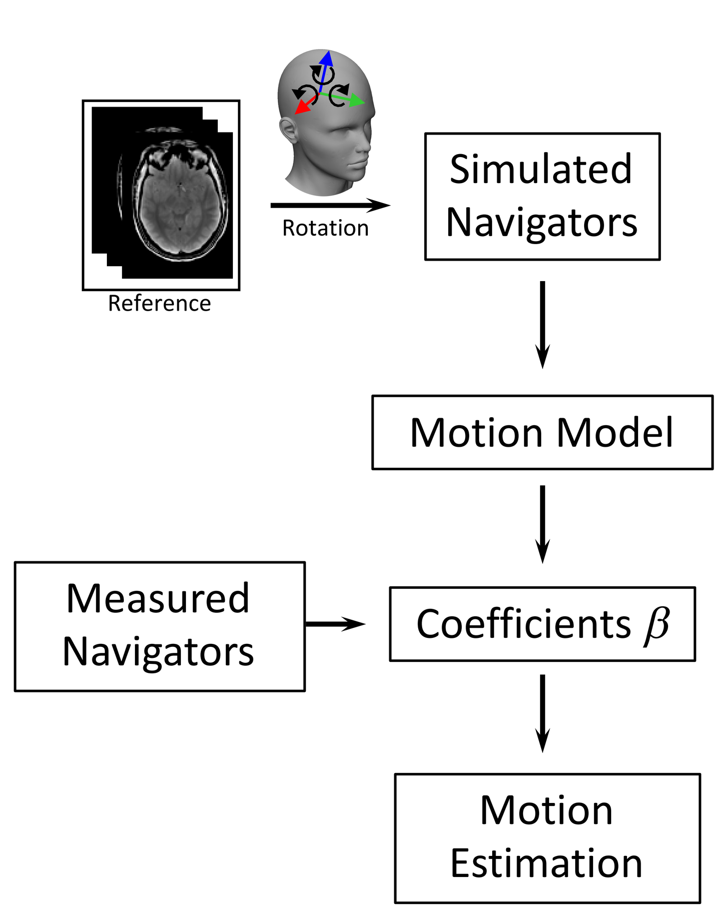

Figure 1 Scheme of the proposed motion estimation method

Results

- Result of motion estimation

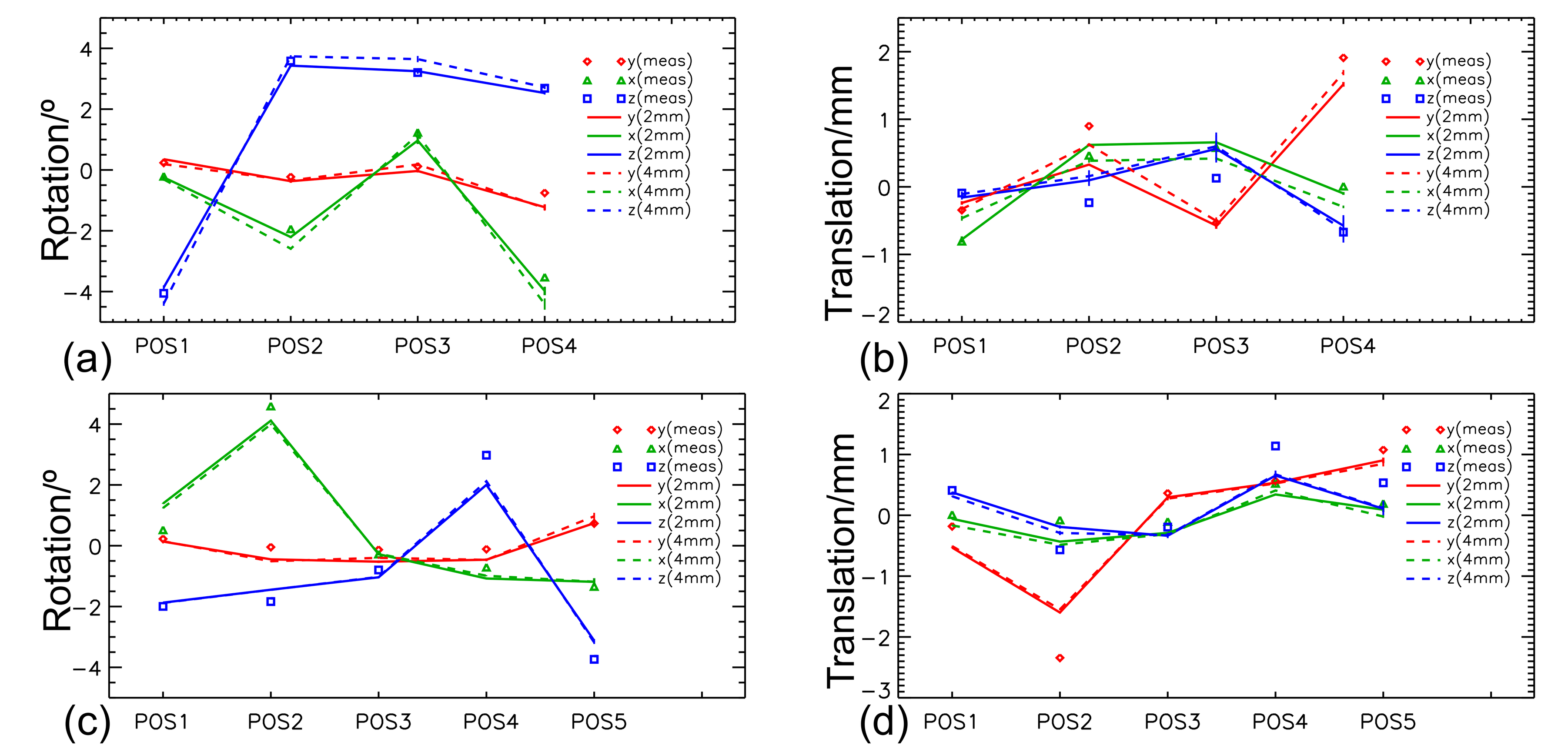

Figure 2 The estimated rotation and translation of the head in comparison with the output of the co-registration (indicated by symbols) in subjects #1 (a and b) and #2 (c and d). The solid and dash lines correspond to the motion estimation using reference images with resolutions of 2 and 4 mm, respectively.

*: The center of the rotation is on the center of the FOV in all three directions.
**: The positive directions of x, y and z axes are towards the left, posterior and head direction of the subject, respectively.

Table I The mean and standard deviation of the error of the estimated motion

	2 mm reference		4 mm reference	
	Rotation/°	Translation/mm	Rotation/°	Translation/mm
Subject #1	-0.1±0.2	0.0±0.3	-0.2±0.4	0.0±0.3
Subject #2	-0.1±0.5	0.1±0.3	-0.1±0.4	-0.1±0.3

- Result of motion correction
  Individual images in different head positions were motion-corrected back to the Neutral position. As shown in the averaged images, the proposed motion correction significantly reduced motion artifacts as indicted by arrows and recovered the contrast between brain tissues.

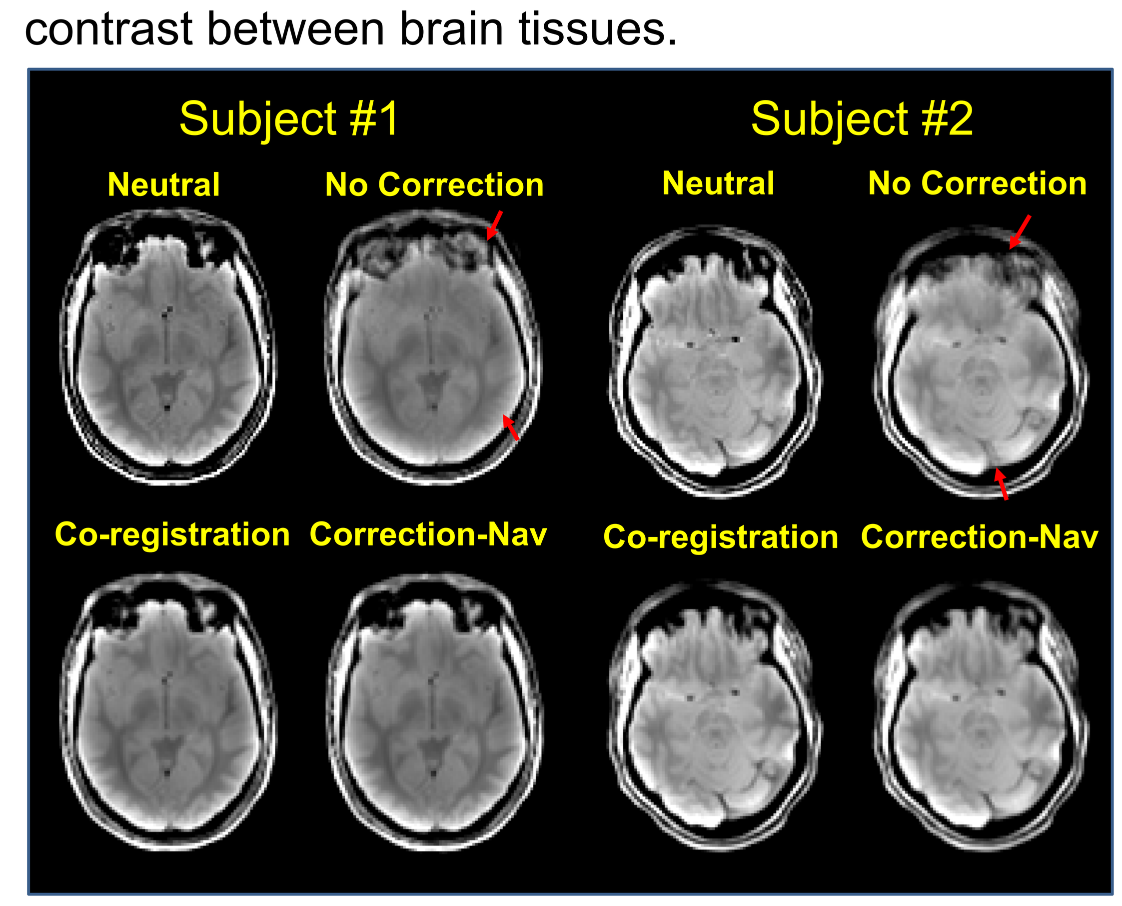

Figure 3 The average image across various positions in reference to the acquired image in the Neutral position. Prior to averaging, images at various positions were either not motion-corrected ('No Correction'), corrected based on the output of the co-registration ('Co-registration') or corrected based on the proposed motion-estimation method ('Correction-Nav').

Conclusions

- A head-motion-estimation method was proposed using three orthogonally gradient-encoded navigator echoes with a total duration about 2 ms and the receive sensitivity profiles of a 32-channel receive head coil.
- The method was evaluated to achieve an rotational and translational error of 0.2±0.4° and 0.1±0.3 mm, respectively, with head motion in the range of -4 to 4° and -3 to 3 mm.

Reference 1. Zaitsev et al., Neuroimage, 2006, 31(3):1038-1050; 2. Qin et al., Magn. Reson. Med., 2009, 62(4):924-934; 3. Welch et al., Magn. Reson. Med., 2002, 47(1):32-41; 4. van der Kouwe et al., Magn. Reson. Med., 2006, 56(5):1019-1032; 5. Babayeva et al., IEEE Trans. Med. Imaging, 2015, 34(9): 1879-1889

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