Non-iterative navigator-based approach: advances towards real time 3D motion correction

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Introduction: Spherical navigator echo (SNAV) techniques have been promising for tracking rigid body motion in all six degrees of freedom [1, 2]. However, excessive computational cost has limited the use of SNAVs to intra-scan registration [1-5]. Specifically, SNAV registration algorithms are iterative and involve slow (seconds) triangulation and interpolation steps, where the searching process may also be trapped in local minima. To achieve non-iterative SNAV registration, an approach was proposed, and verified for data acquired using a quadrature head coil, where a set of pre-rotated baseline SNAVs (preRot-SNAV) are acquired and used as templates during the registration of a baseline and rotated positions [6]. The computation time for determining rotations and translations was about 50 ms, with only tens of seconds required for baseline template acquisition. To be practically useful, the preRot-SNAV technique must be applicable to data acquired using multi-channel RF coils. In this study we demonstrate the effective application of the preRot-SNAV technique using an 8-channel phased array coil; the effect of navigator radius (K_ρ) on the accuracy of rotation determination is evaluated as well.

Theory: The pre-rotated SNAV technique [6] starts by collecting a set of pre-rotated baseline SNAVs, where rotations are applied to the gradients to rotate the SNAV trajectory. These baseline SNAVs are used as a look-up table for subsequently acquired SNAVs of the moving object. A cost function (sum of squared differences) is defined to measure the similarity between a physical object rotation SNAV and all of the pre-rotated baseline SNAV templates. The rotation between the baseline and transformed object position is determined by the rotation with the least cost function. Prior to processing the navigator data acquired with the multi-element coil for motion extraction, three raw-data combination approaches [7] were tested; these included: simple summation of the complex raw data (SoR), summation following phase alignment (SoG), and summation of the squares of the k-space magnitude profiles (kSoS).

Methods: A standard fast gradient recalled echo pulse sequence was customized to acquire the SNAV data [2]. All SNAV data were acquired along the entire surface of a sphere in 50 ms (TR = 25 ms) using a two-shot approach, collecting 1212, 1254, and 1328 sample points along a hemisphere for each shot with radius K_ρ = 0.2, 0.4 and 0.6 cm^{-1} respectively. The other parameters were: TE = 1 ms, flip angle = 10°, slab thickness = 30 cm. Pre-rotated baseline SNAVs were acquired for 512 random rotations generated to cover the following rotation range: ±6° (Pitch, θ_x), ±6° (Roll, θ_y) and ±20° (Yaw, θ_z). The total baseline acquisition time was 25.6 seconds (512*50 ms).

To evaluate the ability to apply preRot-SNAVs with a multi-element RF coils in a practical situation, a navigator-based 3D brain-volume-realignment experiment was conducted. First, a set of baseline preRot-SNAV data and three sets of orthogonal images were collected (2D FGR, TE/TR = 10/500ms, BW = 15.63kHz, flip angle = 45°, FOV/Thickness = 26cm/3mm, spacing = 1.5 mm, 256×256×18). The volunteer was then moved out of the scanner and repositioned on the scanner bed. A second SNAV was acquired and used to determine the three rotation angles by registering the magnitude profile with the baseline SNAV. Rotation and translation were measured following combination of the raw date using all three of the combination approaches discussed above. The rotation and translation parameters calculated using the SoR combination technique were manually fed to the image pulse sequence and "aligned" images were acquired. Finally, the unaligned images were acquired for comparison. The brain images were also used to quantitatively evaluate the results of the realignment experiment, by using image-based registration.

All experiments were performed on a GE 3.0-T whole-body MRI scanner using a GE eight channel head coil. Processing of all navigators was performed off-line on a 2-GHz, Athlon processor using MATLAB (MathWorks, Natick, MA).

Table 1: Summary of the results of head axial rotation

Methods	K_ρ= 0.2 cm^{-1}	K_ρ= 0.4 cm^{-1}	K_ρ= 0.6 cm^{-1}
SoR	15.3° ± 0.2°	15.6° ± 0.1°	16.8° ± 0.1°
kSoS	17.0° ± 0.1°	16.5° ± 0.2°	16.8° ± 0.1°
SoG	18.1° ± 0.2°	15.2° ± 0.1°	15.2° ± 0.2°

Accuracy and precision were calculated and are presented as mean ± standard deviation from the 32 repeated SNAV data sets. The axial rotation angle determined by the image registration (truth) was 15.7°.

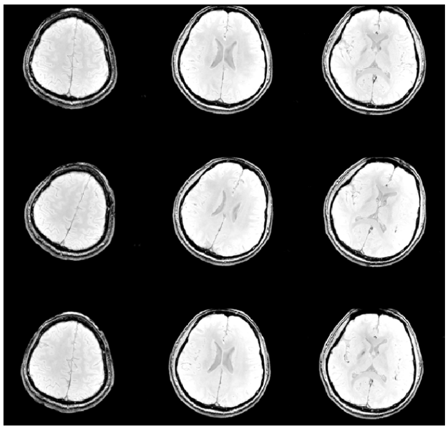

Figure 1. Results from an in vivo brain realignment experiment. From top to bottom are the images acquired at the reference, moved and realigned positions, respectively. The motion parameters determined using K_ρ = 0.4 cm^{-1} were fed back to the scanner.

Results and Discussion: Similar to the conventional SNAV method acquired with the multi-element RF coil [7], the preRot-SNAV with the SoR combination method achieved the best accuracy (Table 1). An example application of the SoR approach of combining raw preRot-SNAV data from an 8-channel head coil in a volume-realignment experiment is presented in Fig. 1. Rotation and translation were detected simultaneously. Qualitative visual inspection reveals excellent agreement between the baseline images and the images acquired following preRot-SNAV-based alignment.

When using the preRot SNAV technique, the dependence of both accuracy and precision of rotation determination depends on Kρ, as it does when the slow iterative registration approach is used [1-2] (Table 1).

The most important finding of this study was that sub-degree and sub-millimeter accuracy and precision can be achieved using the preRot-SNAV by keeping the combined navigator acquisition and processing time below 100 ms. For the first time, we have been able to demonstrate that 3D real-time motion correction is feasible using either a single element or multi-element RF coils.

References: [1] Welch, et al., MRM 47:32-41, 2002. [2] Petrie, et al., MRM 53:1080-1087, 2005. [3] Welch, et al., MRM 52:1448-1453, 2004. [4] Ari and Kraft, ISMRM 14:3195, 2006. [5] Costa et al., MRM 53:150-158, 2005. [6] Liu and Drangova, MRM DOI 10.1002/mrm.22629. [7] Liu and Drangova, MRM 64:1208-1216, 2010.