Toward Practical 3D Motion Correction in MRI Using Spherical Navigator Echoes

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Target Audience: MR scientists developing and applying motion correction techniques.

Introduction The spherical navigator echo (SNAV) technique can be used to measure rigid body motion in all 6 degrees of freedom (1-4). Motion is measured by registering SNAVs, acquired throughout the image acquisition, with a baseline SNAV. The original registration algorithms were iterative and time consuming – severely limiting the use of the method (3). A pre-rotated baseline SNAV (preRot-SNAV) technique proposed by our group demonstrated improved speed and accuracy of registration, making real-time prospective motion correction with SNAVs feasible (4). With the preRot-SNAV technique a set of 512 baseline SNAV templates are acquired at a reference position by pre-rotating the SNAV trajectory by known angles that evenly cover a defined range. This set of baseline templates serves as a lookup table to which subsequently acquired "trial" SNAVs are compared to determine the object's rotation. Using the preRot-SNAV method rotations can be determined in 10's of milliseconds with translation calculations requiring negligible additional time. Unfortunately, the total pre-rotated baseline acquisition time for 512 templates can be prohibitively long (25.6 s). For practical implementation of the technique, the baseline template acquisition time must be reduced to a few seconds at most.

Purpose: The purpose of this study is to develop and evaluate a hybrid baseline approach, which uses acquired and simulated templates to reduce baseline acquisition time to a few seconds.

Methods: Experiments were performed using a 3.0-T whole-body MRI scanner and a birdcage RF head coil. A plastic skull filled with agar was used as a phantom. SNAVs with a 0.4 cm^{-1} radius and 1254 sample points per hemisphere were acquired with a TR of 25 ms. Baseline templates of SNAVs were collected by rotating the gradient rotation matrix by uniformly distributed known amounts. The 512-template distribution (Fig. 1a), previously validated in reference 4, was used as a gold standard to which we compared the results from the hybrid template datasets. An additional set of 170 baseline templates was acquired with a distribution as shown in Fig 1b. Simulated templates that mimic object rotation about the Z axis (SI axis) were interpolated from the 170 acquired templates creating a hybrid baseline set of acquired and simulated templates. The simulation was also performed using an 82-template subset of the acquired 170 templates. To simulate motion, the phantom was positioned at three arbitrary positions (trials); 32 SNAVs were acquired at each position to determine measurement precision. The rotation of the phantom in each of the trials was determined by finding the best-matched SNAV template from each of the three baseline sets (512, 170 hybrid, 82 hybrid). Translations were not measured.

3D SPGR images with a 22 cm field of view and 1.5 mm slice thickness were also acquired at the reference position and the first trial position. Based on the rotations measured using the hybrid 170 SNAV baseline dataset the image rotation matrix was transformed and a third (rotation-corrected) image was acquired. The reference and corrected images were compared using a pixel-by-pixel subtraction to evaluate the accuracy of the measurements and assess the performance of rotation correction in-vitro.

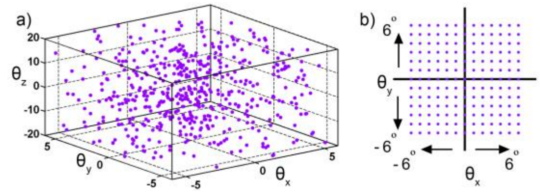

Fig. 1 Angle distributions of the acquired pre-rotated SNAV baseline template data sets: 512 (a) and 170 (b).

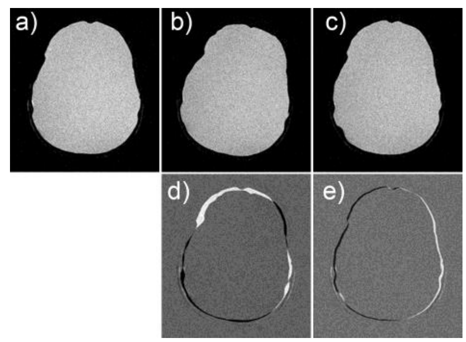

Fig. 2. Single axial slice of the 3D image acquired at the reference position (a) and the first trial rotation position (b). Acquisition following correction for the repositioning, as calculated from the 170 hybrid baseline dataset is shown (c). The reference image is subtracted from the uncorrected (d) and corrected (e) demonstrating excellent correction; residual misalignment is attributed to uncorrected translation.

Table 1. Rotation measurement results for 3 trials motions. Reported values are the mean ± standard deviation from the 32 repeated SNAVs. Unreported standard deviations were < 0.1 º.

	Baselines	θ_x (º)	θ_y (º)	θ_z (º)
Trial 1	512	-4.7	-1.3	-8.8
	170	-5.0 ± 0.2	-0.3	-8.7 ± 0.2
	82	-4.0	-0.3	-8.6
Trial 2	512	-0.1	1.7± 0.2	11.0 ± 0.2
	170	-1.0 ± 0.2	2.0	11.3
	82	-1.0	1.7	11.3
Trial 3	512	0.0	1.3	-10.3
	170	0.3	1.0	-10.7
	82	0.3	1.3	-10.0

Results and Discussion: Measured phantom rotations for the three trial orientations of the phantom are shown in Table 1; all measurements performed using the hybrid baselines are within 1º of the measurements made using the 512-template baseline set. The measured rotations were successfully used to perform in vitro rotation correction as shown in Fig. 2. The baseline acquisition time was reduced to as little as 4.1 s with the 82-template hybrid acquisition, without compromising the accuracy or precision of rotation measurements. Further reduction in time can be achieved by tailoring the SNAV acquisition itself – to reduce the time needed to acquire each navigator. While in the present study translation was not measured or corrected, resulting in remaining misalignment of the rotation corrected-image in in Fig 2c,d., adding the correction for translation is simple and can be achieved in fractions of a millisecond (from the acquired SNAVs). Future studies will involve quantitative evaluation with known motion profiles and i*n vivo*.

Conclusions: The presented hybrid approach, which involves the acquisition of a small set of pre-rotated baseline templates followed by template simulation, results in accurate measurement of rotation angles (1º) using the pre-rotated baseline SNAV technique.

References: (1) Welch, et al., MRM 47:32-41, 2002. (2) Petrie, et al., MRM 53:1080-1087, 2005. (3) Welch, et al., MRM 52:1448-52, 2004. (4) Liu, and Drangova., MRM 65:506-14, 2010