Using the Axis of Rotation of Polar Navigator Echoes to Rapidly Correct 3D Subject Motion

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Introduction: Spherical navigator (SNAV) echoes have shown exciting promise to correct for 3-dimensional rigid-body motion (1). Although fast helical-spiral SNAVs can be acquired in tens of milliseconds, registering the data from two spherical shells can require several seconds to converge to a solution. We have previously shown how the axis of rotation (AOR) between two SNAVs can be used to initialize the minimization algorithm that registers spherical navigator echo data (2), thereby speeding up the analysis of the SNAV technique. Here, we extend the AOR concept to an improved SNAV acquisition and analysis strategy that eliminates the need for a minimization algorithm entirely. At low SNR, the improved strategy was found to detect compound rotations to 0.5-degree accuracy in approximately 100 milliseconds, indicating that 3D prospective motion correction is feasible with this technique.

AOR Algorithm: An efficient sampling strategy to locate the axis of rotation is to only acquire the poles of the spherical shells where the AOR is expected to lie (Fig. 1). Predicting the orientation of the AOR is possible by pre-rotating one of the datasets about one of the major axes, which forces the AOR to lie in a specific polar region of the SNAV. For example, one can apply a large rotation about the z-axis to the base-line polar navigator echo (pNAV). If the subject then rotates by some smaller amount about any combination of axes, the resulting AOR will be a linear combination of all rotations, and will remain nearly parallel to the z-axis. Another advantage to pre-rotating the base-line dataset is that it allows the AOR algorithm to detect a 0^{o} rotation, which is not otherwise possible. For a fixed acquisition time, acquiring only the poles of the spherical shell increases the sampling density of the navigator echo, improving the accuracy in locating the AOR. Once the AOR has been located, orbital navigator (ONAV) echoes are interpolated from the polar cap data in planes normal to the AOR. To increase the SNR, ONAVs from both hemispheres in Fig. 1 are acquired and added together prior to being cross-correlated with ONAVs from another dataset. Lastly, the 2D rotation determined by the cross-correlation is used in conjunction with the orientation of the AOR to calculate rotations about the 3 coordinate axes (θ_x, θ_y, θ_z).

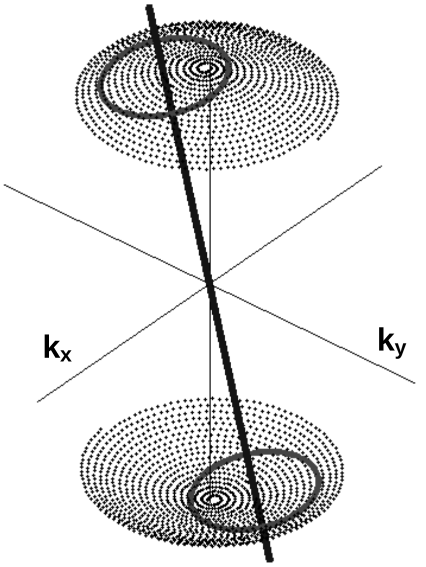

Fig. 1: The AOR technique using only the polar caps of the SNAV. Orbital navigator echoes are obtained in both hemispheres in planes normal to the AOR.

Methods: We tested the precision, accuracy, and processing speed of the SNAV and pNAV-AOR techniques in detecting six compound rotations. Each rotation was about an AOR at 84^{o} latitude, 180^{o} longitude, and ranged from 5-30^{o}. Typical navigator studies collect echoes before and after applying experimental rotations to a phantom. Here, we applied the compound rotations to the navigator trajectories themselves, and collected data from a human skull phantom that remained stationary throughout. This allowed us to minimize the error in the applied rotations. For each rotation, 32 repetitions were acquired. All trajectories had the same radius ($k_\rho = 0.4$ cm^{-1}) and sampling density (~ 4000 pts). Processing was performed off-line on a 2 GHz Athlon processor using MATLAB (Natick, MA).

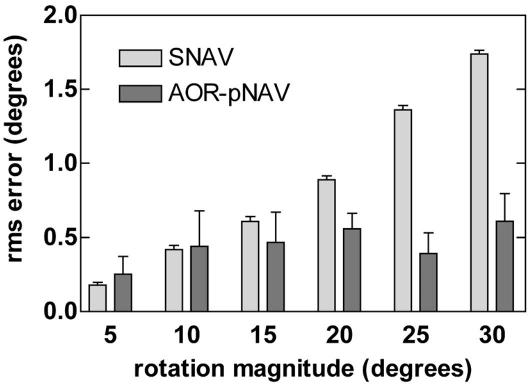

Fig. 2: The accuracy and precision of the two techniques. Although the SNAV technique exhibits high precision, the accuracy decreases for larger rotations. The pNAV-AOR technique is fairly insensitive to rotation magnitude, and detected all rotations to approximately 0.5^{o} accuracy. The root mean squared error is calculated by comparing the three Euler angles (θ_x, θ_y, θ_z) determined by the algorithms to the known rotations.

Results & Discussion: The accuracy and precision of the two techniques are presented in Fig. 2. For small rotations, both techniques exhibited an accuracy of at least 0.5^{o}. For larger rotations, however, the error of the SNAV technique increased to over 1.5^{o}, perhaps because the minimization algorithm converged to local minima. In general, the SNAV technique yields errors of a degree or more for large, compound and/or “cross-thread” rotations. In addition, the minimization algorithm used to register the SNAV data required approx. 5 seconds to converge to a solution. In contrast, the AOR algorithm is non-iterative, and, including the time needed to collect a pNAV with 4000 points, requires less than 100 ms to detect 3D rotations. These results indicate that 3D rigid-body motion could be prospectively corrected with the pNAV-AOR technique. Future development will focus on optimizing the design variables of the AOR algorithm.

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References:

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