Spherical Navigator Echoes Using GRAPPA for Rapid 3D Rigid-body Motion Detection

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Introduction:
The spherical navigator echo (SNAV) technique [1-2] is ideal for tracking rigid body motion in all six degrees of freedom simultaneously. However, the relatively long time required to acquire a spherical navigator echo (~20 ms) limits the utility of SNAV for short TR pulse sequence used in cardiac and functional MRI, without interrupting image-data collection. The goal of this work was to minimize SNAV acquisition duration while maintaining accuracy. A parallel-imaging approach, based on the k-space-based generalized auto calibrating partially parallel acquisitions (GRAPPA) [3] algorithm, is proposed to speed up SNAV acquisition.

Methods:
In order to implement the GRAPPA approach to hemispherical helical-spiral sampling of k-space [2] as required for SNAV acquisition, the spherical trajectory is first represented in 2D longitude (θ) and latitude (φ) space, where the spherical k-space trajectory is described as a series of pseudo parallel lines (Fig. 1). In the θ-φ representation, the number of parallel "segments" depends on the angular velocity of the SNAV trajectory. Acceleration of the acquisition by a factor of R can then be achieved by skipping R-1 out of every R segments.

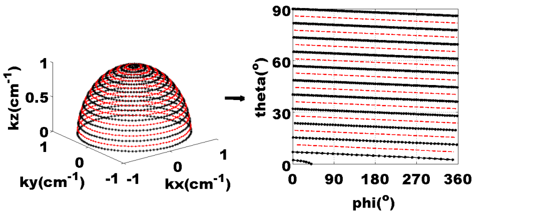

Figure 1. A hemispherical trajectory can be represented as a series of parallel lines in longitude and latitude coordinates. The dashed lines represent skipped segments to be synthesized using the GRAPPA algorithm. The total number of spherical segments is 22, which is independent of radius, K_ρ, and total number of sampled points, N.

To regenerate a fully sampled SNAV from a set of sub-sampled data sets, an approach similar to those proposed for the reconstruction of parallel radial [4] and spiral [5] imaging can be used. A fully sampled scan of all segments is first acquired as the reference data set and is used to calculate the coil weighting factors for each segment and each coil. These coil-weighting factors are then used to regenerate the entire SNAV from the sub-sampled acquisition for each coil. To combine the data from all coils into one SNAV data set, the phase alignment method [6] can be used.

The SNAV-GRAPPA approach was implemented on a 3 T GE scanner equipped with an eight-channel phased-array head coil. SNAV trajectories of different k-space radii (k_ρ), ranging between 0.4 cm^{-1} and 1.8 cm^{-1}, and of approximately equal sampling density (~ 1200 points over each hemisphere) were implemented. To evaluate the effect of SNAV acquisition acceleration on the accuracy of motion characterization, an agarose-gel-filled plastic skull phantom was scanned at three different rotations (rotations in the along-thread (axial) and cross-thread (coronal and sagittal) directions were evaluated). Each SNAV acquisition was repeated 32 times to calculate the precision. GRAPPA acceleration factors (R) of 2, 3 and 4 were evaluated. The rotation angles were calculated by registering the magnitudes of the SNAV-GRAPPA data of the rotated and reference data sets using the simplex optimization algorithm.

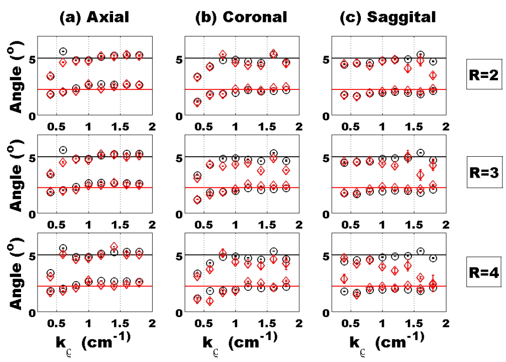

Fig. 2. Measured rotation angles as a function of k_ρ SNAVs were acquired without acceleration (circles) and with 3 different acceleration factors (diamonds). The known rotations are represented by horizontal lines.

Results and Discussion:
Using the SNAV-GRAPPA approach, hemispherical SNAV trajectories could be acquired as fast as 2.5 ms (at a bandwidth of 125 kHz) for R = 4. Shown in Fig. 2 is a summary of the along-thread (axial) and cross-thread (coronal, sagittal) rotation results obtained with different acceleration factors. As expected, at all k_ρ, higher accuracy was achieved when rotation was in the along-thread direction, independent of R. Highest accuracy was achieved for k_ρ between 0.8 and 1.2 cm^{-1}. Although motion could be calculated from the regenerated SNAV data of each of the separate coils, our results indicated a large channel-dependent variability in the measured rotations, which was primarily attributed to variation in the coil sensitivities and the spatial distribution of object features. The acquisition acceleration also results in a reduction of the effect of T2* decay and will enable the insertion of SNAV-GRAPPA acquisition directly within 3D imaging sequences. Furthermore, the approach presented here can be applied directly to accelerating image acquisition with 3D spherical trajectories.

Reference: [1] Welch, et al., MRM 47:32-41, 2002. [2] Petrie, et al., MRM 53:1080-1087, 2005. [3] Griswold, et al., MRM 47:1202-1210, 2002. [4] Heidemann, et al., MRM 56:317-326, 2006. [5] Huang, et al., MRM 57:1075-85, 2007. [6] Debbins, et al., 38:1003-1011, 1997.