Estimating SNR Efficiency in Non-Cartesian Trajectories: Cartesian Is To Apples As BLADE Is To Schnitzel

K. Barkauskas[1], M. Blaimer[1], J. Duerk[1], and M. Griswold[1]
[1]Case Western Reserve University, Cleveland, OH, United States

Introduction: Many non-Cartesian sequences are in use in MRI today. However, very little work exists to quantitatively compare the SNR efficiency of these methods to a Cartesian standard. SNR efficiency estimates are difficult to acquire since they must account for non-traditional factors such as: multiple coils with potential for parallel imaging, disparate K-space sampling densities, unequal regions of k-space support, different point spread functions and the existence of a spatial noise autocorrelation whenever non-Cartesian trajectories are used. This is especially problematic in undersampled trajectories where residual artifacts can look like noise. This non-exhaustive list of complications disqualifies the image domain difference method for SNR estimation[1]. Specifically, this ROI-based method is not appropriate for comparing between trajectories due to the spatial correlation of noise and the spatial variation of noise whenever multiple array channels are used. The multi-repetition method[2] can compute pixel-wise statistics and avoid some of these errors, but imaging conditions are not guaranteed to be stationary over time. In light of these challenges, we have developed a novel SNR estimation method based on bootstrapped statistics. In bootstrapping, multiple repetitions are synthesized from a single noise scan and a single set of rawdata. The synthesized data sets can then be analyzed as in the multi-acquisition method. Here, we specifically apply this method to estimate the SNR efficiency of BLADE/PROPELLER[3-5] and Cartesian trajectories with the results compared to theoretical predictions.

Theory: The bootstrapped estimates of SNR were calculated based on an acquisition of a single rawdata set with a normal acquisition followed by a separate acquisition of only noise. The noise statistics are assumed to be stationary over time, though the signal may not be. The basic bootstrap method assumes that different K-space reorderings of the noise data set are uncorrelated and can therefore be used to simulate separate acquisitions. This eliminates the primary problems of the conventional estimation of SNR discussed above, while preserving the SNR behavior for both array and non-Cartesian reconstructions.

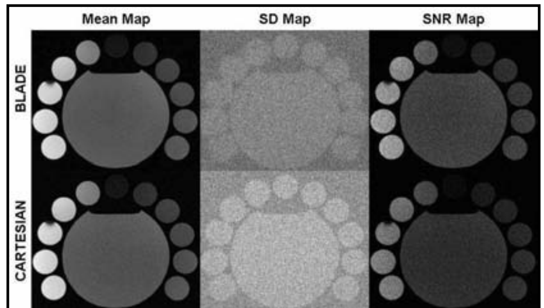

Figure 1: Pixel-wise mean, standard deviation (SD), SNR maps for FLASH. Note, sum of squares combination has been performed, where each column is shown with the same grayscale.

Methods We compared a specific BLADE trajectory to a Cartesian scan to test this basic method. A FLASH SSFP preparation (TE/TR/θ 5ms/20ms/50°) was implemented with a Cartesian (N_{read} x N_{phase}, 512x256) and a BLADE (N_{read} x N_{phase} x N_{blade}, 512x21x19, through 180°) trajectory on a Siemens 1.5T Espree imager (Siemens Medical Solutions, Erlangen, Germany). Additional parameters were: FOV 250mm FOV, 2x read oversampling, single 5mm slice at isocenter, 2 channels of a head array, ADC dwelltime 5.6μs. A Gd-DTPA-doped phantom was used as the signal source. The BLADE trajectory was adjusted *post hoc* to align the blades prior to reconstruction. The noise vector for the corresponding rawdata (i.e., Cartesian or BLADE) was randomly reordered in k-space 50 times and then added to the rawdata. These "bootstrapped" repetitions were gridded with the requisite DCF (Iterative Grid / De-Grid algortihm[6], filter settings [w,β] = [5, 20.7] for calculation and gridding to a 2x oversampled matrix).

Results: Pixel-wise calculation of mean, standard deviation and SNR were conducted on the stack of sum of squares combined images (Figure 1). The ratio of BLADE to Cartesian mean SNR within a 551 pixel ROI at the center of the large phantom was 1.34. Considering only relative imaging time (256 PE steps compared to 399 BLADE acquisitions) would result in an SNR ratio of 1.25. Since the K-space area covered by BLADE is smaller, the voxel size adjusted SNR ratio should be 1.41. Once DCF differences are accounted for, the theoretical ratio of SNR is 1.33. Theoretical and empirical relative SNR efficiency would then be 85.2% and 85.9%, respectively, and in good agreement with each other.

Discussion: For pixel-wise calculation of image statistics, the bootstrap process addresses the object motion and statistical power drawbacks of the commonly used multi-repetition and image difference methods, respectively. Our data confirmed our theoretical predictions of higher SNR of BLADE compared to Cartesian sampling for the trajectories used here. This general analysis concept should be applicable to any non-Cartesian imaging situation when one does not have a Cartesian reference for comparison, especially dynamic scanning, since it can avoid many of the pitfalls associated with other SNR estimation methods. The primary purpose of this abstract is to show that one has to be careful when estimating SNR in a non-Cartesian imaging situation: what works well for apples will not hold for schnitzel.

References: [1] MRM 2005. 54(3):748-54. ; [2] MRM 2005. 54(6):1439-47; [3] U.S. Patent # 5,833,609; [4] JMRI 1998. 8(4):944-54; [5] MRM 1999. 42(5):963-9; [6] ISMRM 2006. p. 2949.

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