Generalized multiple averages (GRAMA) for motion compensation

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Introduction:

A class of approach for motion compensation is to reduce localized data inconsistencies in *k*-space using parallel imaging [1-3]. Multiple copies of the original *k*-space are synthesized with partly restored self-consistency and dispersed errors. Conventional multiple average method [3] adopts a relatively fixed kernel like that in GRAPPA [4] and averages original *k*-space and synthetic *k*-space generated using subsets of the acquired *k*-space. Our work focuses on optimization of the kernel design and takes advantage of averaging *k*-space copies synthesized with different convolution kernel. Especially, the original *k*-space is acquired in an interleaved manner to generate error incoherency between different acquisition segments. We demonstrate our motion compensation method which is named as GeneRAlized Multiple Averages (GRAMA) is robust and effective with experiments dealing with artifacts induced by different motions.

Methods:

Any *k*-space signal can be approximated by an interpolation of its neighboring data points from all used coil channels in parallel imaging [4]. If there is no motion, the convolution results by using different shape of kernels should be similar, except the differences of noise level. A convolution kernel using data with low correlation to the to-be reconstructed signal will result in higher noise level. If there is motion, the data used in different convolution kernels may be contaminated in different levels. Hence, different kernels probably lead to different artifact levels, as shown in ref [3]. Therefore, ideally, data which are both motion free and strongly correlated with the to-be reconstructed data should be used in the convolution kernel to generate the synthetic k-space with both high signal-to-noise ratio (SNR) and low artifact level. However, one could not know the locations of motion-corrupted data before convolution. Alternatively, our work proposes to select a couple of kernels, and average the synthetic k-spaces. In our work, full *k*-space is acquired using turbo spin echo (TSE) sequence with multiple echo trains. Error caused by motions is probably similar among data from the same excitation but incoherent between two acquisition segments. Figure 1 shows kernel design in conventional multiple averages and one possible example in GRAMA. GRAMA selects *k*-space lines from different subsets possessing incoherent motion artifacts and strong correlation with target data point. Original *k*-space is not introduced into the average process for final result since it might contain severe errors due to motions.

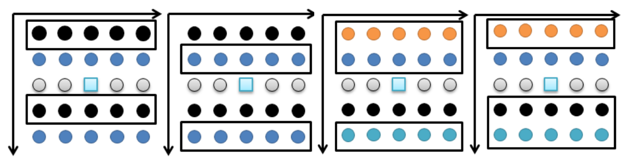

Figure 1: Left two are kernel design in conventional multiple averages. Right two are GRAMA kernel. X-axis is frequency encoding direction, Y-axis is phase encoding direction. Colors indicate the different subsets. Data points in the black box are used to generate a copy of the central signal in rectangle shape.

To validate the advantage of GRAMA, two sets of shoulder images with breathing motion artifacts were acquired with certain TSE sequence on a 3.0T Philips Achieva scanner (Philips, Best, The Netherlands) using a four-channel shoulder coil. Two sets of carotid images with swallowing motion artifacts were acquired on the same system using an eight-channel neck coil. Conventional multiple averages and GRAMA were applied to the motion-corrupted *k*-space respectively. Motion artifacts will generally increase image entropy. Hence entropy can be used to provide a quantitative measure of image quality change [5].

Results:

Figs 2 and 3 compare GRAMA to conventional multiple averages. Entropy of the carotid image sets are 20.30, 19.93 and 19.00. Entropy of the shoulder image sets are 23.20, 22.21, 23.31. The abnormal entropy increase might result from original high noise level in the background. Both GRAMA and conventional method were able to significantly reduce motion artifacts in carotid images. As arrows in figure 2 indicates, GRAMA results in fewer residual artifacts and higher SNR than conventional multiple averages. In shoulder images, conventional method was not successful with breathing motion artifact reduction while GRAMA effectively reconstructed images with low artifact level as arrows in figure 3 shows.

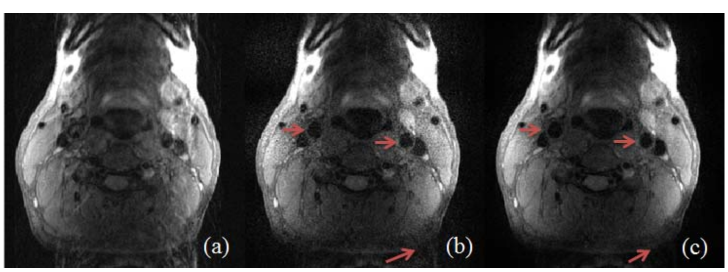

Figure 2. Reconstructed carotid image obtained with (a) swallowing motion polluted *k*-space (b) conventional multiple averages and (c) GRAMA.

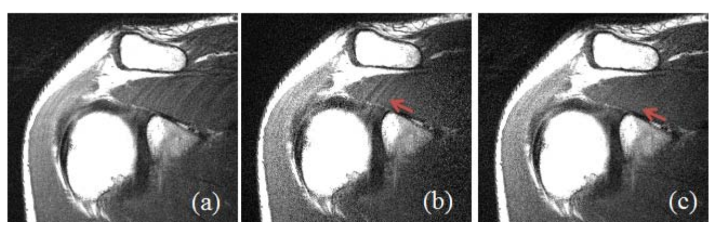

Figure 3. Comparison in (a) original breathing motion corrupted image (b) image obtained with conventional multiple averages and (c) image obtained with GRAMA. Images are zoomed in and brightened for better visibility.

Discussion and conclusion:

This work shows that the kernel design is the essential factor to determine the performance of motion compensation approaches using convolution. The proposed new retrospective method (GRAMA) effectively balances the SNR preservation and the artifacts reduction. Volunteer experiments showed its advantages over conventional multiple averages.

References:

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[4] Griswold, M. A., et. al. MRM 2002;47:1202-1210 [5] McGee, K. P., et. al. JMRI 2000; 11:174–181