Anisotropic Kernel Support for Improved Fast GRAPPA Imaging

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INTRODUCTION In parallel MR k-space reconstruction, a missing datum can be synthesized from selected sampled data points. The selection of the sampled data points or so called kernel is of vital importance to the success of k-space reconstruction algorithms like GRAPPA and PARS [1, 2]. Very commonly, a symmetric kernel is used. Although some recent studies proposed kernels based on error minimization [3, 4], the kernel shape has not yet been justified and studied systematically. Due to the image formation process, we believe most MR k-space signals have an anisotropic pattern. Thus, based on the theory of spatial analysis [5], a kernel with signal-dependent anisotropic shape is preferred for an ideal k-space reconstruction. In this paper, we propose a method to extract k-space signals anisotropy and use it for GRAPPA kernel design. A perceptual difference model (Case-PDM) [6] was used to quantitatively evaluate image quality. Experiments were on both in vivo and phantom data with high acceleration factors.

THEORY AND METHODS The k-space data is obtained from the convolution of the imaged object and coil sensitivity. Anisotropy in the frequency domain is due to the existence of oriented coil sensitivities or anatomical structures in the spatial domain. From spatial analysis theory [5], an anisotropic shape kernel should be used to detect an anisotropic spatial pattern. To better reflect the relationship between the missing signals and sampled signals, a kernel with a specific anisotropic shape should be considered. We refer to k-space anisotropy as the pattern of high power signals in the low frequency region of k-space. The simplest way to construct an anisotropic shape kernel is to threshold the signal magnitudes of ACS, and use pixels having magnitudes higher than the threshold that cover the every other AF lines as the kernel elements. However, signal magnitudes fluctuate across k-space making the kernel full of holes. Thus, instead of thresholding the ACS magnitudes, we fit a bivariate Gaussian function to the magnitudes to capture the anisotropic pattern and threshold this function to get the kernel elements. This bivariate function can model the spread of high power signals along the PE and FE directions. Preliminary findings suggest that this simplified modeling of anisotropy is sufficient for quality reconstruction. The size of the anisotropic kernel is defined by the number of its elements. Our algorithm was tested on 5 MR raw data sets with different anatomical structures (2 brain images, 2 cardiac images and 1 phantom image) and different kernel size, acceleration factor (AF) and ACS size.

RESULTS To demonstrate the robustness of our algorithm, all MR images were reconstructed without ACS integration into final reconstructions. A fixed kernel size of 30 elements was used in the study. Experimental results showed that GRAPPA with anisotropic kernel gave reconstruction with comparable image quality at low AF and significantly better image quality at high AF than one with a rectangular kernel (6×5 elements). Both PDM score and visual inspection in all head-to-head comparisons amongst all test images confirmed findings, with examples shown in the figure. The plot in Figure a shows improvement with reduction factor of 6 or greater. A reconstruction error in k-space analysis shows that GRAPPA with anisotropic kernel generally reconstructs signals with less residual than GRAPPA with rectangular kernel as demonstrated in Figure g.

CONCLUSION Our method can significantly improve image quality of GRAPPA reconstruction, especially at high AF. This is because k-space data are very often anisotropic, and the missing and sampled signals relationship can be captured better with an anisotropic kernel. Computational complexity of our method is comparable to the original algorithm. As the implementation only affects the kernel shape, any regularization methods [7] and robust regression [8] can be incorporated into the algorithm to give further improvement.

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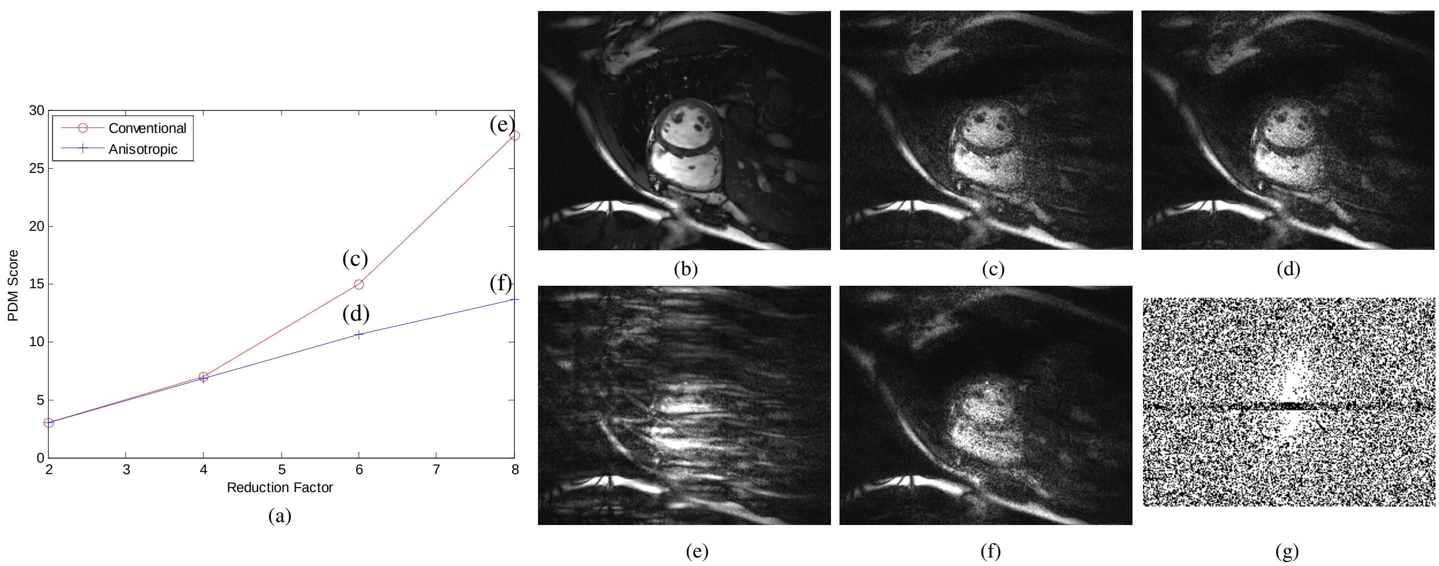

Figure Compared to GRAPPA reconstruction with rectangular kernel, anisotropic kernel obviously improves the reconstructed image quality and outperforms the rectangular counterpart at high acceleration factor (AF), as indicated by PDM scores in plot (a). (b) is a reference image from 8-channel full sampled data. (c) and (e) are images reconstructed by GRAPPA with rectangular kernel at AF of 6 and 8, respectively. And (d) and (f) are the corresponding images reconstructed with anisotropic kernel. Visually, image quality improvement by the anisotropic kernel is obvious. A reconstruction error analysis suggests that GRAPPA with anisotropic kernel generally reconstructs signals with less residual than with rectangular kernel, as demonstrated in a binary map (g) showing a white pixel if absolute residual value of the reconstruction with anisotropic kernel in one channel is lower. There are more than 60% pixels in the map are white with majority at low frequency region where most of the spatial structural information is encoded.