Wavelet-space Parallel Imaging for Fast MRI

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Target Audience: Researchers in the field of parallel imaging and image reconstruction.

Purpose: To develop a new parallel imaging technique that performs image reconstruction in wavelet space.

Introduction: Parallel imaging techniques typically perform image reconstruction in image-space (e.g. SENSE [1]) or k-space (e.g. GRAPPA [2]). They generate aliasing-free images directly from undersampled data. This work introduces a novel parallel imaging technique that performs image reconstruction in wavelet space. Since wavelet space is undersampled, aliasing exists in reconstructed images. However, if this aliasing is well controlled, inverse wavelet transform may be used to produce aliasing-free images. Compared with conventional image- or k-space reconstruction, wavelet-space reconstruction provides better performance for aliasing suppression and noise control in imaging acceleration.

Methods: By wavelet transform[3], multi-channel k-space data may be decomposed into multi-scale and multi-channel wavelet coefficients. Due to down-sampling in wavelet decomposition, images generated from wavelet coefficients have aliasing. In inverse wavelet transform, wavelet coefficients are zero padded and then filtered using a set of wavelet reconstruction filters. This can regenerate the original k-space data without loss. In the presented work, parallel imaging is used to reconstruct wavelet coefficients from collected partial k-space imaging data. Figure 1 shows the flowchart of wavelet-space parallel imaging. Its primary differences from image-/k-space approaches are the introduction of wavelet transform in parallel imaging calibration and inverse wavelet transform after parallel imaging reconstruction. It should be noted that wavelet transform generates a total of 2^L (L is the level of wavelet transform) sets of undersampled wavelet-space data that require 2^L parallel imaging operators for reconstruction.

To prove the concept, a head imaging experiment was conducted using a 32-channel coil array and a 3T clinical MRI scanner. Multi-slice 2D data were collected using a T_1-weighted spoiled gradient echo sequence (FOV 232×232 mm, matrix 232×232, TR/TE 135/4 ms, flip angle 30°). Partial k-space data were generated in offline reconstruction. A total of 24 center phase encoding lines were used as calibration data. SENSE and GRAPPA were used as standard image- and k-space approaches for comparison.

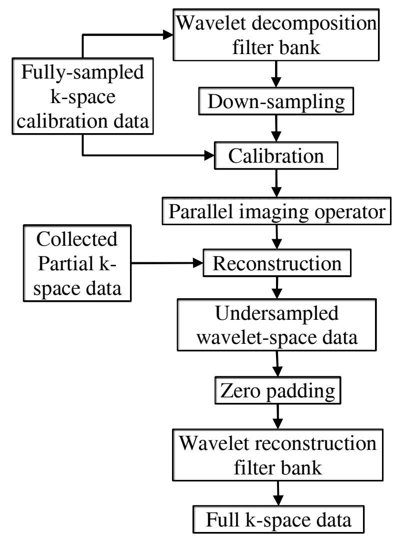

***Figure 1**. Flow chart of wavelet-space parallel imaging.*

Results: Figure 2 shows reconstruction results. Aliasing can be seen in wavelet-space images generated from wavelet transform of the fully sampled k-space data (Figure 2b), and reconstructed from partial k-space data (Figures 2c). We found that wavelet-space aliasing may show different patterns if we use different wavelets or perform wavelet transform of different levels. Using a Haar wavelet[3] and a wavelet transform level of 3, we compared wavelet-space reconstruction with SENSE and GRAPPA. In this experiment (Figures 2e and 2d), it was found that wavelet-space parallel imaging gives lower aliasing and noise than SENSE and GRAPPA in imaging acceleration.

Discussion: Wavelet transform of k-space data contains image information primarily from an image-space region smaller than the FOV. Since aliasing and noise amplification is spatially different in image space, a wavelet-space parallel imaging operator may be optimized for a part of the FOV, providing improved image reconstruction than conventional k- or image-space reconstruction optimized for the entire FOV. However, this approach requires the calibration of 2^L parallel imaging operators, implying the computation cost is higher. Mathematically, wavelet-space parallel imaging operators are equal to the wavelet transform of a k-space reconstruction operator (e.g. GRAPPA weights). This allows for the use of fast algorithms based on polyphase wavelet transform[4] to reduce computation cost.

Conclusions: The new wavelet-space parallel imaging technique improves imaging acceleration with a certain computation cost.

Reference: 1. Prussmann KP, et al., MRM 1999, 42: 952-962. 2. Griswold MA, et al., MRM 2002, 47:1202-1210. 3. Mallat, S, A Wavelet Tour of Singal Processing, Academic Press 2008. 4. Akansu AN, et al., IEEE Trans. On Signal Processing 1992; SP-40.

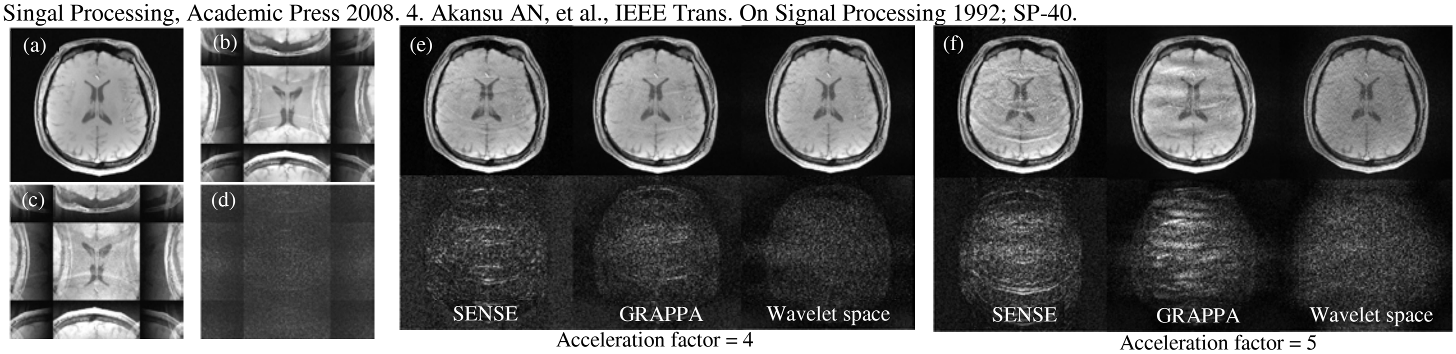

***Figure 2**. (a) A real image for reference. (b)An image generated from wavelet transform of fully sampled k-space data. (c) A wavelet-space image reconstructed from partial k-space data with an acceleration factor of 2. (d) Wavelet-space reconstruction error map: difference image between (b) and (c). (e)&(f) Comparison of SENSE, GRAPPA and wavelet-space reconstruction with acceleration factors of 4 and 5. The top row gives images generated from inverse wavelet transform. The bottom row gives error maps (difference images between the top row images and the real image a). Wavelet-space reconstruction gives lower aliasing and noise.*