Dyadic Wavelet-Based Image Noise Suppression and Enhancement in High-Speed Cardiac MR Parallel Acquisition

Q. Duan1, J. Chen1, A. F. Laine1, and V. M. Pai2

1Biomedical Engineering, Columbia University, New York, NY, United States; 2Radiology, SUNY Upstate Medical University, Syracuse, NY, United States

Introduction

Parallel imaging techniques have become important tools in improving acquisition speeds for cardiac MRI data. However, parallel acquisitions involve well-known tradeoffs between a acceleration and signal-to-noise ratio (SNR) in the reconstructed images due to the physics of acquisition. For a given field-of-view, increasing the parallel imaging rate in general will lead to a corresponding deterioration in signal quality; the faster the acquisition is, the poorer are the resultant images. Image denoising techniques when used as a post-processing step to a parallel-imaging acquisition may provide a means to push the existing limits of temporal resolution of the cardiac cycle while maintaining image quality for high-speed acquisition protocols. Previously, we have developed a wavelet-based denoising technique [1] in improving the SNR of cardiac imaging during such fast acquisition. In this work, the method was extended to combining image denoising and image enhancement.

Method

The proposed method was based on overcomplete 3D dyadic wavelet expansions. A 3D discrete dyadic wavelet transform of M level analysis can be represented as a set of wavelet coefficients:

\[
\{ S_{m,n}(n_1,n_2,n_3), \{ W_{m}^{s}(n_1,n_2,n_3), W_{m}^{d}(n_1,n_2,n_3) \} \}_{k=1,2,3} \text{ and } m=1,...,M \}
\]

where \( W_{m}^{s}(n_1,n_2,n_3) < s \), \( s \geq M \), and \( m=1,...,M \). The wavelet bases were dilated and translated from wavelet functions:

\[
\psi_{m,n}^{k}(x,y,z) = \frac{1}{2^{m-1}} \psi \left( \frac{x-n_1}{2^{m}}, \frac{y-n_2}{2^{m}}, \frac{z-n_3}{2^{m}} \right), k=1,2,3
\]

The processed image \( X_{ew} \) was derived by \( X_{ew} = \sum_{m,n} \rho_{m,n}(X \psi_{m,n}) \psi_{m,n} \), where X was the original image acquired by parallel acquisition, and \( \rho_{m,n} \) was an adaptive mapping function. By properly choosing \( \rho_{m,n} \), noise components can be attenuated or decreasing some coefficient sets in the transform domain while the true signal coefficients can be preserved or enhanced. In our previous application, a soft-thresholding scheme as shown in Fig. 1a was applied to suppress the noise component. In this work, to add signal enhancement feature in addition to the denoising feature, a piecewise linear \( \rho_{m,n} \) as shown in Fig. 1b was adopted. By tuning the turning points and slopes of different segments of \( \rho_{m,n} \), image denoising and image enhancement can be seamlessly integrated into one step without any additional computational cost. The algorithm was preliminarily implemented in Matlab© (Natick, MA). For phantom studies, the ACR MR phantom was imaged using a Siemens Avanto 1.5T MR scanner. Both parallel imaging rates (or acceleration factors, R), A balanced-SENSE imaging data confirmed the benefit of this new method in terms of improving CNR on parallel MR images. Preliminary results suggested that this new integrated denoising/enhancing framework could further push the limits on the temporal resolution by improving the SNR and CNR simultaneously.

Conclusions

An automated integrated denoising/enhancing approach was applied to images acquired by parallel acquisition techniques in cardiac imaging. In comparison with previous denoising only framework, this new proposed method could future increase the CNR of the denoised images. Quantitative evaluation on phantom and clinical data confirmed the benefit of this new method in terms of improving CNR on parallel MR images. Preliminary results suggested that this new integrated denoising/enhancing framework could further push the limits on the temporal resolution by improving the SNR and CNR simultaneously.

References