Rapid Reference-Free Noise Reduction for Parallel MR Images Using a Principal Component Technique in Combination with Adaptive Dyadic Wavelet-Based Denoising

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Introduction

Parallel imaging techniques have become important tools for improving MR acquisition speed. However, parallel acquisitions involve well-known tradeoffs between acceleration and signal-to-noise ratio (SNR). Recently, a principal component technique [1] was proposed to reduce g-factor related noise for highly accelerated scans with the aid of a separately acquired reference image. We propose a method that can adaptively generate a reference image directly from the original accelerated scan. This approach is based on the adaptive dyadic wavelet denoising technique.

Method

In Cartesian SENSE image reconstructions, unaliased pixels can be represented by a complex vector $\left|\mathbf{X}\right\rangle = \left|\mathbf{X}'\right\rangle + \left|\mathbf{dX}\right\rangle$ with true pixel intensity $\left|\mathbf{X}'\right\rangle$ and noise contribution $\left|\mathbf{dX}\right\rangle$. The noise component can be approximated by $\left|\mathbf{dX}\right\rangle = \left|\mathbf{v_1}\right\rangle s_1^{-1}\delta S_1$, where $\left|\mathbf{v_1}\right\rangle$ is the dominant column of matrix **V** in the singular value decomposition (SVD) of the coil encoding matrix **C=USV**$^+$, and s_1 is the dominant singular value. In an original proposal by Larkman et al [2], the unknown multiplier δS_1 was determined using an iterative search designed to minimize joint entropy between the reconstructed image and a separately acquired reference image with lower noise level, either with similar or with different contrast. In our subsequent implementation [1], δS_1 was estimated rapidly and directly from a difference image: $\left|\mathbf{dX}\right\rangle = \left|\mathbf{v_1}\right\rangle s_1^{-1}\delta S_1 \approx \left|\mathbf{X}\right\rangle - \left|\mathbf{X}_{ref}\right\rangle$ where $\left|\mathbf{X}_{ref}\right\rangle$ represents the separately-acquired reference image. In this work, the reference image $\left|\mathbf{X}_{ref}\right\rangle$ was directly derived from the original accelerated scan, using an adaptive dyadic wavelet method [3]. A 3D discrete dyadic wavelet transform of M level analysis can be represented as a set of wavelet coefficients: $\left\{S_M s(n_1,n_2,n_3), \left\{W_M^1 s(n_1,n_2,n_3), W_M^2 s(n_1,n_2,n_3), W_M^3 s(n_1,n_2,n_3)\right\}\right\}$, where $W_M^1 s(n_1,n_2,n_3) = < s, \psi^k_{m,n_1,n_2,n_3} >, k=1,2,3$ and $m=1,\cdots,M$. The wavelet bases were dilated and translated from wavelet functions: $\psi^k_{m,n_1,n_2,n_3}(x,y,z) = \frac{1}{2^{3m/2}}\psi^k\left(\frac{x-n_1}{2^m},\frac{y-n_2}{2^m},\frac{z-n_3}{2^m}\right), k=1,2,3$. The reference image was derived by $\left|\mathbf{X_{ref}}\right\rangle = \sum_{m=0}^{N-1}\rho_m\left(\left\langle \mathbf{X},\psi_m\right\rangle\right)\psi_m$, where ρ_m was an adaptive thresholding function that aims at eliminating noise components by attenuating or decreasing some coefficient sets in the transform domain while preserving the true signal coefficients. The method was tested on an image of an ACR MR phantom, a T1-weighted brain image, and a TrueFISP cardiac image obtained with a four-element array.

Results

Fig. 1a shows a SENSE-reconstructed T1-weighted image with an acceleration factor of 4. Fig. 1b is the noise-reduced image obtained with the principal component technique from [1] using an unaccelerated T2-weighted image as the reference. Fig.1c shows the corresponding results using the wavelet-derived reference image. For comparison, a corresponding unaccelerated image is shown in Fig.1d. Compared to Fig. 1b, Fig. 1c allows improved visualization of anatomical details by utilizing a reference image directly derived from the original image. Fig.2a shows a SENSE-reconstructed four-fold accelerated image of an ACR phantom. The small resolution elements in the phantom are not distinguishable due to the high noise level. On the noise reduced image using the wavelet reference (Fig. 2b), three columns of holes are visible in the image. Signal-to-Noise Ratios (SNR) were measured on the homogeneous region in the phantom images, which yielded a more than 60% increase in SNR for the image denoised with the proposed method in comparison to the 4x SENSE image. Fig. 3a shows a 4-fold accelerated cardiac image in which amplified noise obscures the delineation between endocardium and epicardium. Using our method, the noise level was significantly reduced and the image quality was improved.

Conclusions

The principal component technique offers a rapid approach to noise reduction in parallel MR images using information about the coil sensitivity encoding process. However, this method has in the past required an unaccelerated reference image. We have demonstrated a method based on dyadic wavelet expansion to adaptively derive the reference image from the accelerated one, thereby increasing ease of use. The new method also yielded sharper and more detailed image structures after noise reduction. Overall, the approach is a promising candidate for adaptive and rapid noise reduction in highly accelerated images.

References

[1] A. Patel, et al, ISMRM 2007, p980. [2] D. Larkman, et al, MRM 2006; 55:153–160. [3] Q. Duan, *et al*, ISMRM 2007.

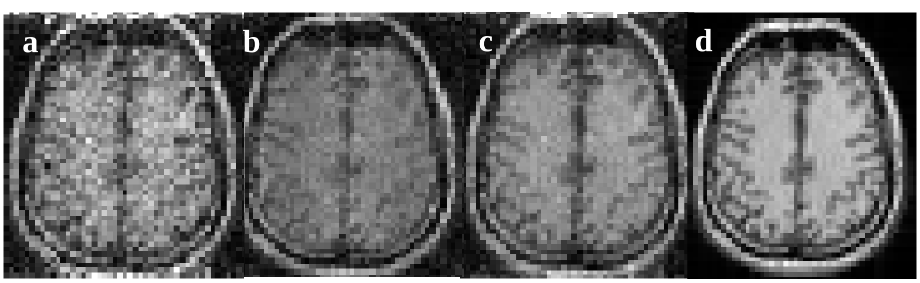

Fig.1: Brain image: (a) 4x SENSE reconstruction; (b) noise reduction in [1] using a T2 weighted reference image; (c) using the wavelet-derived reference image. (d) unaccelerated image.

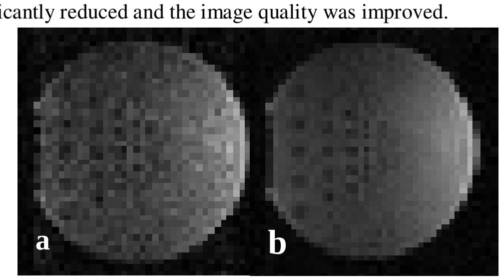

Fig. 2: ACR Phantom images: (a) 4x SENSE reconstruction; (b) noise reduction using wavelet reference.

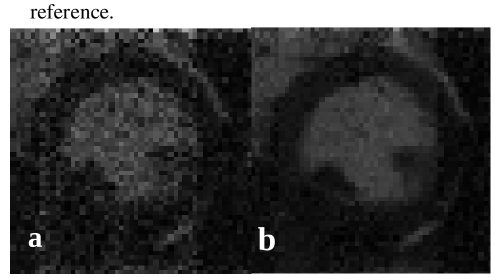

Fig. 3: Short-axis cardiac TrueFISP images: (a) 4x SENSE reconstruction; (b) noise reduction using wavelet reference.