MRI Noise Reduction via Phase Correction and Wavelet-Domain Filtering

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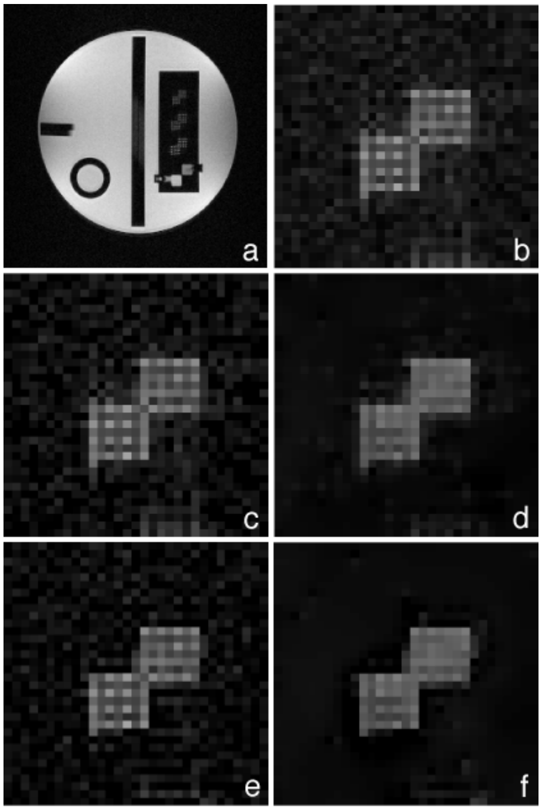

Figure 1. Images produced by post-processing MSSE slice.

Abstract

Post-acquisition processing of MRI images to remove noise can potentially improve their diagnostic value. Currently there are many suggested wavelet thresholding algorithms for denoising MRI data with most of them focused on magnitude-reconstructed images. An alternate approach is to correct phase errors in the image and then take the real value of each pixel as the grayscale intensity. We present a two-step technique, involving first performing phase correction and then wavelet filtering the real values to produce the final image. We compare the results of this two-step process to using just wavelet processing or just phase correction.

Introduction

MRI image pixels, $p(x,y)$, are complex-valued, being the summation of the medically significant signal, $s(x,y)$, and two samples, $n_r(x,y)$ and $n_i(x,y)$, 90° out of phase with each other, from a Gaussian noise process. Each pixel is also rotated by an unknown phase error, $\theta(x,y)$. This can be written as $p(x,y)=s(x,y)\exp(\mathrm{i}\theta(x,y))+n_r(x,y)+\mathrm{i}n_i(x,y)$. Normally the magnitude of each pixel is displayed as a grayscale image. Images constructed this way have Rician noise and thus a positive bias, particularly in low-signal areas [1]. An alternate approach is to estimate and then correct for the phase errors at each pixel. The real component of each pixel can then be displayed, discarding the contribution of the noise process aligned in the imaginary direction and improving feature detectability [2][3]. Images produced this way have Gaussian noise and thus avoid the bias of magnitude images.

It is commonly thought that phase error estimation is too computationally expensive or insufficiently robust to be practical [4]. Instead wavelet algorithms are proposed as a denoising solution, almost exclusively using one of two approaches. The first approach is to apply a wavelet filter targeting Gaussian noise separately on the real and imaginary components of the complex-valued image and then taking the magnitude of the result [5]. The alternate wavelet approach is to apply a wavelet filter for Rician noise to the image after the magnitude transform [4]. Although phase error estimation can sometimes be difficult, for many images there are practical approaches that can be applied efficiently [2][6][7]. Taking the phase corrected image is usually preferable to the magnitude image whenever a phase estimate can be produced. However, it may be valuable to further improve the phase-corrected image by applying wavelet filtering. We compare these approaches.

Methods

To evaluate the output of the different denoising algorithms, we processed images acquired on a 0.35 T Millennium Technology *Virgo* scanner as well as synthetic images. The first denoising approach we consider is the application of Nowak's Rician-targeted wavelet scheme to a magnitude image [4]. Second, we applied the Gaussian-targeted algorithm of Bao and Zhang to the real and imaginary components of the source image separately and then took the magnitude of the result [5]. Third, we evaluated the real component of an image phase-corrected using the algorithm in [7]. The final approach we considered applied the Gaussian-targeted wavelet thresholding to our phase-corrected image's real component. Images were compared by their mean-to-standard-deviation ratio (MSR), signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), and a qualitative inspection.

Results

Our results from processing a phantom image acquired with multi-slice spin echo are shown in Fig. 1 (labels in Table 1). The raw image is not particularly noisy but was chosen instead because it has small structures. In order to highlight the differences between the processes' output, we have blown up the region at the top right of the slice that includes the fine details of the phantom. We also reduced the window height by 50% in order to highlight the noise. The quantitative results are summarized in Table 1, showing phase correction with wavelet processing as the best of the group. Qualitatively, we find that the wavelet schemes can overly smooth and highlight false edges or artifacts in the signal. By performing phase correction first we reduce these false signals and thus improve the results of wavelet processing, as shown in Fig. 1 f. The over-smoothing of fine details does not seem to be affected.

Table 1. Results for phantom images shown in Figure 1

	a,b. Raw (magnitude)	c. Wavelet after magnitude	d. Magnitude after wavelet	e. Phase-corrected real	f. Wavelet after phase-corrected real.
MSR	24.44	24.55	29.08	24.44	31.66
CNR	38.01	41.92	41.02	39.25	44.50
SNR	47.81	44.59	281.20	49.29	291.61

Conclusions

We have confirmed that phase-corrected real reconstructions are preferable to magnitude reconstructions. When have also found that when processing with wavelets is performed the phase-corrected real image provides better input, reducing false noise structures and improving images both qualitative and quantitatively. Further work is needed to clarify what wavelet schemes are best suited to the resulting Gaussian-noised MRI images and to clarify when phase correction is practical.

References

[1] H. Gudbjartsson and S. Patz, "The Rician distribution of noisy MRI data," *Magnetic Resonance in Medicine*, vol. 34, pp. 910-914, 1995
[2] D. Noll, D. Nishimura, and A. Macovski, "Homodyne detection in magnetic resonance imaging," *IEEE Trans. on Medical Imaging*, vol. 10, pp. 154-163, 1991
[3] M. A. Bernstein, D. M. Thomasson, and W.H. Perman, "Improved detectability in low signal-to-noise ratio magnetic resonance images by means of a phase-corrected real reconstruction," *Medical Physics*, vol. 16, pp. 813-817, September 1989
[4] R. D. Nowak "Wavelet-based Rician noise removal for magnetic resonance imaging," *IEEE Trans. on Image Processing*, vol. 8(10), pp. 1408-1418, October 1999
[5] P. Bao and L. Zhang, "Noise reduction for magnetic resonance images via adaptive multiscale products thresholding," *IEEE Trans. on Medical Imaging*, vol. 22(9), pp. 1089-1099, September 2003
[6] G. McGibney, M. R. Smith, and S. T. Nichols and A. Crawley, "Quantitative evaluation of several partial fourier reconstruction algorithms used in MRI," *Magnetic Resonance in Medicine*, vol. 30, pp. 51-59, 1993
[7] D. Tisdall and S. Atkins "MRI denoising via phase estimation," *Proceedings of SPIE Medical Imaging 2005*, in print

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