Wavelet-based denoising of images acquired with parallel-MRI techniques

I. Delakis^{1,2}, H. Omer^{1}, and R. I. Kitney^{1,2}
^{1}Department of Bioengineering, Imperial College London, London, London, United Kingdom, ^{2}MagNET, London, London, United Kingdom

INTRODUCTION

Minimising noise in images acquired with parallel-MRI is a topical issue because parallel-MRI with high speeding factors significantly reduces the image Signal-to-Noise Ratio (SNR) and parallel-MRI is becoming increasingly available on low-field MRI scanners, which have an intrinsically low SNR.

Weaver et al. (1991) first reported that wavelet-based denoising can be used to preferentially remove noise in MRI images while preserving edges and details. Xu et al. (1994) then proposed the spatially selective noise filtration (SSNF) technique, based on the spatial correlation of adjacent wavelet scales. More recent techniques are based on measuring noise in the image background and using statistics to denoise wavelet scales (Gregg and Nowak 1997, Nowak 1999, Pizurica et al. 2003 and Wu et al. 2003). Wavelet-based techniques have been proposed as a way of improving image quality in parallel-MRI by denoising coil sensitivity maps (Liang et al. 2002). Denoising techniques based on measuring noise in the image background cannot be applied on reconstructed parallel-MRI images, as noise cannot be measured accurately in the background due to its spatial variability and the presence of artefacts. The work described in this abstract presents a novel wavelet-based algorithm that produces a noise map for images. This map is then used in conjunction with the Threshold-Based Denoising (TBD) described by Donoho and Johnstone (1995) to denoise images acquired with parallel-MRI. The performance of the proposed methodology is compared with that of the SSNF technique.

METHODOLOGY

Images were acquired on a 0.35T Magnetom C! MRI scanner (Siemens Medical Solutions, Erlangen, Germany) with the standard head array coil. The sequence parameters were: plane=coronal, sequence=Turbo Spin Echo, turbo factor=1, bandwidth=75 Hz/px, TR=1000 ms, TE=30 ms, NSA=1, slice width=5 mm, Field Of View= 25cm×25cm, PE direction=FH. Both GRAPPA and mSENSE reconstructions were used with 35 reference lines and a speeding factor of 2. Images were acquired using seven different matrix sizes N×N with N=128, 192, 256, 320, 384, 448 and 512, keeping all other sequence parameters and experimental conditions constant. Each image was acquired twice for the SNR calculation.

The phantom scanned was cylindrical, filled with an aqueous solution of Copper Sulphate (0.7 g/l) and with Modulation Transfer Function (MTF) blocks inside. Images were analysed using MATLAB (The Mathworks Inc). The edges of the original image were first extracted with Sobel operators (Coifman and Donoho 1995). The image was then decomposed into its first-scale detail and approximation coefficients with Haar wavelet transform (Mallat 1999). The detail coefficients were inverse wavelet-transformed to construct a matrix containing only first-scale details, edges and noise. The standard deviation was calculated for each matrix element and its two adjacent elements in the horizontal direction. Zero-padding was used for matrix elements on the edges. This process was repeated for the vertical and diagonal directions. The lowest of the three directional standard deviation values for each matrix element was defined as the noise level in the corresponding pixel-position of the original image. Using the lowest standard deviation value ensured that noise described statistical signal variation and not the presence of fine edges and details. However, sharp edges were likely to result in higher values of standard deviation; therefore noise was zeroed at the locations of edges detected in the original image in order to minimize smoothing. The images were then denoised on the first wavelet scale using the soft-threshold TBD method (Donoho and Johnstone 1995) with the threshold value: $t=\sigma\sqrt{2}\ \ln(N\times N)$, where N is the image matrix size and σ the noise level calculated with our algorithm. The threshold was computed for each image pixel according to the noise level at the pixel location. Images were also denoised with the SSNF technique described by Xu et al. (1994) using the first three wavelet scales. Image resolution was measured in the original and denoised images using the MTF methodology (Judy 1976). The spatial frequency at 50% of the maximum value of the MTF curve was converted to spatial domain to give the effective pixel size. SNR was measured with the subtraction method (Dietrich et al. 2005).

RESULTS

Figure 1 presents the SNR for the original images and images denoised using the SSNF method proposed by Xu et al. (1994) and the TBD method based on the noise calculation algorithm presented in this abstract. Figure 2 presents the effective pixel size measured in the original and denoised images. Both figures present results from images reconstructed with GRAPPA. Results from images reconstructed with mSENSE showed similar patterns.

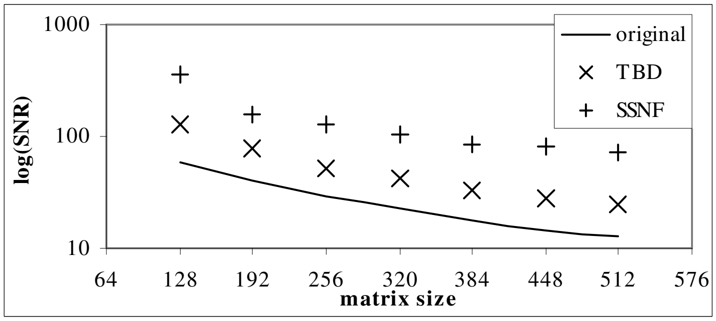

Figure 1: SNR for the original images and images denoised with the SSNF and TBD methods.

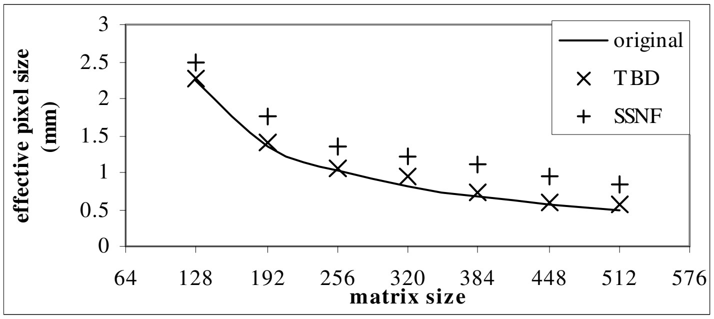

Figure 2: Effective pixel size measured with the MTF method on the original images and on images denoised with the SSNF and TBD methods.

CONCLUSIONS

The results show that the proposed algorithm can be successfully used when filtering images where noise is spatially dependent and cannot be derived from the image background, as is the case for images acquired with parallel-MRI. The proposed algorithm showed to double the SNR while effectively maintaining spatial resolution.

REFERENCES

Coifman, R. and Donoho D., 1995. *Wavelets and Statistics, Lecture Notes in Statistics*. Berlin, Germany: Springer-Verlag
Dietrich, O., Reeder, S.B., Reiser, M.F. and Schoenberg, S.O., 2005. In: *Proc. ISMRM 13th Scientific Meeting, Florida, USA*, No 158
Donoho, D.L and Johnstone, I.M., 1995. *J. Am. Statist. Ass.* **90**, pp.1200-1224
Gregg, R.L., and Nowak, R.D., 1997. In: *Proc. IEEE Nuclear Science Symposium, Albuquerque, NM, USA*, **2**, pp.1117-1121
Judy, P.F., 1976. *Medical Physics*, **3**(4), pp.233-236
Liang Z.P., Bammer R., Ji J., Pelc N.J. and Glover G.H. 2002. In: *Proc. ISMRM 10th Scientific Meeting, Hawai'I, USA*, No 2388
Mallat, S., 1999. 2nd ed. *A Wavelet Tour of Signal Processing*. London, UK: Academic Press
Nowak, R.D., 1999. *IEEE Trans. Image Processing*, **8**(10), pp.1408–1419
Pizurica, A., Philips, W., Lemahieu, I., and Acheroy, M., 2003. *IEEE Trans. Med. Imaging* **22**(3), pp.323-331
Weaver, J.B., Xu, Y., Healy, D. and Driscoll, J., 1991. *MRM*, **21**, pp.288-295
Wu, Z.Q., Ware, J.A., and Jiang, J., 2003. *Electronics Letters*, **39**(7), pp.603-604
Xu, Y., Weaver, J.B., Healy, Jr D.M. and Lu, J., 1994. *IEEE Trans. Image Processing*, **3**(6), pp.747-758