g-factor guided denoising for SENSE reconstructed MR images with edge restoration

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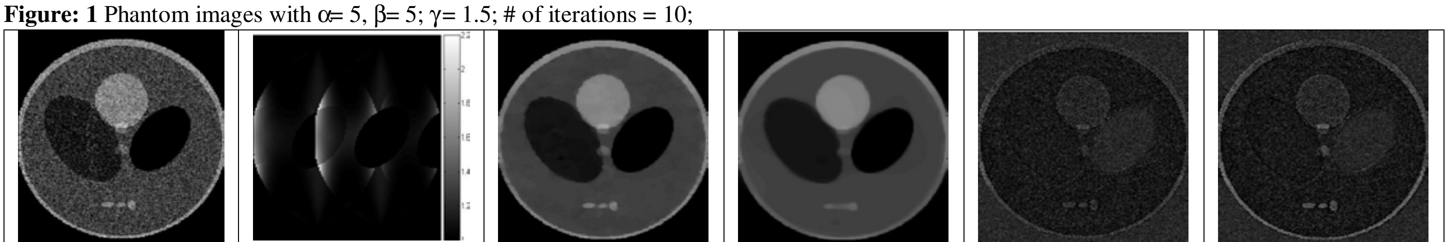
Introduction: The application of SENSE [1] technique to regular clinical images has brought about the benefit of significantly faster acquisitions but at the cost of amplified and non-uniform noise. Owing to the geometry factor (g-factor), there is a great amount of non-uniformity in the distribution of noise. Edges and noise are both high frequency information; low pass filters for denoising cannot distinguish between edges and noise. If the same filter is applied to regions with different noise levels, either the very noisy region is not smoothed enough or the less noisy region is smoothed too much and leads to a loss of edge information. Therefore, the design of filters should use different weights for smoothing different regions. Prior work has been done to smooth and protect the edges for images reconstructed by SENSE to some extent, with the use of noise correlations [2] or g-factor [3] in the design of the filters. In this work, we apply a g-factor guided total variation filtering technique to denoise the images and add back the removed information (which includes both noise and edge information) weighted by g-factor to strike a balance between the smoothing and the edge preservation, thereby leveling the noise distribution while protecting edges.

Methods: The total variation filtering technique makes use of a parameter λ which is a function of the g-factor, to smooth the image appropriately, and the edge recovery also uses g-factor weighting, as follows:

$$u_{lpf} = \arg\min |\int \lambda |u-u_0|^2 + \int |\nabla u|| \quad (1) \qquad \lambda = \alpha/(1+\beta * g) \quad (2) \qquad E = (u_0 - u_{lpf})/(\gamma * g) \quad (3) \qquad u_{out} = u_{lpf} + E \quad (4)$$

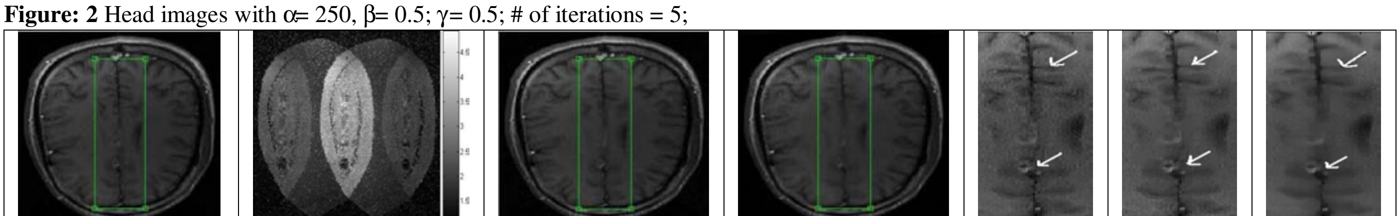
The process may be repeated several times. The anisotropic smoothing method - total variation model [4], is chosen to protect the edge information. The g-factor weighted parameter λ makes sure the image is smoothed based on its noise level. The difference between the original image and the smoothed image contains both noise and edge information, the level of noise, guided by g-factor. Hence Eq. 3 is used to guarantee that less noise but as much as possible edge is added back. It should be noted that the values of α, β, γ affect the extent to which the image is smoothed. For greater smoothing, α needs to be smaller and β needs to be bigger. The edge information is governed by γ. In this work, we performed 5 and 10 iterations with a set of chosen α, β and γ values, to give noticeably better results with significantly better edge information. The new technique was applied to simulated phantom images first whose results are shown in Figure 1. Note that all images compared (a), (c), (d), (e) and (f) are set to the same levels of intensity and that the same values of α, β were used for the smoothing with and without edge restoration. It was then applied to real data acquired using an 8-channel head coil (Invivo Diagnostic Imaging, Gainesville, FL). Full k-space data was acquired and pseudo partial k-space with reduction factor 4 was simulated as shown in Figure 2. Here, the images in (a), (c) and (d) are all set to the same intensity levels. The arrows in (e) depict regions in the image where there is significant loss of edge information if the new technique was not used.

Figure: 1 Phantom images with α= 5, β= 5; γ= 1.5; # of iterations = 10;



(a) Original SENSE reconstructed image	(b) G-factor map R = 3	(c) Image denoised with g-factor guided filtering with edge preservation	(d) Image denoised with only g-factor guided filtering	(e) Difference between (c) and original noisy image	(f) Difference between (d) and original noisy image

Figure: 2 Head images with α= 250, β= 0.5; γ= 0.5; # of iterations = 5;



(a) Original SENSE reconstructed image	(b) G-factor map R = 4	(c) Image denoised with g-factor guided filtering with edge preservation	(d) Image denoised with only g-factor guided filtering	(e) Zoomed versions of (a), (c), (d) show better edges & low noise from new technique

Results and Discussion: As seen from Figures 1 and 2, the proposed method can efficiently denoise images with a good restoration of edge information. There is more edge information in the images processed by the new technique than in the simply g-factor weighted filtered image. Further work is being performed to optimize the choice of parameters and to determine an efficient termination criterion like the standard deviation of noise or maximum energy constraint.

References: [1] Pruessmann K.P, et al. MRM 42:952-962 (1999). [2] Samsonov A.A. et al, Proc. 10th Annual Meeting of ISMRM, 2002, p74. [3] Tsao J. et al, Proc. of 11th Annual Meeting of ISMRM, 2003, p780. [4] Osher S. et al., CAM-Report 04-13 UCLA, 2004.