

Unbiased Nonlinear Filtering of Fast Spin Echo MRI Images

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Introduction: The design of filtering methods for denoising the magnitude MRI images is traditionally fulfilled assuming that that image noise is zero-mean Gaussian, as Rician properties of magnitude MRI image noise usually complicates a method both algorithmically and computationally [1]. This widely used assumption leads to the biased filtering results, the bias increases as local signal-to-noise ratio (SNR) decreases. This systematic error might present a serious problem in studies where contrast-to-noise ratio (CNR) in low SNR areas is essential (i.e. black-blood angiography), or in quantitative evaluations of T1/T2 maps. In this paper, we present a novel scheme for unbiased denoising of fast spin echo (FSE) images and its application to black-blood angiography images. Our method uses phase smoothness property of the spin-echo MRI images for unbiased image filtering. The new method is based on an anisotropic diffusing filter [2] and retains all its attractive properties such as edge-preserving denoising, simplicity, and computational efficiency.

Theory: One way to avoid the biasing in magnitude of the complex MRI image is to accomplish the filtering on real and imaginary parts of a complex MRI image to eliminate zero-mean Gaussian noise in each channel separately. However, anisotropic diffusion filter assumes the underlying image to be piecewise constant or piecewise slowly varying. Real and imaginary parts of MRI image generally significantly deviate from the model due to the complex behavior of the image phase. In case of spin-echo data acquisition sequences, the phase is described by slowly varying function. As a consequence, both real and imaginary parts of the complex spin-echo MRI images are well described by a piecewise slowly varying model and could be used for spatial averaging with limited number of iterations separately. At the same time, the flow-stopping image gradients are derived from the image magnitude part. The method is multivariate formulation of anisotropic diffusion filtering. In Algorithm, N is a number of images of different contrast available from a given scan, g is monotonically decreasing diffusivity function, k is a conductance parameter that sets a threshold between image gradients considered as noise-generated and image gradients considered as generated by image structure edges, $\eta(m)$ is the discretization neighborhood of pixel m , and time step Δt establishes the diffusion rate. The scheme is a particular case of vector-valued diffusion [5].

Methods: The method validation was performed on phantom and patient brain datasets obtained on a 1.5T SIGNA scanner (GE, GE Medical Systems, Milwaukee, WI). Patient data were acquired with a head coil using 3D FSE protocol for black-blood imaging ($T_R=1600$, $T_E=13$, $Rbw=31.5$ kHz, $ETL=12$, matrix 384-by-256). In filtering experiments, the conductance parameter was taken as $2\sigma_{noise}$ where σ_{noise} is image noise standard deviation found from air background area. The time step Δt was set equal to 0.25.

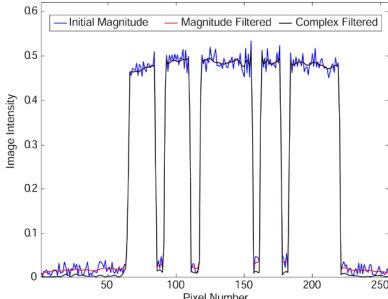
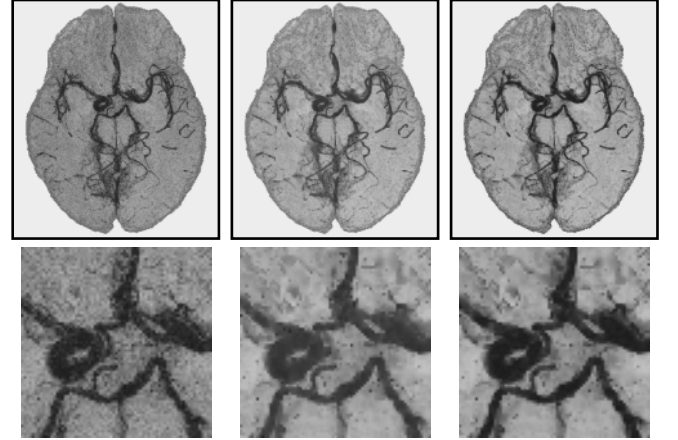


Figure 1. Sample profiles of initial, magnitude filtered and complex filtered phantom images (25 iterations). Note the difference in the profiles in zero-signal areas where the bias is high.

Figure 2. Top row: Minimum Intensity Projection image of black-blood brain images for stack of nonfiltered images, filtered magnitude images, and filtered complex images with the proposed method. Bottom row: Magnified parts of the images in the same order. The images are displayed in the same gray scale range. The noise in the first image pair impedes visual perception of vessels, while denoising the magnitude images decreases image noise but introduced intensity bias that significantly decreases vessel CNR. The final pair of images demonstrates significant improvement in vessel-tissue CNR.



Results: Figure 1 demonstrates results of filtering the phantom object image. Filtering on complex and magnitude images produces almost identical results in high SNR areas, where bias is small. This supports the idea that filtering could be safely done separately on both real and imaginary parts of the spin-echo image. However, the results differ drastically for low signal areas, where the bias is high. The bias for newly proposed method is significantly reduced. Figure 2 shows results of minimum intensity projection (MIP) on a stack of black-blood angiography images without and with different post processing. Application of the new filter results in significant increase of vessel CNR and leads to better vessel visibility.

Discussion: The developed nonlinear filtering method was able to produce unbiased denoising of both phantom and patient FSE images. The phase-smoothness property of such images ensures the model assumption for both real and imaginary image parts allowing their separate filtering. The further development may include filtering on the image derivatives that would further guarantee the model validity [4]. Application of the filter to other kinds of MRI images such as gradient-echo images may be problematic due to the complex behavior of image phase in such images. The method is expected to be particularly useful for filtering black-blood angiography images. The idea of separate filtering of real and complex channels in FSE images might be useful for developing other unbiased denoising approaches.

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