Enhancement of Signal-to-Noise Ratio in Magnetic Resonance Imaging Using Adaptive Template Filtering

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Purpose
Adaptive template filtering is proposed for an enhancement of signal-to-noise ratio in magnetic resonance imaging without degradation of resolution. The proposed algorithm is applied to high resolution MR images, MR angiograms, fast spin echo images obtained at 3T and 1T whole body MR systems. Performance of the proposed algorithm is compared to those of existing filtering methods.

Method
There have been several adaptive approaches to improve SNR without much degradation of resolution, e.g., adaptive filter based on the local statistics with 1-D and 2-D linear least square error algorithm (LLSE), 2-D adaptive recursive filter, and nonlinear anisotropic filters. Since these algorithms assume a fixed template or only a few templates according to mostly 4 directions, they have limitations in adapting to general complex edges.

The proposed algorithm defines multiple templates, and an optimally matched template is first selected. Then an optimal filtering is applied to the template selected. A total of 247 templates of sizes from 3 to 9 are constructed. Selection of the optimal template among the multiple templates at a given pixel is based on the local standard deviations (SD) of the pixel values on the templates. The threshold for classifying plain and edge templates may be defined as

\[ \tau = a \sigma_n \]  

where \( a \) is a scale factor for an adjustment and \( \sigma_n \) is the estimated (measured) noise standard deviation in the image. Selection procedures for the optimal template may be summarized as follows. (1) Calculate local standard deviations for all the templates. (2) Classify the templates into two categories: one is a set of templates having the standard deviations less than the threshold corresponding to plain template\( (S_p) \), and the other having the standard deviations larger than the threshold, corresponding to edge template\( (S_e) \). (3) If there is any element in \( S_p \), the optimal template is the one having the maximum standard deviation in \( S_p \), otherwise the optimal template is the one having the minimum standard deviation in \( S_e \). Once an optimal template is chosen, filter coefficients may be obtained using the two-dimensional adaptive linear least square error algorithm (LLSE) as

\[ y(k,l) = \frac{\sigma^2_y(k,l)x(k,l) + \sigma^2_x(k,l)}{\sigma^2_y(k,l) + \sigma^2_x} \]

where \( y(k,l) \) is the filtered output, \( \sigma^2_y(k,l) \) and \( \sigma^2_x \) are the local variance of the input image at \( (k,l) \) and the noise variance which is constant over the image, respectively. The noise standard deviation in the image may be estimated as 1.526 times the measured noise standard deviation in the background region.

Results
The proposed algorithm appears superior to existing algorithms in high resolution MR images, MR angiograms, and conventional head images obtained at 3.0 Tesla and 1.0 Tesla whole body MR systems. Application of the algorithms to MR angiogram is shown in Fig.1. Little filtering is done on small vessels containing high frequency components with the 2-D adaptive LLSE algorithm (b), edge blurring is observed with the adaptive recursive filter (c), no such image artifact is observed with the proposed algorithm (d).

Fig.1 Filtered images by various adaptive algorithms.