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A New Wavelet Denoising Method for Selecting Decomposition Levels and Noise Thresholds

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ABSTRACT A new method is presented to denoise 1-D experimental signals using wavelet transforms. Although the state-of-the-art wavelet denoising methods perform better than other denoising methods, they are not very effective for experimental signals. Unlike images and other signals, experimental signals in chemical and biophysical applications, for example, are less tolerant to signal distortion and under-denoising caused by the standard wavelet denoising methods. The new method: 1) provides a method to select the number of decomposition levels to denoise; 2) uses a new formula to calculate noise thresholds that does not require noise estimation; 3) uses separate noise thresholds for positive and negative wavelet coefficients; 4) applies denoising to the approximation component; and 5) allows the flexibility to adjust the noise thresholds. The new method is applied to continuous wave electron spin resonance spectra and it is found that it increases the signal-to-noise ratio (SNR) by more than 32 dB without distorting the signal, whereas standard denoising methods improve the SNR by less than 10 dB and with some distortion. In addition, its computation time is more than six times faster.

INDEX TERMS Wavelet transform, wavelet denoising, noise thresholding, noise reduction, magnetic resonance spectroscopy.

I. INTRODUCTION

Experimental signals are often difficult to study because weak signals have a low Signal-to-Noise Ratio (SNR). Based on the discrete wavelet transform (DWT), various wavelet denoising methods like wavelet shrinkage [1]–[16], wavelet coefficient modeling [17]–[20], and wavelet transform modulus maxima (WTMM) [21]–[23] denoising methods have been developed and shown to be more effective than filtering methods [24], [25].

Although denoising increases SNR, many experimentalists are skeptical of the denoised signal as they fear inadequate noise removal and/or unknown signal distortion. More importantly, the current wavelet-based denoising methods are not very reliable in accurately retrieving the signal components, especially for weak signals that have magnitude close to noise. Also, these methods try to eliminate random noise and are not tested against systematic (or coherent) noise generated by the instrument or (e.g. biological) sample. Another problem with current wavelet denoising methods is their practical implementation. They do not provide information regarding the choice of wavelets to use, the number of decomposition levels to denoise, nor do they have the flexibility to adjust the thresholds. A noisy signal clearly indicates its degree of uncertainty, whereas a denoised signal lacks such information. Therefore, to reduce noise, signal averaging [26] is widely used to improve experimental data. In this paper, experimental data from electron spin resonance (ESR) spectroscopy [27] is used, where signal averaging is currently the most reliable method to reduce noise. Although some signal denoising methods like filtering [28] and the traditional wavelet denoising [29] methods have been applied to ESR spectra [30], they have not yet yielded the desired results.

In this paper, a new wavelet denoising approach is presented which is based on wavelet shrinkage, that significantly improves denoising and provides clearer implementation compared to previous methods. It can be reliably used