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STATISTICAL VERSUS WAVELET-BASED DE-SPECKLING TECHNIQUES FOR ENHANCING MEDICAL ULTRASOUND IMAGES

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Keywords:.

Abstract. *This study performs a comparative evaluation of two statistical and three wavelet-based speckle suppression filters as means of improving the diagnostic potential of medical ultrasound images. Three sets of ultrasonic images (25 liver, 32 kidney, and 18 breast) were selected by connecting the video output of an HDI-3000 ATL digital ultrasound system to a Screen Machine II frame grabber, using 512×512×8 image resolution. Two statistical filters, the adaptive weighted median filter (AWMF) and adaptive speckle suppression filter (ASSF), and three wavelet thresholding speckle reduction filters, the soft wavelet thresholding (SWTF), the hard wavelet thresholding (HWTF) and the Garrote wavelet thresholding (GWTF) filters, were developed in C++. For speckle embedding, simulated images were degraded by Gaussian additive noise. The performance of each filter was assessed by means of mean square error (MSE) and signal-to-MSE, as well as by expert physician's evaluation. AWMF achieved the highest noise suppression and SWTF scored the highest signal-to-noise ratio. Furthermore, SWTF has been proved superior by the physician's blind-review evaluation, while at the same time required the minimum processing time, rendering its routine plausible for clinical application.*

1 INTRODUCTION

The Images obtained by ultrasound systems are significantly inferior compared to other medical imaging systems. The major drawback of this imaging technique is the speckle noise. Speckle is a form of multiplicative noise which degrades ultrasound images making visual observation quite difficult and limiting their diagnostic potential.

The purpose of the present study was to investigate the speckle suppression capabilities of two statistical and three wavelet based speckle suppression filters, while simultaneously edge discrimination is maintained.

2 MATERIALS AND METHODS

2.1 Statistical speckle suppression algorithms.

2.1.1 The Adaptive Weighted Median Filter (AWMF).

The AWMF algorithm was introduced by Loupas et al. [.] Using the information acquired by the local first order statistics (variance-to-mean ratio), it performs a spatially adaptive median filtering in a square kernel by means of adjusted pixel values. The pixels are adjusted using a centroid kernel that is calculated as a windowing function similar to the triangular window.

(equation for weight calculation)

The weighted window values are then used for typical median filtering, replacing the center window pixel value by the median value of the weighted area.

(figure: weighted median processing)

Optimal kernel size and coefficients were evaluated through iterative experiments, while W0 was proposed theoretically [.]. The final values calculated for the best AWMF are illustrated in Table 1.

Parameter	W0	g	Kernel Size
Value	*99*	*7.5*	*9x9*

Table 1: AWMF parameter values

2.1.2 The Adaptive Speckle Suppression Filter (ASSF).

This algorithm was developed by Karaman et al[.]. Similarly to the AWMF, the ASSF is also based on local first order statistics (stdev-to-mean ratio). It consists of three main steps: 1) Computation of local statistics on a window of fixed size for every pixel of the original image, 2) region growing procedure for grouping together pixels of similar statistics and 3) median smoothing filtering.

(equations)

All the required parameters for ASSF implementation were re-evaluated against previously suggested values for phantom and liver images [.], in order to achieve optimal results.

(figure: procedure)

The final values calculated for the best ASSF are illustrated in Table 2.

Parameter	a_0	a	b	c	Kernel Size	Kb	$\Delta\mu$
Value	*2.5*	*0.005*	*0.05*	*50*	*11x11*	*5*	*5*

Table 2: ASSF parameter values

2.2 Wavelet-based denoising.

The wavelet-based denoising algorithms have as prerequisite a wavelet-transformed version of the image. In this study, a three level Daubechies' 4 (DAUB4) Dyadic Wavelet Transform (DWT) [.] was implemented and performed on every US image. In the following stage, three different thresholding operations were applied to the wavelet coefficient sets of every level, analyzed in detail in the following sections. Thresholding, also known as "shrinkage", was used to modify the wavelet coefficients according to a shrinkage function. Finally, the de-noised image was obtained through the Inverse Dyadic Wavelet Transform (IDWT). The complete process is depicted in Figure 1.

2.2.1 The Hard Wavelet Thresholding Algorithm (HWTA).

In hard thresholding, the wavelet coefficients that are in absolute value smaller than a predefined threshold are replaced by zero, while all the other coefficients are left unchanged [.]. The shrinkage function and the thresholding procedure are presented in equation 5 and Figure 2 respectively.

$$W_{out}(W_{in}) = \begin{Bmatrix} 0 & \text{if } |W_{in}| \le \mathrm{T} \\ W_{in} & \text{if } |W_{in}| > \mathrm{T} \end{Bmatrix} \quad (5)$$

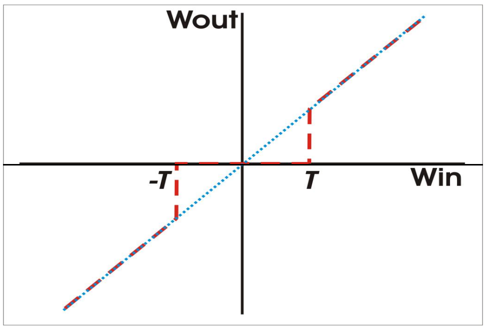

Figure 2: Hard wavelet thresholding.

Win denotes the input and Wout the output coefficient values of the detail wavelet coefficients matrix. For each wavelet decomposition level, a different threshold T has been evaluated in terms of optimal performance and speckle suppression in the resulting image.

2.2.2 The Soft Wavelet Thresholding Algorithm (SWTA).

In the SWTA procedure, the wavelet transform (DWT) coefficients where modified according to Donoho's method for soft thresholding [.].

$$W_{out}(W_{in}) = \begin{cases} 0 & \text{if } |W_{in}| \leq T \\ W_{in} - T & \text{if } W_{in} > T \\ W_{in} + T & \text{if } W_{in} < T \end{cases} \qquad (6)$$

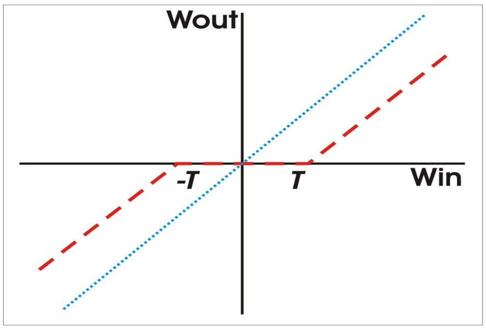

Figure 3: Soft wavelet thresholding

W_{in} denotes the input and W_{out} the output coefficient values of the detail wavelet coefficients matrix. Again, for each wavelet decomposition level, a different threshold T has been evaluated in terms of optimal performance and speckle suppression in the resulting image.

2.2.3 The Garrote Wavelet Thresholding Algorithm (GWTA).

In contrast to the two previous algorithms that use linear mapping transformations for the thresholding, the GWTA algorithm uses non-linear thresholding segments for values above and below the T value, according to the Garrote shrinkage function (7) [.].

$$W_{out}(W_{in}) = \begin{cases} 0 & \text{if } |W_{in}| \leq T \\ W_{in} - \dfrac{T^2}{W_{in}} & \text{if } |W_{in}| > T \end{cases} \qquad (7)$$

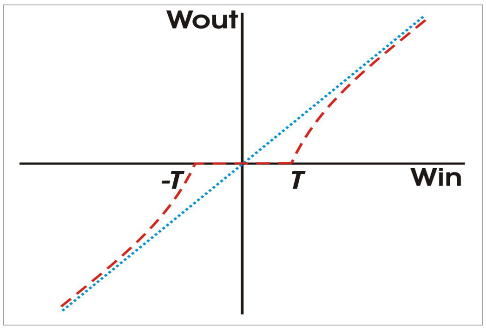

Figure 4: Garrote wavelet thresholding

W_{in} denotes the input and W_{out} the output coefficient values of the detail wavelet coefficients matrix. As before, for each wavelet decomposition level, a different threshold T has been evaluated in terms of optimal performance and speckle suppression in the resulting image.

2.3 Performance Evaluation.

In order to assess the performance achieved by each speckle suppression algorithm, mean-square-error (MSE) and Signal-to-MSE (S/MSE) were calculated for both the speckle-degraded and the restored images. These parameters are defined in equations (8) and (9), calculated over local region-of-interest (ROI) image windows:

$$MSE = \frac{1}{k}\sum_{i=1}^{k}(\overline{S_i} - S_i)^2 \tag{8}$$

$$\frac{S}{MSE} = 10 \times \log_{10}\left(\frac{\sum_{i=1}^{k} S_i^2}{\sum_{i=1}^{k}(\overline{S_i} - S_i)^2}\right) \tag{9}$$

where S is the original image, $\overline{S_i}$ is the despeckled image, and K is the total number of pixels within the current ROI window. The MSE value is a typical error measurement, while the S/MSE is used instead of the classical SNR value in the case of additive noise [.].

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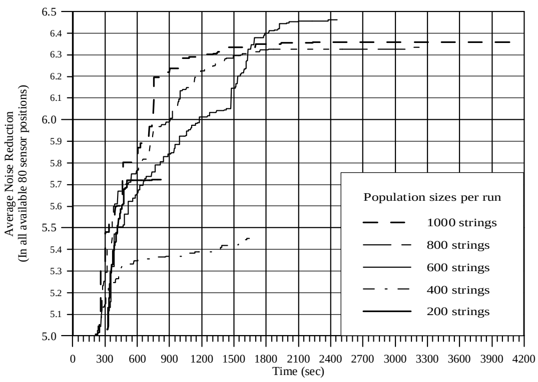

Figure 1. Example of showing of a figure

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The next example is a multi-line equation:

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C11	C12	C13
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C31	C32	C33
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C51	C52	C53

Table 1 : Example of the construction of one table

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[1] Zwicker, E., Fastl, H. (1990), *Psychoacoustics, Facts and Models,* Springer-Verlag, Berlin.

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[1] Nelson, P.A., Curtis, A.R.D., Elliot, S.J. and Bullmore, A.J. (1987), “The active minimization of Harmonic enclosed sound fields, Part I: Theory”, J. Sound and Vibration, Vol. 117, pp. 1-13.

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[1] Tsahalis, D.(1996), “Modelling of Fluid Damping in Thermal Insulation”, *Proceedings of International Conference on Noise and Vibration Engineering, ISMA ’21, Leuven Belgium, 18-20 September*, Vol. II, pp.731-742.