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Speckle Noise Reduction Using Hybrid Wavelet Packets-Wiener Filter

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Abstract— In medical image processing, image denoising has become an essential requirement for correct diagnosis. This paper proposes a hybrid filter which employs Wavelet Packet Transforms and Wiener Filters for removal of noise in ultrasound images. Wavelet Packet Transforms is a generalization of the wavelet transforms that offers a rich set of decomposition structure. On the other hand, the Wiener filter tries to build an optimal estimate of the original image by enforcing a minimum mean-square error constraint between estimate and original image. In the first step, the multiplicative noise is modelled into an additive one followed by application of Discrete Wavelet Packet transforms. This is followed by application of Wiener Filter to the output obtained in the previous stage. The proposed algorithm is tested on different images and is found to produce better results in terms of the qualitative and quantitative measures of the image for both low and high values of noise variance in comparison to many existing techniques.

Keywords— Speckle noise, Wavelet Packet Transforms, Noise variance, Wiener Filter, PSNR, Ultrasound.

I. INTRODUCTION

Medical images are often corrupted by noise[1]-[5] during their transmission and subsequent acquisition. It is therefore of utmost importance that such noise be removed or mitigated as much as possible while retaining as much as possible the important signal features. Ultrasonic imaging is a widely used medical imaging procedure as it is economical, comparatively safe, transferable, and adaptable. It is used for imaging soft tissues in organs like liver, kidney, spleen, uterus, heart, brain etc. However, one of its main drawbacks is its poor quality of images, which are affected by speckle noise. The existence of speckle is unacceptable as it degrades the image quality and affects the tasks of individual interpretation and diagnosis. As such, speckle filtering is a central pre-processing step for many image processing operations including feature extraction, analysis and enhancement of medical images. A large number of papers have been proposed in the literature for speckle noise mitigation. An appropriate method for speckle reduction is one which enhances the signal to noise ratio while conserving the edges and boundaries in the image.

Several methods [6]-[15] have been proposed in the literature for speckle noise removal, based upon different mathematical models of the phenomenon. One of the methods involves using adaptive and non-adaptive filters on the signal processing (where adaptive filters adapt their weightings across the image to the speckle level, and non-adaptive filters apply the same weightings uniformly across the entire image). Such filtering often removes the actual image information as well, in particular high-frequency or detail information viz. edges and lines. Adaptive speckle filtering is better at preserving edges and detail in high-texture areas (such as forests or urban areas). Non-adaptive filtering is simpler to implement, and requires less computational power.

There are many forms of adaptive speckle filtering, including the Lee filter[11], the Frost filter[10], and the Kuan[12]. They all rely upon three fundamental assumptions in their mathematical models viz. Speckle noise in SAR is a *multiplicative* noise, i.e. it is in direct proportion to the local grey level in any area; the signal and the noise are statistically independent of each other; and the sample mean and variance of a single pixel are equal to the mean and variance of the local area that is centred on that pixel.

Recently, the use of wavelet transforms[16]-[20] has led to significant advances in image analysis. The main reason for the use of multiscale processing is the fact that many natural signals, when decomposed into wavelet bases are significantly simplified and can be modeled by known distributions. Besides, wavelet decomposition is able to separate noise and signal at different scales and orientations. Therefore, the original signal at any scale and direction can be recovered and useful details are not lost.

A further improvement using Wavelets[21]-[24] is the introduction of the Wavelet packet transforms that offer a richer set of decompositions structure as compared to wavelet transforms.

The Wiener Filter [21],[25]-[26], developed by Norbert Wiener in 1942, is a statistical based frequency domain technique. It is an image restoration solution that can be applied to images that have been subject to a degradation function and also contain noise.

This paper proposes a hybrid technique employing Wavelet packet transforms that employs modified Bayes thresholding and the Wiener Filter for removal of speckle noise. The technique exploits the features of Wavelet Packet Transforms along with the estimation capability of the Wiener filter for effectively reducing the speckle noise from the speckle corrupted ultrasound image.

Computational simulation indicates that the proposed technique provides significant improvement over many other existing techniques in terms of PSNR.

The rest of the paper is organized as follows. The proposed methodology is introduced in Section II. The experimental results and comparison table are presented in Section III. The conclusions are provided in Section IV.

II. PROPOSED METHODOLOGY

Wavelet Packets are generalization of the wavelet tree decomposition, capable of providing arbitrary frequency resolution. Mathematical groundwork of wavelet packet was laid by Coifman and Wickerhauser in 1992. The main difference between wavelet transform and wavelet packet transform is that, in wavelet packet, non-octave subband decomposition is allowed to adaptively select the basis for a particular signal. The main advantage of wavelet packet is its universality in adapting the transform to a signal without assuming statistical property of the signal. The extra adaptivity of the wavelet packet framework is obtained at a price of added computation in searching for the best wavelet packet basis. The wavelet packet basis is constructed adaptively based on some cost function and choice of decomposition filter applied to an image. The decomposition of a signal can be viewed as a tree, where the left branches represents the low-pass horizontal/low-pass vertical filtering, the right branch represents the high-pass horizontal/high-pass vertical filtering and the middle branches represents the low-pass horizontal/high pass vertical filtering and the high-pass horizontal/low-pass vertical filtering, respectively. The wavelet packet tree is constructed in two steps. First, the image is filtered and subsampled into four new images representing the spatial frequency subbands. Each of the subbands are filtered and subsampled into four new images, a process that is repeated to certain level. By keeping the components in every subband at every level, the wavelet packet tree has the advantage of attaining the complete hierarchy of segmentation in frequency and is a redundant expansion of the image. In the second step, the best basis is chosen so as to represent the input image based on the cost function. The cutting off branches in the tree is controlled by the cost function applied to one node and on its children nodes. These subbands are to be seen as a collection of bases for the particular image and the filter choice.

The Wiener filter tries to build an optimal estimate of the original image by enforcing a minimum mean-square error constraint between estimate and original image. The Wiener filter is an optimum filter. The objective of a Wiener filter is to minimize the mean square error. A Wiener filter has the capability of handling both the degradation function as well as noise.

The reduction of speckle noise using this hybrid technique is carried as follows:

Stage 1: Transformation of the multiplicative noise model into an additive one by taking the logarithm of the original speckled data.

Stage2: Four level Wavelet Packet decomposition using a particular wavelet to obtain Optimal Wavelet Base of a noisy image using Shannon entropy.

Stage 3: Estimation of the noise variance using eq. (1) viz.

$$\sigma_n = \frac{Median(|Y_{ij}|)}{0.6745}, \quad Y_{ij} \in \text{subband } HH_1 \qquad (1)$$

Stage 4: Computation of the statistical parameters and threshold value for each subband S in level d:

a) Determination of the subband's variance using eq. (2)

$$\sigma_x^2 = \frac{1}{n^2}\sum_{i,j=1}^{n} X^2(i,j) \qquad (2)$$

where $X(i,j)$ is the (noise) corrupted image, $f(i, j)$ is the original signal and $n(i, j)$ is the noise and are related by eq.(3).

$$X(i,j) = f(i,j) + n(i,j) \qquad (3)$$

Since the noise and signal are independent of each other, it can be stated that

$$\sigma_x^2 = \sigma_f^2 + \sigma_n^2 \qquad (4)$$

b) Pre-estimation of the variance of original image using eq. (5).

$$\sigma_f^2 = \max\left(\sigma_X^2 - \sigma_n^2,\ 0\right) \qquad (5)$$

c) Calculation of the term $\alpha_{d,s}$ using eq. (6).

$$\alpha_{d,s} = \sum_{i\subset s} SWF_H(i) + \sum_{j\subset s} SWF_V(j) \qquad (6)$$

where SWF_H and SWF_V are the subband weighting function in horizontal and vertical direction at level L of the wavelet packet decomposition.

d) Computing of the threshold using eq.(7).

$$T_B = \beta \frac{\sigma_n^2}{\sigma_s^2} \qquad (7)$$

where σ_n^2 is the noise variance and σ_s^2 is the signal variance without noise. In the conventional Bayes threshold expression, $\beta = 1$. Here value of β is adaptive to different subband characteristics and is given in eq. (8) as

$$\beta = log \frac{L}{k} \qquad (8)$$

where L is the number of wavelet decomposition level and k is the level at which subband is available.

Stage 5: Thresholding all subband's coefficients using the soft thresholding technique.

Stage6: Application of the inverse Wavelet Packet Transformation (WPT) to reconstruct the initial denoised image.

Stage 7: Application of Weiner filter to the output of stage 6.

Stage 8: Application of the exponent function to the output of the step 7 to obtain the final denoised image.

III. SIMULATIONS RESULTS

This section compares the proposed algorithm, the Hybrid Wavelet Packets-Weiner Filter (HWPWF) with other existing techniques based on their simulation results. Peak signal-to-noise ratio (PSNR) is used to access the restoration results which measures how close the restored image is to the original image. The PSNR (dB) is defined as

$$\text{PSNR}= 10log_{10}\frac{(2^b-1)^2}{\frac{1}{MxN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}(X(i,j)-Y(i,j))^2} \quad (9)$$

where b refers to a b-bit image, M x N is the size of the image, *X(i,j)* refers to the original image and *Y(i,j)* refers to the denoised image. Since image is subjected to the human eyes, visual inspection is also carried out on the filtered images to judge the effectiveness of the filters in removing impulse noise.

The measurement of PSNR of the filtered image and the inspection of its visual quality is carried out to judge the efficacy of the filters. A wide range of noise variances varying from σ^2 = 0.02 to 0.1 in steps of 0.01 have been used for this purpose on the ultrasound image and the results tabulated as shown below.

Table 1 compares the restoration results in PSNR of this technique, HWPWF with six other approaches for 512x512 'Ultrasound' image corrupted by speckle noise with noise variances varying from σ^2 = 0.02 to 0.1 in steps of 0.01. ratio levels varying from 10% to 90% with increments of 10%. These include Visushrink, Median, Wiener, Kuan, Frost and Lee filter. Fig. 1 graphically depicts the comparison of efficacy of restoration in terms of PSNR for the HBWF method and the six existing methods for the image 'Ultrasound' corrupted with varying degrees of noise percentage. Fig. 2 depicts the improvement in the results qualitatively.

TABLE 1
Comparison of Restoration Results of HWPWF for 'Ultrasound' Image in terms of PSNR(dB)

Noise variance (σ^2)→ / Filtering technique↓	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
INPUT PSNR	25.49	23.82	22.64	21.68	20.93	20.35	19.76	19.34	18.89
VISU SHRINK	28.73	27.61	26.80	26.16	25.66	25.18	24.78	24.50	24.20
MEDIAN	29.34	28.00	27.14	26.29	25.71	25.16	24.53	24.18	23.79
WIENER	29.19	27.63	26.45	25.58	24.81	24.14	23.57	23.14	22.74
KUAN	30.79	29.86	29.15	28.51	27.93	27.41	27.07	26.79	26.42
FROST	30.84	29.99	29.31	28.67	28.20	27.73	27.10	26.96	26.36
LEE	30.84	30.00	29.29	28.59	28.13	27.55	27.15	26.92	26.42
HWPWF	31.44	30.40	29.55	28.94	28.33	27.77	27.27	26.70	26.44

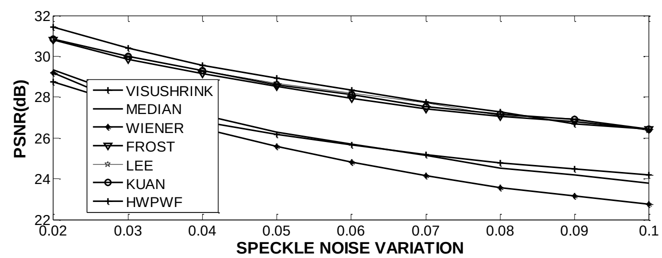
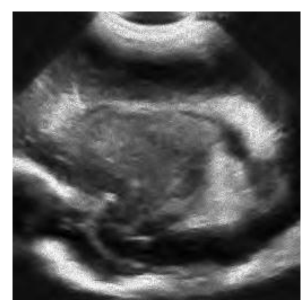


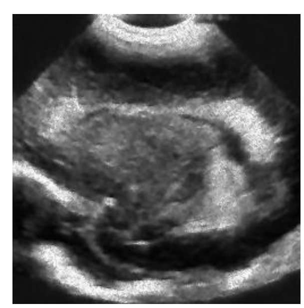
Fig. 1 Restoration Results for 'Ultrasound' Image

(a)

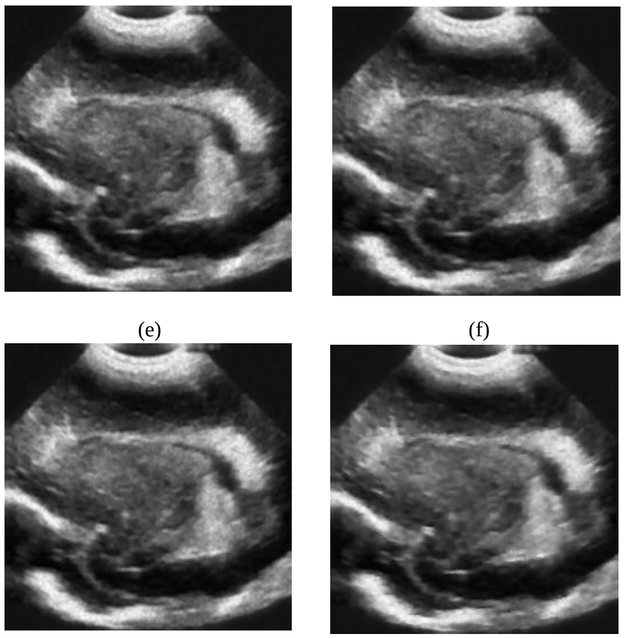


(b)

(c)



(d)



(e) (f)

(g) (h)

Fig. 2 Restoration Results for ‘Ultrasound’ Image Corrupted with Speckle Noise of Variance 0.1. (a) Corrupted Image (b) VisuShrink (c) Median (d) Weiner (e) Kuan (f) Frost (g) Lee (h) HWPWF

It can be seen from Table 1 that the PSNR values are superior for all values of noise variance in comparison to Visushrink, Median, Wiener, Kuan, Frost and Lee Filter.

IV. CONCLUSION

A hybrid denoising technique for removing speckle noise is proposed in this paper. This technique employs both the Wavelet Packets and the Wiener filter and exploits their properties to attain the required aim. This technique is suitable for both low and high values of noise variance. The experimental results demonstrate that the Hybrid Wavelet Packets-Wiener Filter (HWPWF) performs better than Visushrink, Median, Wiener, Kuan, Lee and Frost filter for all values of noise variance in terms of both quantitative evaluation and visual quality.

It is suggested that future research should focus on reducing the processing time when the image is corrupted with speckle noise of high variance.

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