Speckle noise reduction in ultrasound image based on A Multiplicative Multiresolution Decomposition (MMD)

M.Outtas, A.Serir and F.Kerouh
LTIR, Faculté d’électronique et d’informatique
mouttas@usthb.dz, aserir@usthb.dz, f.kerouh@usthb.dz

Abstract—This paper turns on ultrasound image despeckling by using Multiplicative Multiresolution Decomposition MMD. The proposed method is based on MMD’s coefficient thresholding. The used thresholds are automatically evaluated from the transformed image content. Tests are conducted on simulated speckled and real ultrasound images. Obtained results show that the proposed method outperforms the considered existing ones.

Keywords—Ultrasound imaging; Speckle noise; MMD transform; Wavelet transform.

I. INTRODUCTION

Speckle noise is inherent to ultrasound imaging (US) modalities. It appears because of interference phenomena between the incident and reflected signals [1]. There exist two possibilities to reduce speckle. The first consists of compounding method which requires hardware modification and the other turns on post acquisition methods which reduce speckle noise through algorithm implementation without affecting important features of the image (diagnostics information in ultrasound images) [2].

The second techniques encompass spatial filtering methods and multiscale methods. The filtering methods are based on many spatial filters proposed in the literature; they originated from despeckling of the synthetic aperture radar (SAR) community [3]. The filters that perform in both SAR and ultrasound imaging are: Median filter [4], Wiener filter, Lee filter [5], Frost filter [6].

Since the speckle is a multiplicative noise some authors propose a homomorphic filtering. This last refers to a technique which transforms non-additive noise into additive one using some nonlinear operator like log-transforming. The obtained image is treated as corrupted by additive noise [7]. In [8] the authors introduced a homomorphic approach for speckle filtering by using a Wiener filter.

A wide class of algorithms for speckle reduction in ultrasound image use multiscale methods mainly based on wavelet decomposition and noise free coefficient. Image denoising by applying a universal threshold to wavelet coefficient (visu-shrink) was first proposed by Donoho [9].

In [10] the authors propose to use the donoho’s soft thresholding in a homomorphic way. The means of a Bayesian minimum absolute error (MMAE) estimator is used for reducing speckle in wavelet domain [11]. The authors implemented algorithm that performs soft thresholding with an adaptive threshold (bayes shrink) depending on the noise statistics of each subband.

Although many interesting works on reducing speckle in images have been done, there is still room for improvement. Of particular interest to this work, is to prospect new ways for analysis and reduce speckle in ultrasound images in relation with the multiplicative property of the considered noise. Herein, we propose to use Multiplicative Multiresolution Decomposition [12] called MMD. Thus to analyze speckle, we propose to use a multiplicative representation, which could deal with speckle’s properties.

The rest of the paper is organized as follows. Section 2 covers the MMD analysis. In section three, the proposed speckle reduction approach is introduced in details. Experiments and results are discussed in section four. Concluding remarks of this work with some perspectives are given in the last section.

II. MULTIPLICATIVE MULTiresOLUTION DECOMPOSITION (MMD).

A new multiscale method is proposed in [12] for speckle reduction in SAR image. This nonlinear multiplicative decomposition has efficient application in [13] [14]. It uses filter banks with critical subsampling and perfect reconstruction. The authors consider a description of the analysis and the synthesis inputs–outputs systems with equal symbol rates at both the input and the output. The wanted structure is obtained by performing a polyphase decomposition of the 2D signal (image). The four polyphase components of the input image are \( x_{11}, x_{12}, x_{21}, x_{22} \). Figs. 1 and 2 illustrate analysis and synthesis by MMD. Herein, \( h \) and \( f \) are the bi-dimensional linear filters. \( D \) and \( R \) are the analysis and synthesis nonlinear filters. \( P \) stands for polyphase decomposition [12].
The component \( y_1 \), which is the weighted mean of the four polyphase components, it is considered as an approximation sub-band. \( h_{12} = \alpha h_{11}, h_{21} = \gamma v_{11} \) and \( h_{22} = \gamma h_{11} \), where \( \alpha, \gamma \) and \( \gamma \) are positive scalars. The nonlinear analysis filter \( D \) is then given by:

\[
\begin{align*}
\beta_{x_{11}}^{x_{12}}, \text{ for } x_{12} > x_{11} \\
\alpha, \text{ for } x_{12} = x_{11} = 0
\end{align*}
\]

where \( h \) is a positive scalar.

At the highest resolution \( j \), the original discrete signal at the resolution 1 is represented by the set \( S \) defined by:

\[
S = \left\{ y_1^{(i)}, y_2^{(i)}(i), y_3^{(i)}(i) \right\}, \ 2 \leq i < J
\]

Inversely, an approximation of the original signal at resolution \( j = 1 \) is obtained by using multi-resolution synthesis scheme based on the set \( S \).

III. PROPOSED METHOD

In this paper the speckle reduction in ultrasound image is carried out in the MMD domain. The coefficients \( y_2^{(i)} \) in transformed domain are subjected to thresholding. The threshold is determined by the analysis of the noise under the multiresolution decomposition (MMD). We assume that the \textit{a priori} variance of noise can be derived from a local region. We set up a neighborhood \( \Omega \) in sliding window along the image details, to locate a smooth area (MMD’s coefficients close to \( \beta \)). The calculation is performed with MMD’s coefficients by minimizing criterion based on a median absolute deviation measure:

\[
\text{mad} = \frac{1}{n} \sum_{i=1}^{n} |y_2^{(i)} - \beta|_{(i \in \Omega)}
\]

where \( \beta \) is a positive scalar. Hence, for \( x_{11} \neq 0 \) (that is equivalent to have \( y_2^{(i)} \neq \beta \), \( y_{2h}^{(i)} \neq \gamma \) and \( y_{2d}^{(i)} \neq \gamma \)), according to equations \( (4), (5) \) and \( (6) \), the nonlinear filters \( r_{ij} \) are expressed as a function of the nonlinear outputs \( y_{2h}, y_{2d} \).

To perform a multiresolution analysis several subband decompositions are performed using analysis filter bank that operates at different stage of the outputs. The subband \( y_1 \) is split to its polyphase components \( y_{11}, y_{12}, y_{21}, y_{22} \) and then filtered [12].

At the resolution \( j = 1 \),

\[
\begin{align*}
y^{(i)}_{11} &= x_{11}, \quad y^{(i)}_{12} = x_{12}, \quad y^{(i)}_{21} = x_{21}, \quad y^{(i)}_{22} = x_{22}.
\end{align*}
\]
at resolution j. However, to design an efficient filter within the MMD, a finest thresholding is performed. When \((1-C_n^j)/4 \leq w_i^j < (1+C_n^j)/4\), the coefficient represents a smooth area and the threshold coefficient are set to \(\beta\). Otherwise the coefficient \(w_i^j\) reflects a transition pixel. In order to reduce the speckle in this transition (heterogeneous area) we propose to add or subtract an offset as follows:

\[
\begin{align*}
    w_i^j &= v w_i^j + \gamma \quad & \text{if} & \quad w_i^j \geq \frac{1+C_n^j}{4} \\
    w_i^j &= v w_i^j - \gamma \quad & \text{if} & \quad w_i^j \leq \frac{1-C_n^j}{4}
\end{align*}
\]

(10)

where \(v = \frac{1}{\sqrt{1+C_n^j}}\), \(\gamma = 1 - \frac{1}{\sqrt{1+C_n^j}}\) and \(w_i^j\) are speckle free MMD’s coefficient from which the image at resolution \((j-1)\) will be reconstructed.

IV. EXPERIMENTS, RESULTS AND DISCUSSIONS

Experiments have been carried out in MATLAB using synthetically speckled and real medical ultrasound images to deduce the performances of MMD filtering.

The results are compared with that of median, homomorphic Wiener [8], Visushrink [9], Visushrink preprocessed by homomorphic (wavelet homomorphic).

The synthetically speckled image is obtained by corrupting the classical Lena image (512x512) with speckle noise. One could use three versions of noised image by the same standard deviation. The considered noised image is the mean of the three versions.

The relationship between the normalized standard deviation at different resolutions is experimentally carried out by considering a uniform image and calculating the \(C_n^j\) through the multiresolution details. The results have been validated with tests conducted into a smooth area of a speckled real image. By analyzing the evolution of \(C_n^j\) through the resolutions, \(C_n^j\) could be approximated form the knowledge of \(C_n^{j-1}\) by:

\[
C_n^j = 2C_n^{j-1}/3.
\]

The Peak Signal to Noise Ratio (PSNR) and the Signal to Noise Ratio SNR are used as comparing criteria to carry out the performances of the different methods.

Table I summarizes the obtained results in term of PSNR. It is clearly shown that the proposed method outperforms the others. One could notice that median filter which is a simple process provides relatively good results in term of PSNR. From Fig.3, one could notice that the obtained image by the proposed method is less noisy and less blurred then the other obtained images. To evaluate the quantity of blur introduced by the speckle reducing process one could measure this quantity by a no-reference metric dedicated to blur (PBIIQA) [16].

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>29.60</td>
<td>29.41</td>
<td>29.16</td>
<td>29.78</td>
<td>30.84</td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>26.09</td>
<td>27.70</td>
<td>26.17</td>
<td>26.67</td>
<td>27.95</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>25.03</td>
<td>25.59</td>
<td>24.34</td>
<td>24.86</td>
<td>25.76</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>20.46</td>
<td>18.91</td>
<td>19.63</td>
<td>20.37</td>
<td>20.50</td>
<td></td>
</tr>
</tbody>
</table>

TABLE I. COMPARATIVE PSNR OF DESPECKLING METHODS

IV. EXPERIMENTS, RESULTS AND DISCUSSIONS

Experiments have been carried out in MATLAB using synthetically speckled and real medical ultrasound images to deduce the performances of MMD filtering.

The results are compared with that of median, homomorphic Wiener [8], Visushrink [9], Visushrink preprocessed by homomorphic (wavelet homomorphic).

The synthetically speckled image is obtained by corrupting the classical Lena image (512x512) with speckle noise. One could use three versions of noised image by the same standard deviation. The considered noised image is the mean of the three versions.

The relationship between the normalized standard deviation at different resolutions is experimentally carried out by considering a uniform image and calculating the \(C_n^j\) through the multiresolution details. The results have been validated with tests conducted into a smooth area of a speckled real image. By analyzing the evolution of \(C_n^j\) through the resolutions, \(C_n^j\) could be approximated form the knowledge of \(C_n^{j-1}\) by:

\[
C_n^j = 2C_n^{j-1}/3.
\]

The Peak Signal to Noise Ratio (PSNR) and the Signal to Noise Ratio SNR are used as comparing criteria to carry out the performances of the different methods.

Table I summarizes the obtained results in term of PSNR. It is clearly shown that the proposed method outperforms the others. One could notice that median filter which is a simple process provides relatively good results in term of PSNR. From Fig.3, one could notice that the obtained image by the proposed method is less noisy and less blurred then the other obtained images. To evaluate the quantity of blur introduced by the speckle reducing process one could measure this quantity by a no-reference metric dedicated to blur (PBIIQA) [16].

TABLE II. COMPARATIVE BLIND BLUR IMAGE QUALITY METRIC OF IMAGES IN FIG.3

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PBIIQA</td>
<td>0.9432</td>
<td>0.9914</td>
<td>0.9825</td>
<td>0.9918</td>
<td>0.9863</td>
</tr>
</tbody>
</table>

TABLE III. COMPARATIVE SNR OF DESPECKLING METHODS

<table>
<thead>
<tr>
<th>Std. of noise</th>
<th>RELATED METHOD IN [15]</th>
<th>Proposed method</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>19.14</td>
<td>18.21</td>
</tr>
</tbody>
</table>

This metric is close to 1, when the image is sharp and to zero in the opposite. In order to substantiate the visual perception Table II shows the quantity of blur introduced by different process.

From Table I and II we can conclude that the proposed method is more efficient than the others.

To evaluate and compare this method to recent ones, we have tested our algorithm in the same conditions described in [15].

Table III highlights the quality of despeckling and shows that the proposed method performances are close to [15].

Nevertheless as the proposed method has lower computational complexity than the Bhuiyan’s method [15], which is based on Dual-tree Complex Wavelet Transform, then proposed method performs a good trade-off between despeckling performance and low complexity implementation.

To observe how our method performs on real medical image; we have tested it on liver ultrasound images. Fig.4 shows that the obtained images are less speckled and the features are preserved (edges and textures).

V. CONCLUSION

In this paper we propose a new despeckling method. Through Multiplicative Multi-resolution Decomposition, the \textit{a priori} speckle parameters are automatically obtained from the noisy data. The obtained results showed that the proposed method outperforms the other techniques in providing images with a better PSNR, SNR and good visual quality. In addition, the low computational complexity of the MMD transform provides some latitude to future works. As perspectives we aim to bring out diagnostically important features.

VI. REFERENCES


