

A Novel Multiscale Statistical Model for Despeckling Medical Ultrasound Images

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ABSTRACT

Speckle intrinsic in ultrasound medical images suppress the crucial information required for clinical diagnosis. An accord between suppression of speckle and perpetuation of clinical information has become imperative in ultrasound despeckling. In this paper a novel Multiscale statistical filter is proposed for speckle suppression, which computes the maximum and median values of eight blocks oriented in horizontal, vertical, diagonal and curved directions. The values are compared with center pixel and the median of all the five values is assigned as the new pixel value. The proposed filter is evaluated and verified on the basis of Peak Signal to Noise Ratio (PSNR), Edge Preservation Factor (EPF) and Feature Similarity Index (FSIM). The experimental results demonstrate that the proposed filter can reduce the speckle noise effectively without blurring the edges.

Key words: Speckles, median, statistical filter, despeckling.

INTRODUCTION

Medical ultrasonography more widely used due to its lack of ionization, non-invasiveness and relatively low cost in clinical diagnosis and therapy. However at the time of acquisition it produces interfering echoes with random phase and amplitude exhibiting an intricate, specular pattern called speckle. These speckles mask clinical details and degrade the image quality thereby increasing the level of difficulty in interpreting an ultrasound image. Despite the structure of human tissue speckles depend on bandwidth, frequency and placement of transducer probe [1]. The existence of speckle suppresses human perception, edge detection, and diagnostic values during clinical interpretation [2]. To curb this difficulty many despeckling algorithms are being discussed in literature [3]. In this paper, a statistical filter is proposed for speckle reduction considering the multiplicative characteristics of speckle.

STATE OF ART

Several adaptive speckle reduction filters are proposed in spatial domain. Adaptive filters suppress speckles and preserve edges by modifying the image based on the statistics extracted locally from each pixel. Lee filter [4] estimates the value of pixel of interest by employing the statistical distribution of pixels in moving window. It is based on the fact that the mean and variance of the pixel of interest is equal to local mean and variance of all pixels within the moving window. The Kuan filter [5] has the same form as lee filter but upholds a different weighting function. The frost filter [6] computes the weighted sum of values within the moving window to replace the current pixel. The weighting factor decreases with distance from pixel of interest and increases for central pixel as the variance within the window increases. Median filter

[7] is a non-linear filter that assigns median value to each pixel of its neighbourhood. The median is calculated by sorting all the pixel values from the surrounding neighbourhood into numerical order and then replacing the pixel being considered with the middle pixel value. In truncated median filter [7] values farthest from the mean are discarded so that the median is shifted towards the mode. Hybrid median filter [8] is another modification of median filter. It computes the median of diagonal, horizontal and vertical elements. These values are compared against the center pixel and the median value of that set is saved as new pixel value. The modified hybrid median filter [10] is the modified version of hybrid median filter. It computes the maximum of diagonal elements, median of the rest and the values are compared against center pixel. The bilateral filter [11] is a non-linear filter that performs spatial weight averaging without smoothing edges. The weights are determined in both spatial and intensity distance.

SPECKLE NOISE MODEL

The speckle noise model may be approximated as multiplicative and is given by

$$f_{i,j} = g_{i,j}u_{i,j} + a_{i,j} \quad \text{-----}>(1)$$

where $f_{i,j}$ is the noisy pixel $g_{i,j}$ represent the noise free pixel, $u_{i,j}$ and $a_{i,j}$ represent the multiplicative and additive noise respectively and i,j are indices of the spatial locations. The effect of additive noise has less impact compared to that of multiplicative noise hence (1) may be written as

$$f_{i,j} \approx g_{i,j}u_{i,j} \quad \text{-----}>(2)$$

Logarithmic compression is applied to the envelope – detected echo signal in order to fit within the display range [12]. Logarithmic compression affects the speckle noise statistics and it becomes much close to white Gaussian noise. The logarithmic compression transforms multiplicative form in (2) to additive noise form as

$$\log(f_{i,j}) = \log(g_{i,j}) + \log(u_{i,j}) \quad \text{-----}>(3)$$

The term $\log(f_{i,j})$, which is the ultrasound image after logarithmic compression is denoted as $x_{i,j}$ and the terms $\log(g_{i,j})$, $\log(u_{i,j})$ which are the noise free pixel and noisy component after logarithmic compression, as $y_{i,j}$ and $n_{i,j}$ respectively(4).

$$x_{i,j} = y_{i,j} + n_{i,j} \quad \text{-----}>(4)$$

PROPOSED TECHNIQUE

In this paper a novel statistical technique for despeckling ultrasound images is proposed which applies the median, max filter to the eight blocks figured below. The pixel at any particular point has more intervention with its neighbouring homogenous pixels than their distant

and dissimilar ones. The proposed method focuses mainly to suppress speckle and preserve edges. This is carried out by including the block based approach along with horizontal, vertical and diagonal elements.

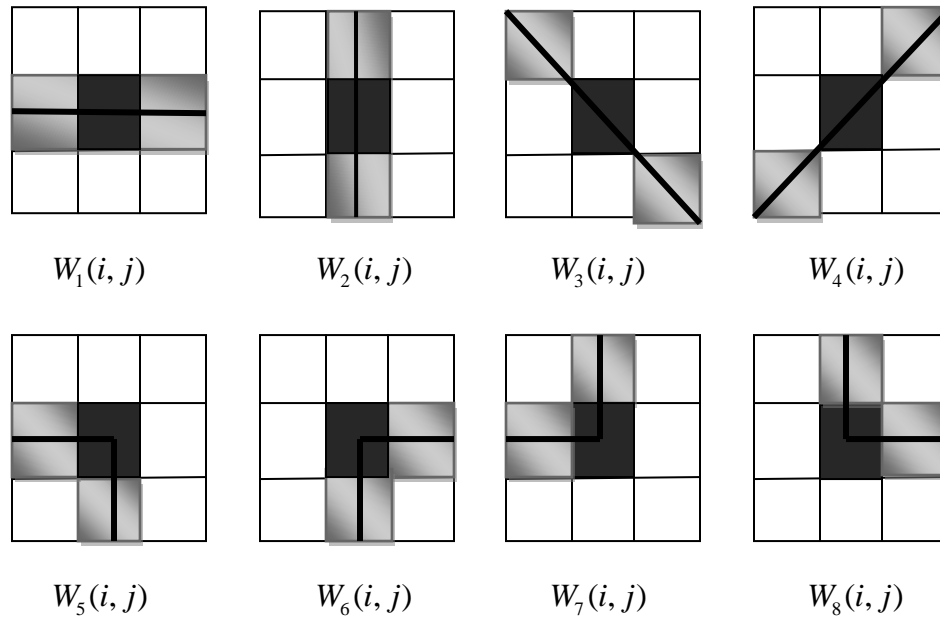


Fig 1: Direction of blocks selected in a 3x3 mask

Let us consider W as a $(2N+1) \times (2N+1)$ square filter window. The pixels in this square window are divided into eight subwindows. The homogeneity is measured along eight directions to ensure that lines and edges are preserved along the horizontal, vertical, diagonal and curved directions.

$$W_1(i, j) = \{F(i+l, j); -N \leq l \leq +N\} \text{-----} > (5)$$

$$W_2(i, j) = \{F(i, j+l); -N \leq l \leq +N\} \text{-----} > (6)$$

$$W_3(i, j) = \{F(i+l, j+l); -N \leq l \leq +N\} \text{-----} > (7)$$

$$W_4(i, j) = \{F(i-l, j+l); -N \leq l \leq +N\} \text{-----} > (8)$$

$$W_5(i, j) = \{F(i-l, j), F(i, j), F(i, j+l); l > 0\} \text{-----} > (9)$$

$$W_6(i, j) = \{F(i+l, j), F(i, j), F(i, j+l); l > 0\} \text{-----} > (10)$$

$$W_7(i, j) = \{F(i, j-l), F(i, j), F(i-l, j); l > 0\} \text{-----} > (11)$$

$$W_8(i, j) = \{F(i, j-l), F(i, j), F(i+l, j); l > 0\} \text{-----} > (12)$$

The median of all the pixels in the sub window $W_n(i, j)$, $1 \leq n \leq 8$ is generalized as $X_n(i, j)$, $1 \leq n \leq 8$.

$$X_n(i, j) = \text{median}[W_n(i, j)]; 1 \leq n \leq 8 \text{-----} > (13)$$

The median of horizontal and vertical pixels is compared with the center pixel to obtain a new value $U_1(i, j)$, maximum of two diagonal pixels are compared with center pixel $F(i, j)$ to obtain $U_2(i, j)$. Similarly $U_3(i, j)$ and $U_4(i, j)$ are the median values of upper and lower curved blocks compared against the center pixel value.

$$U_1(i, j) = \text{median}[F(i, j), X_1(i, j), X_2(i, j)] \text{-----} > (14)$$

$$U_2(i, j) = \max[F(i, j), X_3(i, j), X_4(i, j)] \text{-----} > (15)$$

$$U_3(i, j) = \text{median}[F(i, j), X_5(i, j), X_6(i, j)] \text{-----} > (16)$$

$$U_4(i, j) = \text{median}[F(i, j), X_7(i, j), X_8(i, j)] \text{-----} > (17)$$

The filtered output is finally the median of all the five values along with the center pixel. This value is assigned as the new value.

$$y(i, j) = \{F(i, j), U_1(i, j), U_2(i, j), U_3(i, j), U_4(i, j)\} \text{-----} > (18)$$

$$Y(i, j) = \text{median}[y(i, j)] \text{-----} > (19)$$

MATERIALS AND METHODOLOGY

Two ultrasound images of gallbladder and fetus foot are imaged from scanner and a noise variance of .02 is added. The speckled image is processed in MATLAB. The proposed filter is compared with linear and non-linear filters like, Lee, Median, Bilateral, Hybrid median, Modified hybrid median. The performance of the filter is assessed using image quality metrics, Peak Signal to Noise Ratio (PSNR), Edge Preservation Factor (EPF) and Feature Similarity Index (FSIM).

Algorithm

- 1) Find the median of pixels in the 3x3, 5x5 sub window as $W_n(i, j)$,
- 2) Compute the median for horizontal, vertical $W_n(i, j)$ and center pixel, $U_1(i, j)$
- 3) Compute the maximum of diagonal and center $W_n(i, j)$ pixels $U_2(i, j)$

- 4) Compute the median of upper curved block and center pixel $U_3(i, j)$.
- 5) Compute the median of lower curved block and center pixel $U_4(i, j)$.
- 6) Finally compute $Y(i, j)$.

Image evaluation metrics

Peak Signal to Noise Ratio (PSNR) is computed using,

$$PSNR = 20 \cdot \log_{10} \left(\frac{g^2_{\max}}{RMSE} \right) \quad (20)$$

Where g^2_{\max} is the maximum intensity in the unfiltered images. The PSNR is higher for a better transformed image.

The edge preservation ability of the filter is compared by Edge Preservation Factor and is computed using,

$$EPF = \frac{\sum (\Delta x - \overline{\Delta x})(\Delta y - \overline{\Delta y})}{\sqrt{\sum (\Delta x - \overline{\Delta x})^2 \sum (\Delta y - \overline{\Delta y})^2}} \quad (21)$$

where Δx and Δy are the high pass filtered versions of images x and y , obtained with a 3x3 pixel standard approximation of the Laplacian operator. The larger value of EPF means more ability to preserve edges.

Feature similarity index [12] calculates the similarity between images f_1 and f_2 . It computes the local similarity map and then pools the similarity map into a single similarity score. FSIM is formulated as,

$$FSIM = \frac{\sum_{x \in n} S_L(x) \cdot PC_m(x)}{\sum_{x \in n} PC_m(x)} \quad (22)$$

Phase congruency and gradient magnitude are the two components calculated to obtain FSIM, Where,

$$PC_m(x) = \max[PC_1(x), PC_2(x)] \quad (23)$$

$$S_L(x) = \left[\frac{2PC_1(x) \cdot PC_2(x) + T_1}{PC_1^2(x) + PC_2^2(x) + T_1} \right] \cdot \left[\frac{2G_1(x) \cdot G_2(x) + T_2}{G_1^2(x) + G_2^2(x) + T_2} \right] \quad (24)$$

T_1 and T_2 are the positive constants to increase the stability S_{PC} . $PC_1(x)$ and $PC_2(x)$ are phase congruency of f_1 and f_2 . $G_1(x)$ and $G_2(x)$ are gradient magnitude of f_1 and f_2 .

RESULTS AND DISCUSSION

From the Table 1 the PSNR values show that the proposed technique outperforms the other

techniques in speckle suppression and the high EPF shows that despite speckle suppression the proposed filter also preserves the edges. Fig 5. shows the original, speckled and despeckled image obtained from the proposed filter

Table1. Comparison of PSNR, EPF and FSIM values for various filters

FILTER	Gall bladder image			Fetus foot image		
	PSNR	EPF	FSIM	PSNR	EPF	FSIM
Lee	35.2306	0.2539	0.9908	32.2254	0.5116	0.9941
Median	34.7581	0.3967	0.9872	35.0430	0.4401	0.9930
Bilateral	36.1209	0.7545	0.9949	33.9231	0.6101	0.9952
Hybrid median(HM)	36.9088	0.6972	0.9944	35.6480	0.6027	0.9953
Modified HM	36.6170	0.7540	0.9955	34.5490	0.6169	0.9958
Proposed	37.0382	0.7567	0.9956	35.8427	0.6261	0.9956

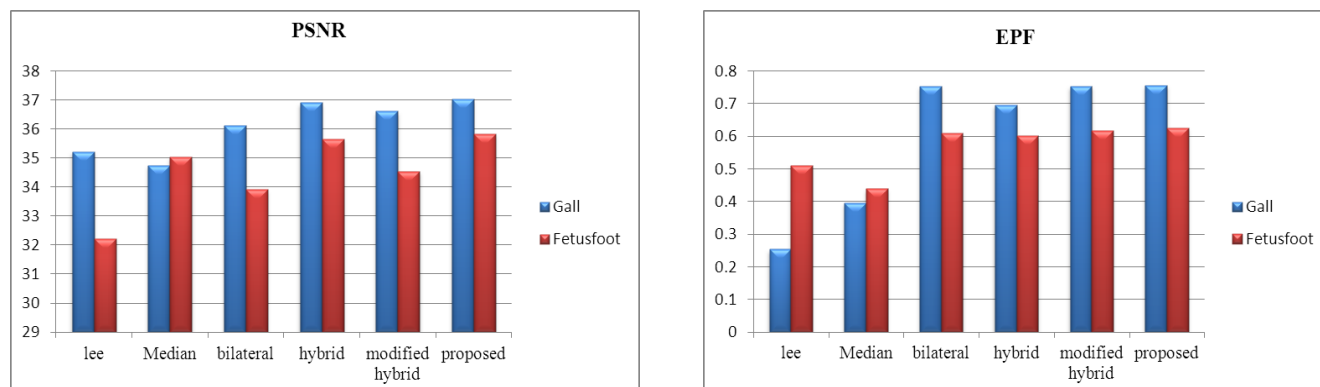


Fig 2,3 : Comparison plot of PSNR,EPF values for various filters

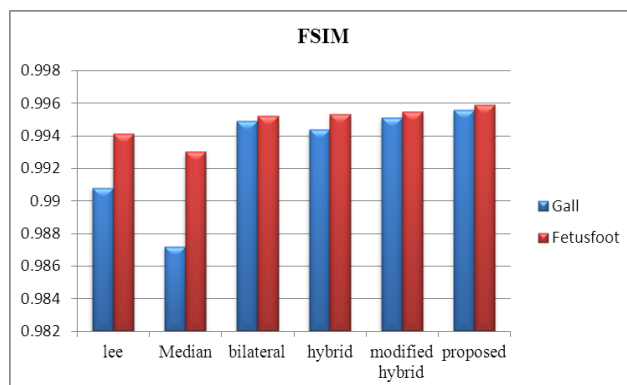


Fig 4: Comparison plot of FSIM values for various filters

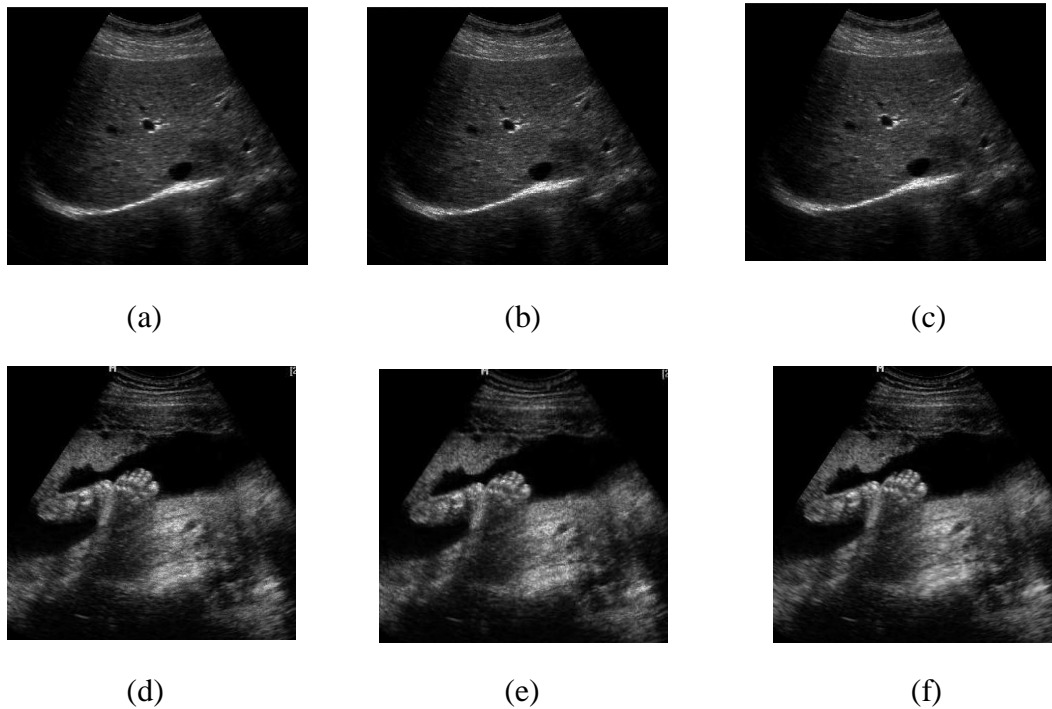


Fig 5.(a) Ultrasound gallbladder image (b) speckled image (c) proposed technique
(d) Ultrasound fetal foot image (e) speckled image (f) proposed technique

CONCLUSION

In this paper an algorithm for despeckling medical ultrasound images is proposed. The performance is tested in ultrasound images of gallbladder and fetus foot with noise variance of 0.02. The results are compared with minimum noise-free image. The proposed technique gives better performance in terms of Peak signal to noise ratio (PSNR), Edge Preservation Factor (EPF), Feature Similarity Index (FSIM). It enhances the visual quality by comparing with other techniques like Lee, Median, Bilateral, Hybrid Median and Modified Hybrid Median.

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