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Innovative Technique For Ultrasound Image Denoising Based On Iphmf

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Abstract - Worldwide Cardiac diseases are considered a major contributor to total deaths. Ultrasound is a frequently utilized system in clinical diagnostics, as it is safe, continuous, non-obtrusive, radiation-free, and more economical than other methods. The aim of this article is to devise an algorithm for denoising of heart ultrasound images.

Speckle noise is a major issue in ultrasound videos and images. This work proposes a new algorithm, 'Information Preserving Hybrid Median Filter (IPHMF)' for speckle noise reduction. The purpose is to improve the preservation of edges, and information capability and make this new filter suitable for ultrasound image denoising in the medical field where information loss cannot be abided. The proposed filter efficiency is tested for the ultrasound videos collected from the hospitals and taken from the open-source repositories.

The proposed method gives results as RMSE: 1.21, PSNR: 46.77, SSIM: 0.97, as compared to LEE (RMSE: 4.10, PSNR: 36.32, SSIM: 0.82), HMF (RMSE: 2.48, PSNR: 40.95, SSIM: 0.92), MHMF (RMSE: 1.61, PSNR: 44.33, SSIM: 0.96). Experimentation shows that IPHMF outperforms, HMF, LEE, and MHMF filters and maintains the balance between speckle suppression and feature preservation based on the performance metrics like RMSE, PSNR, and SSIM.

Keywords: Two-Dimensional Echocardiography (2D Echo), Apical Four Chamber (A4C), Information Preserving Hybrid Median Filter (IPHMF), Hybrid Median filter (HMF), Modified Hybrid Median Filter (MHMF)

Introduction

In many medical modalities, noise and artifacts cause image degradation. Noise in ultrasound is called speckle noise [4], [9]. Human interpretation is greatly affected by degraded images. As a result, in the medical field, a considerable amount of research is going on for image denoising.

Problem Statement

Speckle noise present in ultrasound hampers the quality of images which in turn considerably increases the difficulty in medical visual inspection. The diagnostic accuracy will be more if the image is less noisy, this necessitates the use of an efficient de-speckling filter. This will take care of object detection, and loss of information and improve the visual evaluation.

Scope of the work

1. Propose a new filter for denoising of heart ultrasound images.
2. Compare the results of existing denoising filters with the proposed filter
3. Showcase how the proposed filter is better than existing filters

The work presented in this paper is part of the researcher's work carried out for the automatic detection of heart abnormalities/disorders.

Methodology

In the present work, different existing filters are implemented and experimentation was carried out on LEE, Hybrid Median filter (HMF), and Modified Hybrid Median Filter (MHMF). Further, a new filter 'Information Preserving Hybrid Median Filter (IPHMF)' is proposed.

Filter performance is analyzed based on RMSE, PSNR, and SSIM quality metrics. Where, the high value of RMSE indicates poor image quality, on the other hand, high values of PSNR and SSIM indicate better denoising.

Block Schematic

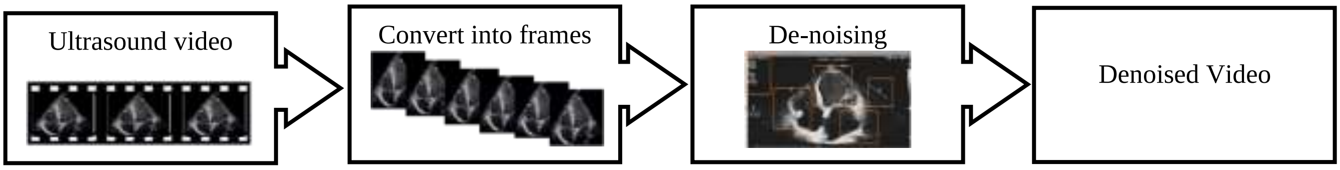


Figure 1. Block Schematic for Denoising of Video

Figure 1, demonstrates the block schematic of the end-to-end process flow for denoising of ultrasound video; each step in this block diagram is explained at a high level as below:

Ultrasound video: Input is given as ultrasound normal/abnormal video for analysis.

Convert into frames: Above input, the video is converted into frames for further processing.

Denoising: Multiple noise models and de-noising filters were studied and evaluated based on various performance parameters such as RMSE, PSNR, and SSIM. As part of a pre-processing best performing 'Information Preserving Hybrid Median Filter (IPHMF)' is used for de-noising.

Denoised Video: Output is obtained in the form of denoised video.

Literature Survey

Jinbum Kang et al. [1], proposed a new method for ultrasound B-mode imaging. Antonios Perperidis et al. [2], reviewed the performance of various artifact removal techniques and listed the limitations for future research opportunities. Christos P Loizou et al. [3], showed the results of intima-media thickness (IMT) and common carotid artery (CCA) for the establishment of cardiovascular disease (CVD). Arun Balodi et al. [4], presented a comparative study of twelve de-speckling filters for ultrasound images. Andreas S Panayides et al. [5], for ultrasound videos of compressing plaque, provided a comparison of various compression techniques.

Gabriel Ramos-Llorden et al. [6], by using a tissue-selective philosophy proposed a probabilistic-driven memory-based anisotropic diffusion filter to overcome the over-filtering problem. Nikhil S. Narayan et al. [7], classified the speckle-related pixels of thyroid glands into three echogenic levels and use them to segment an ultrasound image into trachea, carotid, muscles, and thyroid. Sean Finn et al. [8], presented a comparison and detailed description of speckle reduction in ultrasound, by experimenting with fifteen speckle reduction filters. Karl Krissian et al. [9], analyzed the anisotropic diffusion filter based on numerical schemes properties, using semi-explicit schemes for the automatic processing of images. C. Loizou et al. [10], evaluated the classification performance of six different de-speckling filters on carotid plaque ultrasound images based on the k-nearest neighbor classifier.

S. Pattichis et al. [11], evaluated the carotid artery ultrasound image quality criteria based on MSE, SNR, SSIM. Norashikin Yahya et al. [12], proposed a sub-space-based speckle reduction technique for ultrasound images. Arun Balodi et al. [13], presented a comparative study of twelve despeckle filters for ultrasound images. A. Bini et al. [14], for low contrast and SNR ultrasound images, presented a new anisotropic level method for de-speckling. Fernanda Palhano Xavier de Fontes et al. [15], presented an NL-means modified algorithm for real-time denoising of ultrasound images.

Mohamad Forouzanfar et al. [16], for extraction of wavelet inter-scale dependencies and to increase the visual quality of ultrasound images, introduced a new multiscale speckle reduction method. Ambily N Mimisha et al. [17], reviewed the existing significant de-speckling techniques of ultrasound medical images. K Mohan et al. [18], presented a comparative study of various de-speckling filters. Performance is evaluated based on RMSE and PSNR values for spatial domain filters. JS Lee [19], proposed an innovative computational technique for contrast enhancement and de-speckling of image arrays based on local mean and variance. Joachim Weikert et al. [20], explained in detail Anisotropic Diffusion in image processing.

D. T. Kuan [21], developed adaptive speckle reduction filters for intensity speckle images where only the speckle intensity is recorded and the phase information is lost in the recording process. VS Frost et al. [22], derived a model for the radar imaging process and presented a method for smoothing noisy radar images. Deepika Sood et al. [23], presented a comparative study on de-speckling filters such as Kuan, Frost, anisotropic diffusion, wavelet, and homomorphic filter. R.Vanithamani et al. [24], proposed a modified version of HMF in the form of a statistical de-speckling filter. The effectiveness of the proposed filter is compared based on PSNR, RMSE, SSI, QI, and Edge Preservation Factor (EPF). Kshitij Susheel Jauhri et al. [25], explained the use of the Blind Metric Based Variational Approach for Ultrasound Image Denoising.

Azrah Rubanee et al. [26], explained the use of Fuzzy logic in Speckle Noise Reduction in Ultrasound Images. C. Rodrigues et al. [27], using a combination of bilateral and wavelet thresholding explained ultrasound image denoising. Shivendra Singh [28], presented the comparative analysis of contrast enhancement techniques like CLAHE, HE, BBHE, DSIHE. Mrunal N. Annadate and Manoj S. Nagmode [29], given the comparative evaluation of various de-noising techniques used in ultrasound imaging.

The performance of these de-noising techniques was evaluated based on MSE, PSNR, SSIM, and QI. S Pradeep, P Nirmaladevi [34], compared various spatial, transform and CNN techniques for ultrasound image denoising, and performance was evaluated based on MSE and PSNR. Simone Cammarasana et al. [35], defined real-time denoising of ultrasound images using a novel deep learning framework (tuned WNNM (Weighted Nuclear Norm Minimisation)).

Summary of Literature Survey

Over the past few decades for speckle reduction in ultrasound imaging systems, several filters have been proposed. They include LEE, KUAN, SRAD, HMF, and MHMF. Few researchers opted for an anisotropic diffusion filter and various artifact removal techniques.

Further, they have used median filters, hybrid median filters, and moving average hybrid median filters. Also, explored multiscale speckle reduction method based on wavelet filters.

The performance of speckle reduction filters was evaluated based on MSE, SNR, PSNR, RMSE, and SSIM.

Another method adopted to enhance image quality in ultrasound is contrast enhancement techniques like Histogram Equalization, CLAHE, HE, BBHE, and DSIHE.

Method

Aim

The aim of this research article is to devise an algorithm for denoising of heart ultrasound images.

Dataset

The data set used in this work for experimentation is 2D echocardiography–apical four-chamber view (A4C) videos gathered from the hospitals. The length of each video is considered as one second because one heartbeat or cardiac cycle takes about 0.8 sec to complete one cycle. All videos have a standard frame rate of 30fps. Videos used are in AVI format. Experimentation is carried out on 37 different videos.

Filter Overview

This section covers the explanation of existing filters that are implemented as part of this work. All of these filters are part of the spatial domain, which involves the direct manipulation of pixels in an image.

Lee Filter

Works on the multiplicative model, local statistics are used to effectively preserve edges, smoothing is performed if the variance is high or not constant [19], [31].

Lee Filter is given by the formula

Yij = K + W * (C – K) ……(1)

To calculate the de-speckled image Yij following steps are carried out;

1. Calculate the mean of kernel/window i.e., K
2. Calculate the center element in the kernel/window i.e., C
3. Calculate the variance of the reference image i.e., σ^2
4. Calculate the variance of the pixel in the kernel of the specked image i.e., $\sigma^2 k$
5. Calculate the weighting function $W = \sigma^2 k / (\sigma^2 k + \sigma^2)$

Kuan Filter

It is a signal-dependent additive noise formulation and is given by the equation [8], [21].

$$\hat{Y}(x,y) = I(x,y)\, W(x,y) + \overline{I(x,y)}\, \{1 - W(x,y)\} \quad \text{………. (2)}$$

Where $\hat{Y}(x,y)$ is the signal estimates, and W(x,y) is a weighting function given by

$$W(x,y) = 1 - C_n^2 / C_I^2 (x,y) \frac{1 - C_n^2 / C_I^2 (x,y)}{1 + C_n^2} \quad \text{……(3)}$$

Frost Filter

The Frost filter carries out the denoising by convolving the observed image with a spatially varying kernel as [8], [22].

$$\hat{Y}(x,y) = I(x,y) * m(x,y) \qquad (4)$$

The kernel m(x,y), is at a center with a pixel location of (x_0, y_0) and is given by

$$m(x,y) = K1 \exp(-KC_I^2 (x0, y0)|x,y|) \qquad (5)$$

Anisotropic Diffusion Filter (AD)

The diffusion process of the image can be expressed as [13]:

$$\begin{cases} \dfrac{\partial u(x,y;t)}{\partial t} = \nabla\left(\begin{bmatrix} c(|\nabla I_\sigma(x,y;t)|) \\ * \ \nabla I(x,y;t) \end{bmatrix}\right) \\ I(x,y,0) = I_0(x,y) \end{cases} \quad \text{………..(6)}$$

Here $\nabla I(x,;t)$ is an original image to be processed, $\partial I(x,y,t)/\partial t$ is the partial derivative of $I(x,y,t)$ and

$$c(x,y,t) = g\left|\left|\nabla I(x,y,t)\right|\right| = e^{||\nabla I(x,y,t)||/K^2} \quad \text{……..(7)}$$

Where K is the diffusivity parameter. This filtering technique is successfully applied to 2D ultrasound images. This anisotropic diffusion filter gives a better result when the image is corrupted by additive noise, while its performance is not as good for multiplicative noise like speckle noise.

Speckle reducing anisotropic diffusion filter (SRAD)

Yu and Acton established a diffusion-based technique for speckle reduction [13].

The same equation 8 is used, where c (·) is a function of the instantaneous coefficient of variation (ICOV) q and given by the ratio of standard deviation to mean [13]:

$$q(x,y^{\cdot},t) = \frac{std\{I(x,y^{\cdot},t)\}}{\bar{I}(x,y^{\cdot},t)} \qquad (8)$$

The diffusion function c(.) is given by

$$c[q(x,y^{\cdot},t), q_0(t)] = \left(1 + \frac{q^2(x,y^{\cdot},t) - q_0(t)}{q^2(x,y^{\cdot},t)\left(1 + q_0^2(t)\right)}\right) \quad \text{…………(9)}$$

Here q_0 is the speckle scale function

Median Filters

It is a typical non-linear filter in which each pixel is checked against its neighbours and the median value is used to replace each pixel [24], [29]. Sorting the pixel values in the window yields the median value. This median value is then used to replace the pixel in question. Because it preserves picture details, the median filter produces better filtering [24], [29]. The disadvantage of this filter is that the edges are not preserved.

Hybrid Median Filter (HMF)

A hybrid median filter, also known as a corner preserving median filter, is one of the variants of the median filter [24], [29]. A three-step ranking technique is performed in this process, in which neighbourhood pixels are ranked in three groups: 45^0, 90^0, and the centre value. The median value 'MD' of the neighbours in "X" is derived using the pixel values of 45^0 neighbours.

The median value 'MR' of the pixels constituting the "+" is obtained after the pixel values of 90^0 neighbours form a "+." The median is calculated using these two values as well as the value of the centre pixel. This is now utilised as a pixel value. HMF's computational complexity does not rise despite the use of three-step ranking. The reason for this is that the total number of values in all three types of ranking procedures is minimal in comparison to the entire 3x3 window, which will have 25 values for comparison, resulting in increased complexity.

Both the "X" and "+" groups in HMF have only 9 values each, and the final comparison has only three values. When compared to the traditional median filter, the hybrid approach adds logic and value manipulation; even so, the hybrid method is faster. The HMF [24], [29] solves the problem of median filters erasing thinner lines and round corners.

$$M = \text{median}\ (MD, MR, C) \tag{10}$$

Where M is a new pixel value, MD is the Median of diagonal neighbors, MR is the Median of vertical and horizontal neighbors

C is the Center pixel value. Filters explained above are studied as part of previous research and published in [29]

Modified Hybrid Median Filter (MHMF)

For speckle reduction and edge preservation in ultrasound images, a Modified Hybrid Median Filter (MHMF) [24] was designed. It's similar to HMF in that it works with sub-windows. The suggested filter employs a 5x5 window size [24]. Wx and W+ are used to represent pixels in 45^0 and 90^0 neighbours, respectively [24]. Instead of using the median as in HMF [24], the maximum value of the pixels in the Wx sub-neighborhood is used to retain the diagonal edges.

The MHMF is implemented as follows:

$$W_H\ (i, j)=\{\ y(i, j–l);-N \leq l \leq N, \text{ where } N \neq 0\ \} \tag{11}$$

$$W_V\ (i, j) = \{\ y(i\text{-}l, j);\ -N \leq l \leq N, \text{ where } N \neq 0\ \} \tag{12}$$

$$W_{D1} = \{\ y(i+l, j–l);\ -N \leq l \leq N, \text{ where } N \neq 0\ \} \tag{13}$$

$$W_{D2} = \{\ y(i\text{-}l, j–l);\ -N \leq l \leq N, \text{ where } N \neq 0\ \} \tag{14}$$

Where pixels in the horizontal direction are denoted as (W_H), vertical as (W_v), and diagonal as (W_{D1}) and (W_{D2}), respectively, in equations 11 to 14 [24].

The window W_X is a combination of the two sub-windows W_{D1}, $W_{D2,}$ and the center pixel and is given in equation 15.

Similarly, the two sub-windows W_H, $W_{V,}$ and the center pixel are combined to represent the pixels in W_+ as in equation 16.

$$W_X\ (i, j) = \{y(i, j), W_{D1}\ (i, j)\ , W_{D2}\ (i, j)\ \} \tag{15}$$

$$W_+\ (i, j) = \{y(i, j), W_H\ (i, j)\ , W_V\ (i, j)\ \} \tag{16}$$

Information Preserving Hybrid Median Filter (IPHMF)

The proposed filter's (IPHMF) efficiency is tested for the ultrasound videos collected from the hospitals and taken from the repository. The effectiveness of the filters is proved with the computation of RMSE, PSNR, and SSIM. It works on the sub-windows similar to MHMF. The window size used for the proposed filter is 3x3. The pixels in 45^0 neighbors and 90^0 neighbors are represented by W_X and $W_{+,}$ respectively [24]. To preserve the diagonal edges as well as information contained in the selected window, the maximum and mode values of the pixels in the sub-neighbor-hood are taken.

The IPHMF is implemented as follows [31]:

Let W be a (2N+1) x (2N+1) square filter window and the pixels in this window are divided into four sub-windows consisting of the pixels in horizontal (W_H), vertical (W_V) and diagonal (W_{D1}), and (W_{D2}) directions and are given by below equations.

Where, k = [1,2,3…n]

$$Horizontal\ and\ Vertical\ Elements\ W_{+} = MODE\ (W_H \cup W_V \mid (W_H = Y_{i\pm k,\ j}, W_V = Y_{i,\ j\pm k}))$$

$$\text{Diagonal Elements}\ W_X = MAX\ (W_{D1} \cup W_{D2} \mid (W_{D1} = W_{D2} = Y_{I\ \pm k,\ j\pm k}))$$

The final pixel value of the IPHMF is calculated as: $\hat{Y}(i,j) = MEDIAN\ (Y_{(i,j)}, W_X, W_{+})$ (17)

Pseudo Code – IPHMF

Input: Ultrasound Video
Output: Filtered/Denoised Video

1. Begin
2. Choose and read the video
3. Calculate number of frames – no_of_frames
4. Initialize tmp to 1
5. while tmp < no_of_frames
6. Extract- desired frame – Img
7. Convert RGB to gray
8. Calculate size of reference image Img
9. Call the function FImg=IPHMF(Img,3)
10. Obtain denoised/filtered image in FImg
11. Calculate MSE, PSNR, RMSE and SSIM
12. MSE = immse(double(FImg), double(Img));
13. PSNR = 10 * log10(256^2 / MSE);
14. RMSE = sqrt(MSE);
15. SSIM = ssim(double(FImg), double(Img));
16. tmp=tmp+1

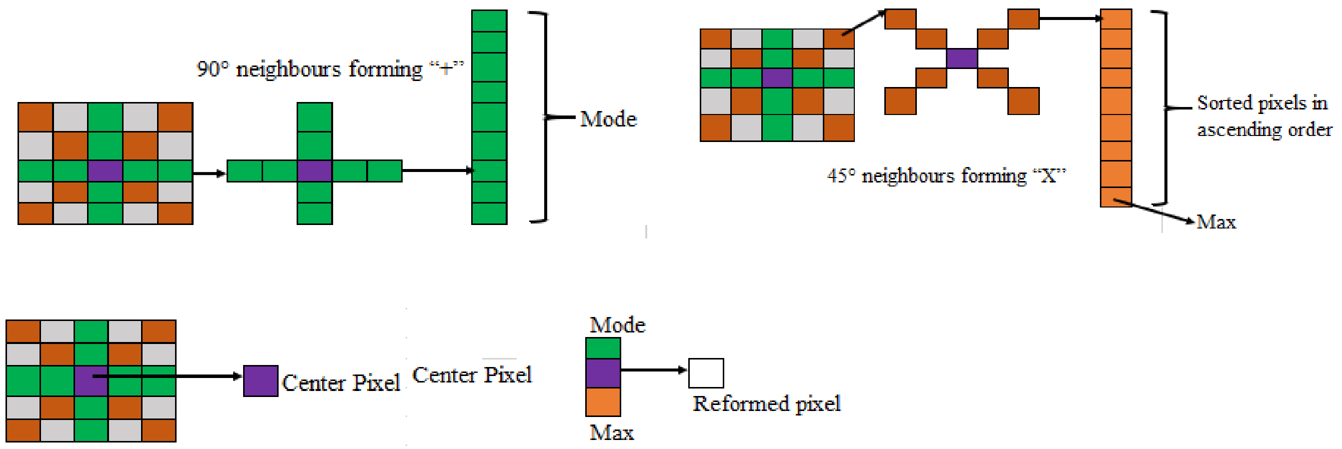


Figure 2. Illustration of Information Preserving Hybrid Median Filter (IPHMF)

Figure 2 is the diagrammatic illustration of IPHMF, which shows how the neighboring pixels are formed for 45^0 and 90^0.

A window of size 3x3 is selected and two sub-neighborhoods W_X and W_+ are formed. The pixels in the sub-neighborhoods W_X and W_+ are arranged in ascending order. Mode value of the pixels in W_+ and the maximum value of the pixels in W_X are computed. The values obtained above and the center pixel are arranged in ascending order and the median value is obtained. Finally, the filter replaces the center pixel with the median value obtained in the above step. The simulation is carried out in a MATLAB 19 environment to assess the performance of the proposed filter.

Performance parameters used [6], [18]-[19], [24], [29]

Mean Squared Error (MSE):

$$\frac{I}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\left[I(m,n)-\hat{I}(m,n)\right]^2 \qquad (18)$$

Where, I (m, n) original image, Î (m, n) filtered image, M: rows, N: columns.

Peak Signal to Noise Ratio (PSNR):

$$10 \log_{10} (2B - 1)^2 / MSE \qquad (19)$$

Where, B: Number of bits

Structural Similarity (SSIM)

$$\frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)} \qquad (20)$$

Where, μ = average of x & y window, σ = variance, c1 & c2 are variables to stabilize the division with weak denominator.

Root Mean Squared Error (RMSE)

$$\sqrt{\frac{I}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\left[I(m,n)-\hat{I}(m,n)\right]^2} \qquad (21)$$

Where, I (m, n) original image, Î (m, n) filtered image, M: rows, N: columns.

Sum of Absolute Difference (SAD)

$$\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} | C(i, j) - R(i, j) | \qquad (22)$$

Where, N: Size of the macro-block. Cij: Pixels in the current macroblock, Rij: Pixels in the reference macroblock.

Results

The analysis of noise removal with the preservation of edges is done by various performance

parameters for an algorithm. Standard parameters for the analysis of de-speckling algorithms are available in the literature.

PSNR and MSE are two measures for measuring noise reduction that are available. These aren't useful in evaluating the performance of edge preservation capabilities [13].

PSNR's mathematical methodology estimates the suppressed noise in the reconstructed image by calculating the difference between pixels in two images [13]. Various measures [17] such as PSNR, RMSE, and SSIM are used to evaluate the performance of each approach.

Kernel size finalization for denoising [31]

To decide the kernel size experimentation was carried out on all filters using 3x3 and 5x5 as kernel size.

Table 1, gives the experimentation results of 3x3 and 5x5 size kernels. Results show that 3x3 kernel performance is better than 5x5 kernel, measured against RMSE, PSNR, and SSIM.

Based on the results of table 1, 3x3 kernel is considered for further analysis in the proposed filter.

Table 1. Performance evaluation of various filters for 5x5 and 3x3 kernels

5x5											
RMSE				PSNR				SSIM			
LEE	HMF	MHMF	IPHMF	LEE	HMF	MHMF	IPHMF	LEE	HMF	MHMF	IPHMF
4.36	2.91	1.24	1.62	35.9	39.93	46.6	44.19	0.8	0.92	0.97	0.97
3x3											
RMSE				PSNR				SSIM			
LEE	HMF	MHMF	IPHMF	LEE	HMF	MHMF	IPHMF	LEE	HMF	MHMF	IPHMF
10.2	2.33	1.22	1	29.2	41.56	47.09	48.52	0.7	0.97	0.99	0.99

Table 2. Computation Complexity

Video	3x3	5x5
Video1	0.061728	0.109581
Video2	0.061142	0.108977
Video3	0.061467	0.119892

Video4	0.076722	0.138375
Video5	0.061508	0.110832
Video6	0.062742	0.109122
Video7	0.061949	0.111895
Video8	0.057917	0.105061
Video9	0.059759	0.109229
Video10	0.061366	0.106398

Video	**3x3**	**5x5**
Video11	0.068797	0.146591
Video12	0.068284	0.148283
Video13	0.069007	0.12724
Video14	0.067961	0.121197

Video15	0.0744	0.173538
Video16	0.06542	0.108688
Video17	0.054656	0.123672
Video18	0.058003	0.124965
Video19	0.075963	0.133879
Video20	0.062449	0.141108

Average 3x3: 0.064562

Average 5x5: 0.123926

Based on the results of Tables 1 and 2, the 3x3 kernel is considered for further analysis in the proposed filter.

Also, the results in table 2 show that the average computation complexity of 3x3 kernel size against 5x 5 kernel size is 50% less.

Using 3x3 kernel size experimentation was carried for LEE, HMF, MHMF, and IPHMF filters. Qualitative analysis and quantitative analysis of these filters are carried out to select the best performing filter.

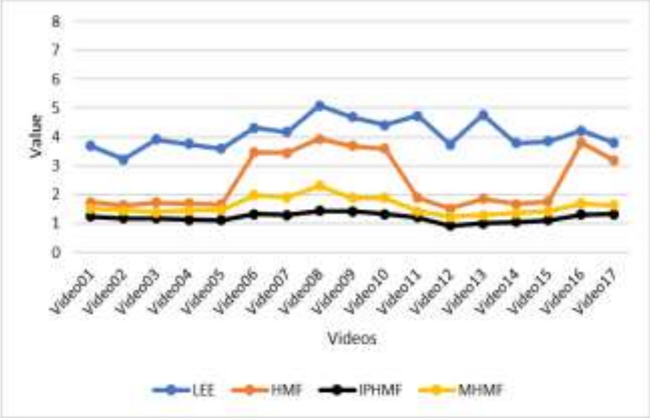
Quantitative Analysis:

Table 3. Comparison of results between existing and proposed filter

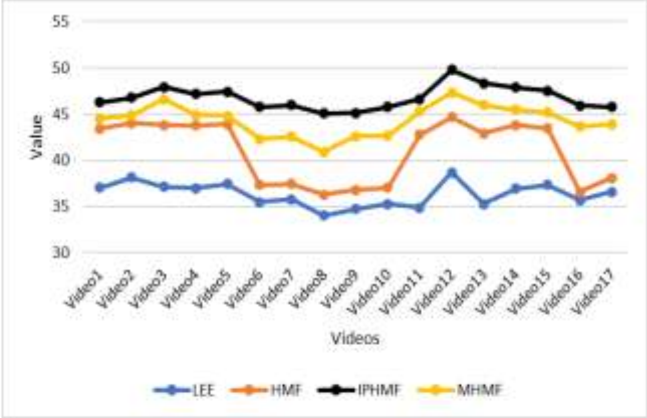
Videos	RMSE				PSNR				SSIM			
	LEE	HMF	MHMF	IPHMF	LEE	HMF	MHMF	IPHMF	LEE	HMF	MHMF	IPHMF
Video01	3.687	1.75	1.525	1.253	37.04	43.42	44.53	46.29	0.773	0.908	0.955	0.958
Video02	3.226	1.628	1.461	1.178	38.16	44	44.87	46.8	0.828	0.92	0.96	0.965
Video03	3.92	1.731	1.398	1.178	37.12	43.84	46.65	47.95	0.749	0.908	0.963	0.965
Video04	3.758	1.692	1.455	1.139	36.99	43.75	44.94	47.2	0.774	0.913	0.96	0.963
Video05	3.59	1.659	1.477	1.112	37.45	43.92	44.82	47.42	0.804	0.919	0.96	0.965
Video06	4.314	3.467	1.979	1.322	35.51	37.37	42.31	45.8	0.93	0.956	0.985	0.989
Video07	4.168	3.447	1.911	1.296	35.79	37.42	42.57	45.97	0.936	0.959	0.985	0.99
Video08	5.083	3.934	2.311	1.436	34.05	36.27	40.9	45.06	0.912	0.947	0.982	0.986
Video09	4.684	3.694	1.895	1.423	34.75	36.82	42.63	45.13	0.923	0.953	0.983	0.987
Video10	4.414	3.597	1.889	1.322	35.27	37.05	42.66	45.78	0.911	0.953	0.983	0.987
Video11	4.728	1.885	1.419	1.222	34.87	42.78	45.26	46.62	0.678	0.889	0.961	0.961
Video12	3.734	1.526	1.238	0.925	38.69	44.69	47.33	49.78	0.754	0.863	0.945	0.947
Video13	4.765	1.863	1.303	1.013	35.28	42.9	45.98	48.35	0.743	0.904	0.959	0.961
Video14	3.783	1.675	1.368	1.057	36.94	43.81	45.49	47.88	0.756	0.895	0.957	0.959
Video15	3.843	1.765	1.425	1.125	37.36	43.47	45.18	47.51	0.774	0.881	0.955	0.957
Video16	4.214	3.802	1.691	1.318	35.68	36.58	43.65	45.9	0.924	0.948	0.985	0.989
Video17	3.801	3.187	1.633	1.33	36.58	38.11	43.93	45.76	0.924	0.956	0.986	0.989

Table 3, shows the experimental results of 17 different videos. As seen from table 3, proposed IPHMF results (highlighted) outperformed the other existing filters, including MHMF which was proposed in [24].

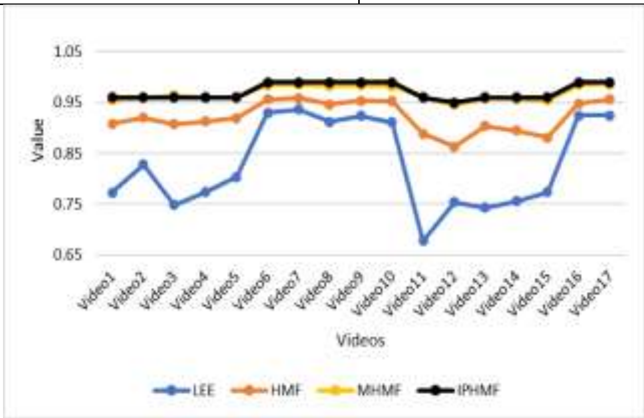
RMSE and PSNR values in table 3, are represented graphically in Graph 1, 2, and 3. From graphs, one can see that RMSE and PSNR values of IPHMF are better than other filters under evaluation.



Graph 1. RMSE values of IPHMF



Graph 2. PSNR values of IPHMF



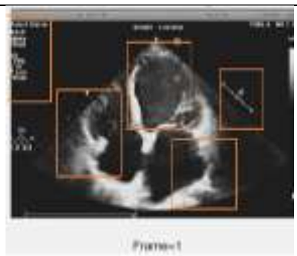
Graph 3. SSIM values of IPHMF

Qualitative Analysis:

(a) Original Image

(b) Lee Filtered Image

(c) HMF Filtered Image



(d) IPHMF Filtered Image

Figure 3. Qualitative analysis of Denoising filters

Figure 3, shows the qualitative analysis of various denoising filters under evaluation. Figure 3(a) is an original image, figure 3(b) is a Lee filtered image, figure 3(c) is an HMF filtered image and figure 3(d) is an IPHMF filtered image. For visualization purposes, sample ROIs are marked in figure 3(d) to showcase the output of the filter and comparison of results with other filters. It is observed that IPHMF not only preserves the information of an image but also helps in the preservation of sharp edges.

Discussion

From the results presented in table 2, it can be inferred that even though the PSNR values of LEE filter are comparable with HMF, the visual quality of these images is not up to the mark hence PSNR doesn't correlate well with a subjective measure of image quality. The fundamental disadvantage of the LEE filter is that it ignores speckle-noise at the edges. SSIM values of LEE filter algorithm is comparable but are less than HMF and IPHMF. It fails to remove noise due to high correlation.

A Modified Hybrid Median Filter (MHMF) is developed by another researcher for speckle reduction and edge preservation of ultrasound images. It works on the sub-windows similar to HMF. The window size used in MHMF filter is 5x5. The pixels in 45^o neighbors and 90^o neighbors are represented by and W_x and W_+ respectively. To preserve the diagonal edges, the maximum value of the pixels in W_x sub-neighbourhood is taken, instead of the median as in HMF.

The obtained results indicate that the IPHMF performs efficient de-speckling for images involving sharp and curved edges. The visual quality is also enhanced and the measured quality metric shows that the IPHMF technique has low RMSE and high SSIM and PSNR in comparison with HMF and LEE. IPHMF has improved the detectability of small structures without compromising the original image's clarity or anatomical information. IPHMF works well and also preserves the edges and minute details effectively.

Conclusion

In healthcare lot of importance is given to information preservation, any loss of useful information is not acceptable as a result presence of minimum noise can be tolerated in ultrasound imaging.

After, exhaustive experimentation on different existing denoising algorithms available in the literature, and came up with a new algorithm “Information Preserving Hybrid Median Filter (IPHMF)”.

The proposed filter IPHMF outperforms, LEE, HMF, and MHMF filters. Maintains balance between speckle suppression and feature preservation based on the performance metrics like RMSE, PSNR, and SSIM.

IPHMF reduces the speckle noise and at the same time maintains the edges and medical information of the video. The preserved edges after IPHMF denoising helps to estimate the anatomical information effectively. Ultrasound videos contain the inherent speckle noise which originates from the scanning probe. The proposed method gives results as RMSE: 1.21, PSNR: 46.77, SSIM: 0.97, as compared to LEE (RMSE: 4.10, PSNR: 36.32, SSIM: 0.82), HMF (RMSE: 2.48, PSNR: 40.95, SSIM: 0.92), MHMF (RMSE: 1.61, PSNR: 44.33, SSIM: 0.96).

SSIM gives better quality assessment, but this method is computationally quite complex, and on the other hand, RMSE and PSNR are the simpler ones. In this research, real ultrasound videos were used. SSIM values of the proposed filter are better than LEE and HMF and are comparable with MHMF. The proposed filter IPHMF is good in feature preservation when compared to the other filters. It is also observed from the tables that the other filters show only low to moderate performance in terms of PSNR and RMSE.

Disclosure and Conflicts of Interest

The authors declare that they have no competing interests

Hazards and Human or Animal Subjects

The authors declare that work involve does not make use of any animal subject, hazardous material or human subjects.

The data that support the findings of this study was made available by the hospitals and utmost care while sharing and usage of the data is taken care. It has been provided in the form of masked data with proper prior ethical approval and consent to use it for the research, as such no specific approval is required from the hospitals or person for the publication of this research paper.

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Authors Contribution

Mrunal Annadate, collected the data from the hospital, carried out the experimentation, analysed the results and got it reviewed with subject matter experts from the hospitals. Shamla Mantri have contributed equally in writing the manuscript. Both the authors read and approved the final manuscript.

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