Partial Differential Equation (PDE) based Hybrid Diffusion Filters for Enhancing Noise Performance of Point of Care Ultrasound (POCUS) Images

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***Abstract*—A hybrid filter is developed by combining smoothing and edge preservation properties of anisotropic diffusion (AD) filters and noise reduction features of median filtering. Mixed Gaussian Impulse noise and speckle noise are considered for analysis. The performance of this hybrid filter is verified using ultrasound images. The effectiveness of this filter is assessed with Point of Care Ultrasound (POCUS) images to verify whether the algorithm developed is applicable to them. POCUS refers to a handheld portable ultrasound instrument that can be used at patient bedside. Quantitative analysis with COVID-19 POCUS images, in terms of SNR, SSIM and MSE is performed. Results demonstrate that for all test images, the proposed filter has the best SNR, least MSE, and highest SSIM. Significant improvement in image quality is thus observed both qualitatively and quantitatively. The novelty of suggested technique is its effectiveness in reducing both mixed Gaussian impulse noise and speckle noise in ultrasound as well as POCUS images without the need for separate filters. POCUS has played a significant role in the diagnosis and management of pulmonary, cardiac and vascular pathologies associated with COVID-19. Automatic segmentation of these images and subsequent automatic detection and diagnosis are becoming increasingly popular due to the rapid development of artificial intelligence technologies. These results are useful in implementing better pre-processing prior to segmentation of ultrasound images to facilitate improved patient care.**

Keywords—Anisotropic diffusion filter; POCUS; mixed Gaussian impulse noise; speckle noise

I. Introduction

The use of ultrasound imaging for medical diagnosis is widely accepted due to its non-invasiveness, no risk factor, and efficiency. However, the acquisition process introduces noise in the signal, which has an impact on subsequent processes like segmentation, quantitative analysis, etc. The granular interference called, speckle noise is inherent in Ultrasound images. Impulse noises are yet another sort of noise present in ultrasound imaging. Another common type of noise found in medical images is Additive White Gaussian noise. Several different kinds of filters must be designed in order to effectively remove these noises. A median filter is a good choice for eliminating impulsive type noises. But it cannot suppress median tailed noise distributions like Gaussian. If linear filters are used to process such noise, they tend to blur the edges of the image [1]. Also, they cannot remove mixed Gaussian impulse noise and speckle noise adequately [2]. Studies show that various types of nonlinear filters [3] can be effectively used to remove such noises. Partial Differential equation based Anisotropic Diffusion (AD) filters are known for their ability to preserve edges in an image during denoising. AD approaches are being used in image processing since 1987 when Perona and Malik [4] introduced a non-linear method of edge preserving smoothing that outperformed the existing traditional linear methods [5]. Since ultrasound images are mostly affected by speckle noise and impulse noises [6], a combination of filter structures, which can filter out all types of noises, need to be derived. Median filter is usually employed for suppressing impulse noises like salt and pepper noise. However, it is not effective for reducing Gaussian noise or speckle noise [4]. Anisotropic Diffusion filters are the best choice in removing Gaussian noise and speckle noise. This paper introduces a new hybrid form of median and AD filters combining the advantages of median filters in removing impulse noise and AD filters in rejection of Gaussian and speckle noise. This hybrid form is found adequate for the removal of both mixed Gaussian impulse noise and speckle noise. The results are verified qualitatively and quantitatively.

In 1987, Perona and Malik proposed Nonlinear Anisotropic diffusion [4]. It is a filtering technique based on partial differential equation (PDE). It performs nonlinear smoothing and effectively reduces the image noise. The salient feature of AD filtering is that it can preserve important image features such as edges. While smoothing the rest of the image, it can maintain crisp texture detail at all viewing orientations [7]. It implies that blurring of edges and thus loss of information can be avoided. [8] Provides a derivation of AD filters for speckle reduction. Speckle noise is a form of multiplicative noise, usually present in medical ultrasound images and Synthetic aperture radar (SAR) images. Nonlinear means of removing speckle noise is vital in such cases. Some of the classical speckle removing filters like Lee filter or Frost filter tends to remove some important data also. Recent developments based on anisotropic diffusion filtering overcome the major drawbacks of conventional spatial filtering [8][9], and significantly improve image quality and provide better results than above mentioned filters[9][10].

Motivated from the work of Perona and Malik, various additive as well as multiplicative noise removal algorithms have been developed. A speckle reducing anisotropic diffusion (SRAD) method was proposed by Yu and Acton [8] which handles various noise distributions, especially, speckle. Further improvement of the SRAD was presented by Karl et al. with the oriented speckle reducing anisotropic diffusion (OSRAD) method [11], incorporating local directional variance of image intensity. Both these methods have the drawback of producing over smoothed images. This problem was solved by anisotropic diffusion with memory based on speckle statistics (ADMSS) method [12] by Ramos, Zhou et al. [13] proposed a doubly degenerate nonlinear diffusion (DDND) model by using the diffusion equation theory. It guides the denoising process with the aid of the gradient information and the grey level information. In [14] speckle noise suppression and image segmentation of ultrasound image using AD filters with an improved diffusion coefficient is discussed. In [15] the drawbacks of SRAD filter are eliminated using an optimization algorithm for diffusion coefficient. The algorithm well removes speckle and is more suitable for image segmentation. However, no other noise than speckle is considered [16][17]18]. In [21], Mei Gao et al. proposed a filtering scheme for ultrasound images, which the noise at the edge is processed during denoising process. This is achieved by analyzing the divergence term. Most of the above mentioned developments and research, aided in speckle noise removal of ultrasound images. Such an extensive research has been done in the area of AD filters viewing its selective smoothening and edge preserving capability and speckle denoising property [19][20][22][23][24]. But almost all of them works on speckle removal only and doesn't mention about the other relevant noises.

However, in addition to speckle noise, impulse noise is present in ultrasound images and Gaussian noise is common in medical images. None of the above works consider the removal of such noises. In [2], Meenavati and Rajesh proposed a method to remove mixed Gaussian impulse noise from images using volterra filters. But the analysis does not consider ultrasound images or reduction of speckle noise. Since speckle is an important consideration in US images, AD with removal of speckle as well as mixed Gaussian impulse noise is significant. All these discussions clearly demand the development of a filter which can eliminate both speckle and mixed Gaussian impulse noise.

The uniqueness of proposed work is that the same filter can be used for reduction of both mixed Gaussian impulse noise and speckle noise. In this paper, the emphasis is given to the analysis of POCUS (Point of Care Ultrasound) images to verify whether the algorithm developed is applicable to POCUS images. Analysis with parameters like SNR, MSE, and SSIM is done to quantitatively verify the performance of the proposed filter for POCUS images. Results are found to be better than using median and simple AD filters for noise removal.

Significances of the work are listed below:

- Addresses the removal of almost all kinds of noise such as mixed Gaussian impulse noise and speckle noise, whereas the previous literature on AD primarily discusses speckle noise.
- No prior work has considered the denoising of POCUS images.
- Qualitative and quantitative analysis gave better results with high PSNR, least MSE and improved SSIM compared to the existing methodologies.

This paper is organized as follows. In Section II, a brief review of POCUS is given. The design features of median and nonlinear AD filters are analyzed in Section III. In Section IV, the features of the proposed filter are discussed. Methodology of work is presented in Section V. Experimental results and Quantitative analysis using these images is given in Section VI. Concluding remarks are presented in Section VII.

II. A Review of POCUS

Point-of-care ultrasonography (POCUS) refers to handheld portable ultrasound Instrument that can be used at patient bedside. In the midst of COVID-19 pandemic, such hand-carried ultrasound devices emerge as a tool that can simplify the imaging process [25]. These devices are perfect for COVID-19 scans because they are small enough to be covered completely with a probe cover and due to its small size, the decontamination process is also simplified. Several studies have indicated that wrapping the whole device in plastic or using single-use plastic sterile probe covers is enough to condense the decontamination process. In addition, a trained healthcare provider requires only 5 to 10 minutes to conduct a lung POCUS study [25]. Experts from China have specifically advocated for the use of hand-held POCUS in COVID-19 due its clinical and economic value [26]. The utility of these devices in continuous monitoring COVID-19 patients managed at home have also been reported. The salient features of POCUS such as its ability to connect to smartphones and tablets, artificial intelligence-assisted diagnosis, wireless feature, rechargeable batteries, and low cost make them a convenient and practical imaging option suitable even in remote areas [25][26][27]. Research has shown that point-of-care ultrasound device can help manage infectious diseases, as well as abdominal cardiac and pulmonary pathologies [25]-[29]. Images of some of the POCUS instruments available in market are shown Fig. 1

(a) Lumify Portable Ultrasound by Philips

(b)

Fig. 1. (a) Lumify Portable Ultrasound by Philips (b) The Breakthrough Butterfly iQ Vet ultrasound System (Photo Courtesy of Butterfly Network, Inc.).

III. Filtering Techniques

A. Anisotropic Diffusion Filters

As presented by Perona and Malik in [4], the basic PDE equation of anisotropic diffusion can be represented as

$$\frac{\partial I}{\partial t} = div(c(x,y,t)\nabla I) = \nabla c \nabla I + c(x,y,t)\Delta \mathrm{I} \quad (1)$$

Here original Image is $I_0(x,y)$. I(x,y,t) is the smoothened image via anisotropic diffusion method as the solution of equation (1). Δ is the Laplacian operation, ∇ is the gradient of the image. *div(...)* denotes the divergence operator and c(x,y,t) is the diffusion coefficient. c(x,y,t) is a function of the image gradient which preserves edges and controls filtering process by controlling the rate of diffusion. The Diffusion coefficient can be evaluated by the two functions:

$$c(\|\nabla I\|) = e^{-(\frac{\|\nabla I\|}{k})^2} \quad (2)$$

$$c(\|\nabla I\|) = \frac{1}{1+(\frac{\|\nabla I\|}{k})^2} \quad (3)$$

where k is the edge magnitude parameter.

A four-neighbourhood discrete form of (1) is given by

$$I(x,y,t+\Delta t) = I(x,y,t) + \frac{\Delta t}{4\sum_{\rho \epsilon z} G(\nabla I(\rho,t))} \quad (4)$$

where Z is the set of the four neighbourhoods of pixel (x,y), denotes a neighbourhood of (x,y) , and $\nabla I(\rho,t) = I((\rho,t) - I(x,y,t)$is the image gradient at current time t . The above equation is recursive over time until it meets the stopping criterion. Perona and Malik suggested that a desirable diffusion coefficient should satisfy the basic condition that it diffuses more in smooth areas and less around high-intensity transitions. By this technique, noise or unwanted texture is smoothed, while edges are sharpened [30]. The function G is a monotonically decreasing function, the edge magnitude parameter. Depending upon the value of the monotonically decreasing function G and the |d| which is the absolute value of gradient, the anisotropic diffusion filtering can be formulated as follows:

- The range of G is [0, 1]. For any given parameter k, Monotonically decreases with |d|. If |d|→ 0 then G→1 is isotropic diffusion (Gaussian filtering); if |d| → ∞ then G→ 0 the diffusion flow is arrested and the edges are preserved.
- For any given |d|, G monotonically increases with parameter *k*, which means that *k* controls the generosity of the anisotropic diffusion filter. For higher value of k, the diffusion process is more likely to smooth the image and reduce the noise; while for lower value of k, the diffusion process is more restricted and is more likely to preserve image features [31].

The advantage of this technique is that it reduces noise and preserves the edges so that crisp edge features will be obtained.

B. Median Filter

Median filter is a nonlinear filter used for noise reduction in images. Each pixel value is obtained by taking the median value of neighboring pixels under the window. Thus, the result is the middle value after the input values have been sorted. When an image is considered, each pixel of the filtered image is replaced by median brightness value of its neighbourhood pixels in the original image.

Median filtering is a kind of smoothing technique like Gaussian filtering. Almost all the smoothing techniques including Gaussian filter adversely affect edges since they blur the image. Preserving edges is critically important for visual appearance of the image. For moderate levels of Gaussian noise (medium tailed distribution), median filter performs better than Gaussian filter and preserve edges. However, its performance is not significantly improved for high noise levels [32]. For removing salt and pepper noise (impulsive noise) median filters are more effective.

C. Proposed Hybrid Filter

The proposed filter is developed by combining the ability of median filter to remove impulsive noises with capabilities of AD filters to filter out Gaussian noise and speckle noise. Designing process involves two steps. The first step is to determine the median value of each and every pixel in the image being analysed. In the second step, these median values are used to design discretised form of anisotropic diffusion equation given in (5). To incorporate advantages of median filter, each pixel of the noised image used in the anisotropic diffusion process is replaced by median value its neighbourhood pixels and further processing is done. As described in [9], the discretized form of Perona –Malik Anisotropic diffusion equation is

$$I_{t+1}(s) = I_t(s) + \frac{\lambda}{\eta_s} g_k(|\nabla I_{s,p}|) \| \nabla I_{s,p} | \quad (5)$$

Where I is the discretely sampled image, s the pixel position in the 2D grid, t denotes iteration step, g denotes conductance function and k is the gradient threshold parameter [7]. Constant $\lambda \in (0,1)$ determines the rate of diffusion and η_s

denotes the spatial 4-pixel neighborhood of s, $\eta_s = \{ N,S,E,W\}$ are the neighboring pixels of s in North, South, East and West directions. Visualization of 2D discrete diffusion is given in Fig. 2. The degraded image with each pixel replaced by its median value is given to the AD filter so that better removal of noise can be achieved.

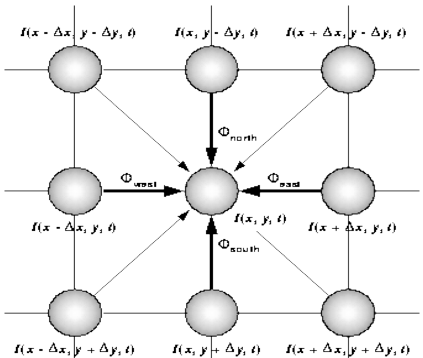

Fig. 2. Eight Neighborhood Visualisation of 2D Discrete Diffusion.

IV. Methodology

This work consists of four steps. They are

- Design of filters
- Implementation
- Qualitative Comparison
- Quantitative Comparison

Design is based on the design equations discussed in Section III. The work is implemented using Matlab R2018b. The images used are degraded by mixed Gaussian impulse noise of standard deviation = 0.02 and impulse noise of density =0.02 in order to assess how different filters respond to noise. Zero mean speckle noise with variance 0.04 is used for speckle noise analysis. In the proposed algorithm, the US image contaminated with mixed Gaussian impulse noise is decomposed into mask images considering 8-pixel neighborhood. The median filtered mask images are used to evaluate the diffusion coefficient in equation (3), which is further utilized for calculating AD algorithm. Initially, 15 iterations are done for simple AD and the proposed hybrid AD filters.

The qualitative analysis and comparison is performed by visually analyzing resultant images. By comparing SNR, MSE and SSIM, using the equations given in Section 4.2, quantitative analysis is done.

V. Experimental Results

Kidney-cut ultrasound image of size 522X469 and Ben1 ultrasound image of size 538X317 are used for initial verification of noise filtering process. Gaussian noise of standard deviation σ =0.02 and impulse noise density ρ=0.02 are added to the image. The proposed hybrid filter output is compared with simple AD filter and median filter outputs. The output of kidney_cut and Ben1 US images to simple AD filter, proposed hybrid filter and median filter are shown in Fig. 3. It can be seen that though simple AD filter is not good for eliminating Gaussian impulse noise, the performance is robust for the proposed hybrid AD filter. For median filter, visual quality seems comparatively far better than simple AD filter. But from quantitative analysis we can see that proposed hybrid filter outperforms median filter in SNR, MSE and SSIM.

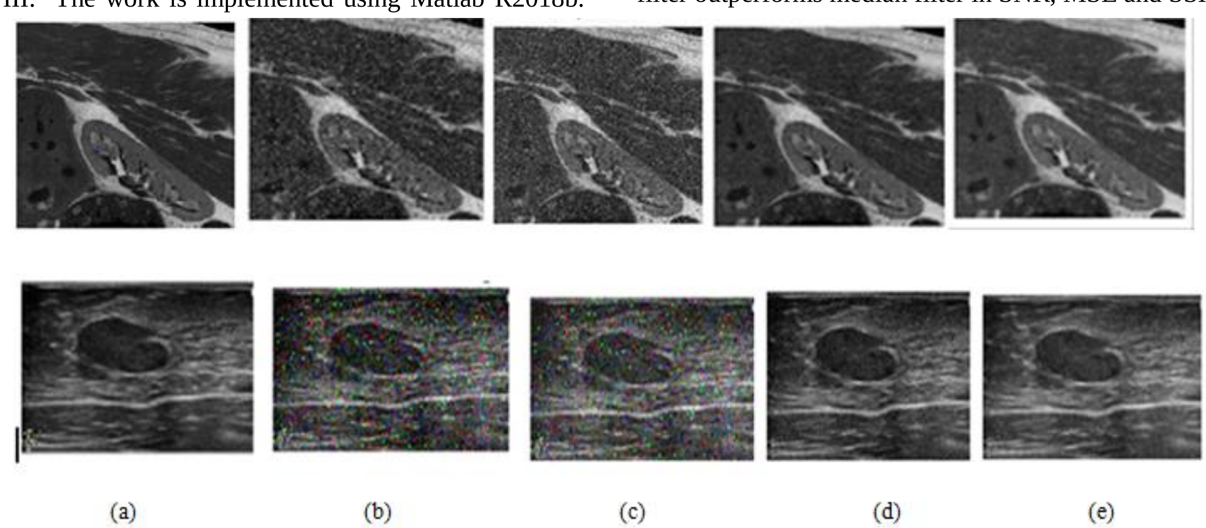

Fig. 3. Filter Response for Kidney Cut Ultrasound Image and Ben1 Image Corrupted by a Noise of Standard Deviation σ =0.02 and Impulse Noise Density ρ=0.02. (a) Original Image (b) Mixed Guassian Impulse Noised(c) Simple AD Filter (d) Median Filtered (e) Proposed Hybrid Filter.

A. *Response of POCUS images to Mixed Gaussian Impulse Noise*

POCUS images are collected from the dataset of https://github.com/jannisborn/covid19_pocus_ultrasound are used for the evaluation of noise filtering process. 50 POCUS images of COVID-19 are used from this dataset. Gaussian noise of standard deviation σ =0.02 and impulse noise density ρ=0.02 are added to the image and the output is analysed. COVID-19 POCUS image, Cov_severe, of size 367X367 is used for initial verification of noise filtering process. The proposed filter output is compared with simple AD filter and median filter. Results are shown in Fig. 4 and Fig. 5

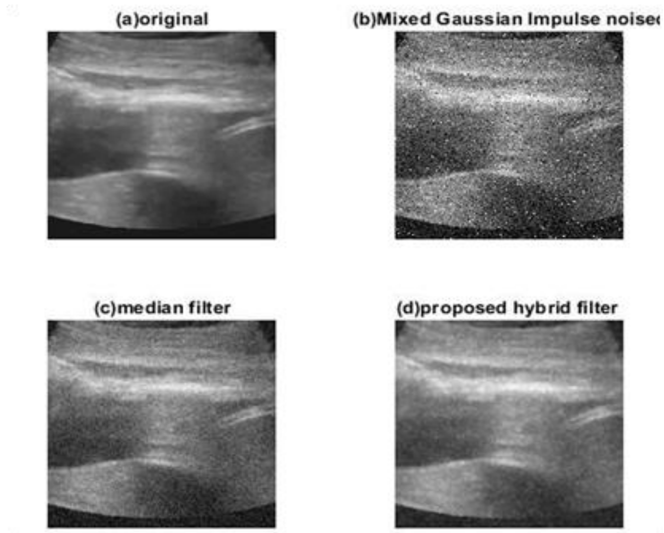

Fig. 4. Response of Various Filters (a) cov_severe POCUS Image (b) Image Corrupted by Mixed Gaussian Impulse Noise (c) Response of Median Filter (d) Output of Proposed Filter.

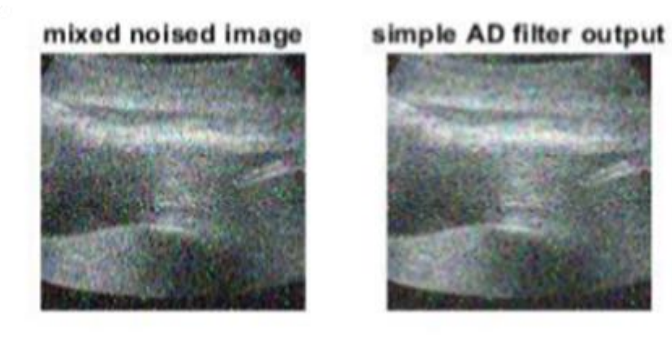

Fig. 5. Response of Simple AD Filter to cov_severe POCUS Image.

Performance of the filter is evaluated using various POCUS images. A sample set of 10 images is shown in Fig. 6. Images used are degraded by mixed Gaussian impulse noise of standard deviation σ = 0.02 and impulse noise of density ρ=0.02

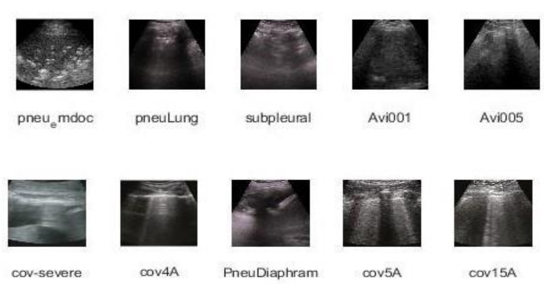

Fig. 6. Test Images used in Experiments.

Output for pneuLung image is shown in Fig. 7 and Fig. 8 respectively. For all the POCUS images, proposed filter provided better results. Visual quality of the proposed filter also seems better.

Fig. 7. Simple AD Filter (a) Original pneuLung POCUS Image (b) Image Corrupted by Mixed Gaussian Impulse Noise (σ =0.02 and ρ=0.02) (c) Response of Simple AD Filter.

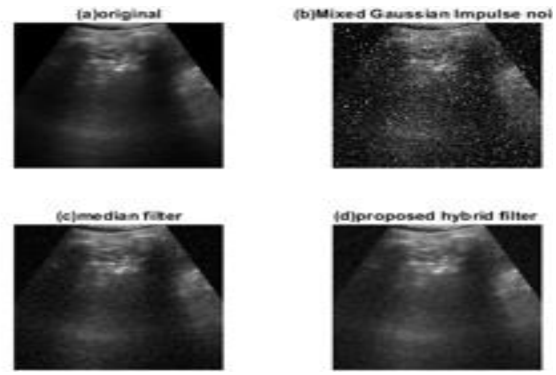

Fig. 8. Filter Response for pneuLung POCUS Image (a) Original Image (b) Mixed Gaussian Impulse Noised (c) Median Filter o/p (d) Proposed Filter Output.

B. Response to Speckle Noise

The proposed hybrid AD filter performance is analyzed with an input corrupted by speckle noise. Results show that speckle removal can be efficiently achieved if the image is processed using the proposed hybrid filters.

Speckle noise is the major type of noise present in an ultrasound image. It limits contrast resolution of images by affecting the edges and fine details and make diagnostic more difficult. Anisotropic diffusion filters are efficient in removing speckle noise. Combining the advantages of median as well as AD filter, the performance of the proposed filter to POCUS images corrupted with zero mean speckle noise with variance 0.04 is analysed.

Fig. 9 compares outputs of simple AD filter, median filter and proposed hybrid filter responses for kidney_cut US image for speckle noised image.

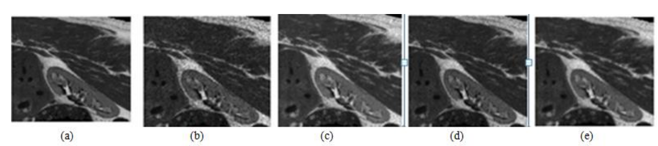

Fig. 9. Various Filter Responses for Kidney Cut Ultrasound Image for Speckle noise. (a)Original Image b) Speckle Noised (c)Simple AD (d)Median Filter Output (e)Proposed Filter Output.

Fig. 10 and 11 compares outputs of simple AD filter, median filter and proposed hybrid filter responses for Cov_severe POCUS image for speckle noised image. Here, the same zero means speckle noise with variance 0.04 is used. Here also, the visual quality is improved and noise removal is achieved.

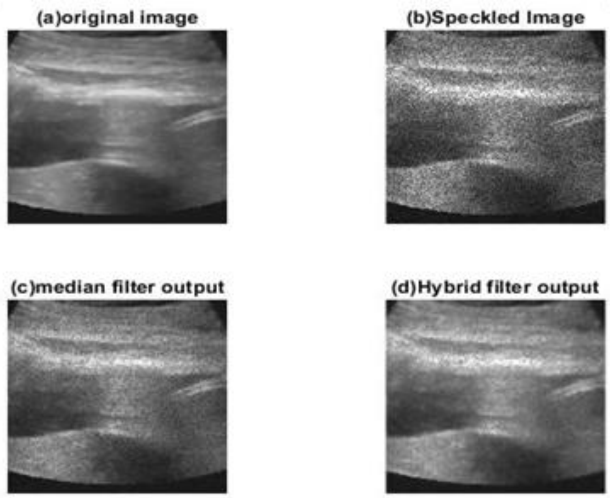

Fig. 10. Various Filter Responses for cov_severe POCUS Image for Speckle Noise.

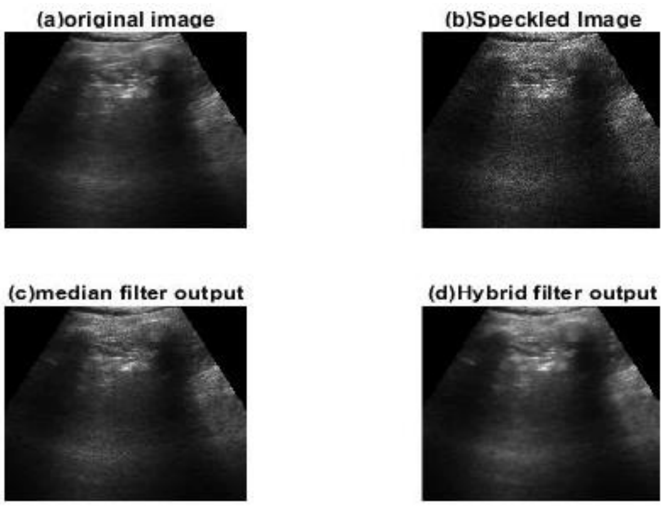

Fig. 11. Various Filter Responses for pneuLung POCUS Image for Speckle Noise. (a) Original Image (b) Speckle Noised (c) Median Filter o/p (d) Proposed Filter Output.

Simple AD filter response for pneuLung POCUS Image using zero mean speckle noise with variance 0.04 is shown in Fig. 11. For all these experiments, 15 iterations are done initially and verified the process using 20 and 30 iterations.

C. Quantitative Analysis

A quantitative analysis is done to evaluate the performance of the proposed anisotropic diffusion filter by comparing the parameters such as Signal to Noise Ratio (SNR), Mean Square Error (MSE) [6] and structural Similarity Index (SSIM).

The SSIM is a method for measuring the similarity between two images. The SSIM index can be viewed as a quality measure of one of the images being compared while the other image is considered as of perfect quality. Maximum value of SSIM is 1, reachable only in the case of two identical sets of data [33].

The SNR and MSE are computed using the formula [2]:

$$SNR = 10\log_{10}\frac{\sum_{p=1}^{N}\sum_{q=1}^{N}v(p,q)^2}{\sum_{p=1}^{N}\sum_{q=1}^{N}(u(p,q)-v(p,q))^2} \tag{6}$$

$$MSE = \frac{1}{NXN}\sum_{p=1}^{N}\sum_{q=1}^{N}\left(u(p,q)-v(p,q)\right)^2 \tag{7}$$

Quantitative analysis results with parameters SNR, MSE and SSIM for Ben1 and kidney_cut US images are shown in Table I. Table II shows SNR, MSE and SSIM values for five sample COVID-19 Lung US images corrupted with mixed Gaussian impulse noise. The parameters were measured after 15 iterations using Simple AD filter, median filter and the proposed filtering method. Results are sketched in Fig. 12. A comparison of SSIM values are plotted in Fig. 13. From these sketches, it is clear that the proposed method outperforms the other methods and turns out to be the most robust scheme, as it yields better SNR, minimum MSE and highest SSIM for all the images.

TABLE I. QUANTITATIVE ANALYSIS OF BEN1 AND KIDNEY_CUT US IMAGES ON MEDIAN, AD & PROPOSED FILTERS FOR MIXED GAUSSIAN IMPULSE NOISE

Image	Parameters	Mixed Gaussian Impulse noise		
		Median Filter	Simple AD filter	Proposed filter
Ben1	SNR (dB)	18	8	19.35
	MSE	28.16	31	2.96
	SSIM	0.52	0.25	0.65
Kidney cut	SNR (dB)	10.05	8	22.49
	MSE	25	32	1.4
	SSIM	0.52	0.19	0.69

TABLE II. QUANTITATIVE ANALYSIS OF POCUS IMAGES ON MEDIAN, AD & PROPOSED FILTERS FOR MIXED GAUSSIAN IMPULSE NOISE

Image	**Parameters**	**Mixed Gaussian Impulse noise**		
		Median filter	*Simple AD filter*	*Proposed filter*
Cov_severe	SNR (dB)	10.5	8.7	25.9
	MSE	22.76	33.8	0.65
	SSIM	0.51	0.15	0.76
Pneu_lung	SNR (dB)	10.7	5.8	28.4
	MSE	18	19	0.36
	SSIM	0.4	0.1	0.6
Cov_5A	SNR (dB)	10.6	9	26.4
	MSE	22	30.8	0.58
	SSIM	0.59	0.2	0.74
Cov_15A	SNR (dB)	10	9.4	27
	MSE	21.8	30	0.5
	SSIM	0.53	0.15	0.73
Sub_pleu	SNR (dB)	10	8	27
	MSE	19.5	28	0.49
	SSIM	0.45	0.12	0.6

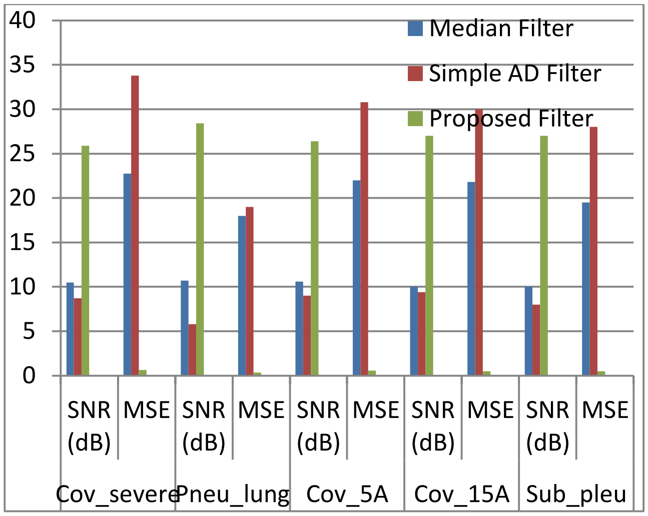

Fig. 12. Comparison of SNR, and MSE using 5 Sample Images with Mixed Guassian Impulse Noise. Results of Median, Simple AD and Proposed Filtering Schemes.

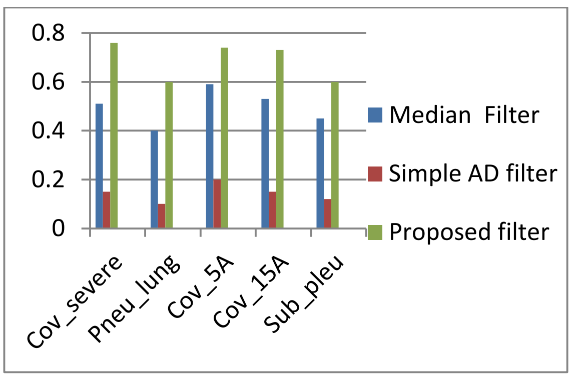

Fig. 13. Comparison of SSIM Values.

Table III shows the same parameters for images degraded with speckle noise. SNR and MSE plot is shown in Fig. 14 and SSIM plot in Fig. 15. From these plots, we can see that Simple AD filters are better in performance than median filters in speckle filtering process, while they perform poor in reducing Gaussian impulse noise. The proposed filter gives more satisfactory results for all the three parameters for all images with highest SNR value of 19.8, minimum MSE of 3 and maximum SSIM of 0.896.

TABLE III. QUANTITATIVE ANALYSIS OF PROPOSED FILTER, SIMPLE AD & MEDIAN FILTER FOR SPECKLE NOISE

Image	**Parameters**	**Speckle Noise**		
		Median Filter	*Simple AD filter*	*Proposed filter*
Cov_severe	SNR (dB)	7.5	13	19.2
	MSE	44	40	3
	SSIM	0.56	0.4	0.78
Avi_005	SNR	9.5	13	19.8
	MSE	28	5.5	2.6
	SSIM	0.73	0.82	0.84
Cov 15A	SNR (dB)	9.5	13	19
	MSE	28.28	19.9	2.7
	SSIM	0.7	0.63	0.84
Pneu_lung	SNR (dB)	12	15.8	17.5
	MSE	12	5	1.56
	SSIM	0.86	0.8	0.896

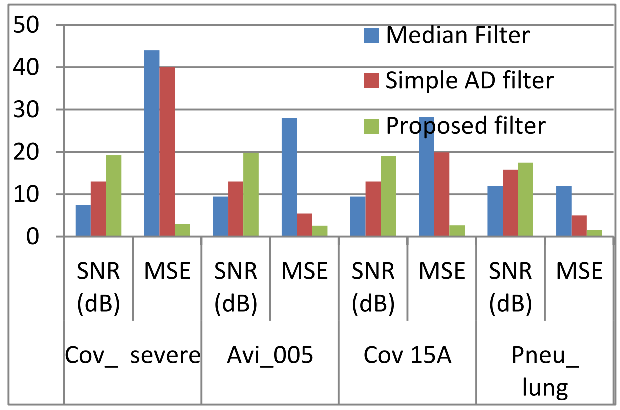

Fig. 14. Comparison of SNR and MSE using Four Sample Images with Speckle Noise. Results of Median, Simple AD and Proposed Filtering Schemes.

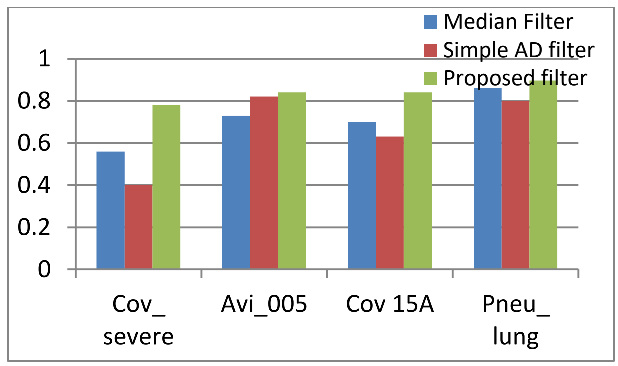

Fig. 15. Comparison of SSIM Values for Median, Simple AD and Proposed Filtering Schemes when Speckle Noise is Added to 4 Different Covid POCUS Images.

VI. CONCLUSION

This paper introduces a new method of noise filtering of POCUS images based on hybrid anisotropic diffusion filters. The smoothing and edge preservation properties of AD filters and the noise reduction features of median filtering are combined to optimize the performance. Both mixed Gaussian Impulse noise and Speckle noise are considered. The resultant images are analysed quantitatively using parameters SNR, MSE, and SSIM. For mixed Gaussian impulse noise, the proposed filter yields a maximum SNR of 28.4 while median and simple AD filters gave only 10.7 and 9.4 respectively. Similarly, the proposed filter has the highest SNR value of 19.8 with speckle noise. The maximum MSE is 0.58, 30.8 and 21.8 for proposed, median and simple AD respectively, with proposed filter scoring minimum MSE for all images. With speckle noise, these MSE values are 3, 44 and 40 respectively. SSIM values are also the highest with 0.76 and 0.896 with mixed Gaussian impulse noise and speckle noise respectively. These findings show that the proposed filter delivers maximum SNR, least MSE, and highest SSIM for all test images. The results were uniform and consistent across all the test images after 20 and 30 iterations.

Due to its low cost, quick diagnosis, and non-exposure to radiation, Ultrasound is recommended in many clinical scenarios, including respiratory, cardiovascular, and thromboembolic elements of COVID 19, obstetrics, etc. The development of artificial intelligence technology has made automatic segmentation and further diagnosis and detection excellent. A pre-processing stage prior to segmentation is inevitable in all these cases due to the presence of speckle and other noises, poor contrast, and acoustic shadows in US images. These robust software tools, when used in conjunction with point-of-care technologies, are well-suited to replace X-ray and CT scan on patient triage and immediate care.

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