Effect Comparison of Speckle Noise Reduction Filters on 2D-Echocardigraphic Images

Faten A. Dawood, Rahmita W. Rahmat, Suhaini B. Kadiman, Lili N. Abdullah, Mohd D. Zamrin

***Abstract*—**Echocardiography imaging is one of the most common diagnostic tests that are widely used for assessing the abnormalities of the regional heart ventricle function. The main goal of the image enhancement task in 2D-echocardiography (2DE) is to solve two major anatomical structure problems; speckle noise and low quality. Therefore, speckle noise reduction is one of the important steps that used as a pre-processing to reduce the distortion effects in 2DE image segmentation. In this paper, we present the common filters that based on some form of low-pass spatial smoothing filters such as Mean, Gaussian, and Median. The Laplacian filter was used as a high-pass sharpening filter. A comparative analysis was presented to test the effectiveness of these filters after being applied to original 2DE images of 4-chamber and 2-chamber views. Three statistical quantity measures: root mean square error (RMSE), peak signal-to-ratio (PSNR) and signal-to-noise ratio (SNR) are used to evaluate the filter performance quantitatively on the output enhanced image.

***Keywords*—**Gaussian operator, median filter, speckle texture, peak signal-to-ratio

I. Introduction

SPECKLE noise reduction in 2D-echocardiographic image is used to enhance the visual quality by removing the noise from image with keeping the important features like myocardial wall tissue. In general, speckle texture could be a form of multiplicative noise that depends on the structure of the imaged tissue and various parameters concerning echocardiography imaging characteristics. Therefore, recently the image segmentation process is one of important challenging issue for most researchers in the field of diagnostic the heart abnormality through complete cardiac cycle. In the literature, there are a number of investigative research projects into the field of medical image analysis that present several methods for reducing the speckle-noise from an image based on a noise model.

Most of noise modeling is affected by the acquisition instrument, data transmission media, image quantization and discrete source of radiation [1]-[3]. An appropriate method for speckle noise reduction is one which enhances the signal-to-noise ratio while conserving the edges of an object in the image [4].

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There are many filters that are used as an initial action before post-processing (i.e. image segmentation) by taking neighboring pixels into consideration which extremely ‘noisy’ pixels that could be filtered out. Spatial filtering is the most common technique for speckle noise reduction. The averaging technique is the most popular linear filtering method among the various spatial filters which successfully removes noise from a distorted image but it has the effect of potentially blurring the image [5]-[8]. Gaussian Low-pass filtering is another common technique which has been much used in previous researches to remove speckle noise from Ultrasound images [9], [10]. It is considered as a smoothing operator to perform a weighted average of surrounding pixels based on a Gaussian distribution.

The median filter is one of the most popular nonlinear spatial filters for removing noise because of its good de-noising effect [11] and it is widely used in Ultrasound and echocardiography imaging [12]-[14]. Although it has good performance, the main drawback is that noisy pixels are replaced by a median value in their vicinity without taking into account the local features such as the presence of edges.

II. Spatial Filtering for Noise Reduction

A. Linear Mean Filter

The mean filter is a linear technique which is often used to performs spatial filtering and is applied as a smoother to average the speckles in each individual pixel in an image using grey-level values in a square window size (i.e. 3x3 , 5x5 or 7x7) surrounding each pixel. Practically, all pixels are filtered by replacing each pixel intensity value in the image with the mean (‘average’) value of its neighbours, including itself. However, this filter has the effect of potentially blurring the speckled image. It could be an optimal choice for additive Gaussian noise.

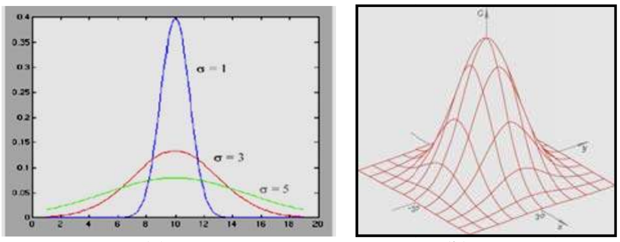
B. Low-pass Gaussian Filter

A low-pass Gaussian filter has been proposed in the literature as an attempt to remove the speckle noise in Ultrasound images. It is considered as a smoothing operator and performs a weighted average of surrounding pixels based on the Gaussian distribution. The Gaussian operator generates a matrix of values $G(x, y)$ that are applied to groups of pixels in the image.

These matrix values can be defined by the following 2D Gaussian equation:

$$G(x,y) = \frac{1}{2\pi\sigma^2}\exp\{\frac{x^2+y^2}{2\sigma^2}\} \quad (1)$$

Where Sigma σ is the standard deviation of the distribution and defines the amount of blurring and also the degree of smoothing. The filtered image could be even smoother when high sigma σ values are used, but the difficulty is that it requires significantly more calculations per pixel. Fig. 1 shows the distribution of a 2D Gaussian distribution with different sigma values and a 3D view.



(a) (b)

Fig. 1 (a) 2D Gaussian distribution and (b) 3D view

C. *Non-linear Median Filter*

The median filter is one of the most common Non-linear spatial filters and is widely used for medical images, especially 2DE images because it is more effective at eliminating speckle-noise and can produce less-blurred images by keeping the details. However, this approach is based on statistical ordering of the data collected from the image. Thus it is time consuming due to the high computational cost for sorting N pixels intensities. Even with the most efficient sorting algorithms the temporal complexity is O (N log N) [15].

The median filter is also a sliding-window spatial filter and it is simply implemented as every pixel P_{ij} in the window to be filtered is replaced by the median value of all the neighbouring pixels. The algorithm of the median filter can be summarized as follows:

1) Create a list of N pixels intensities surrounding the center pixel P_{ij} according to the window size that used (i.e. 3x3, 5x5 or 9x9).
2) Sorting the list into numeric descending order.
3) The median value is the value that located in the middle of the sorted list.

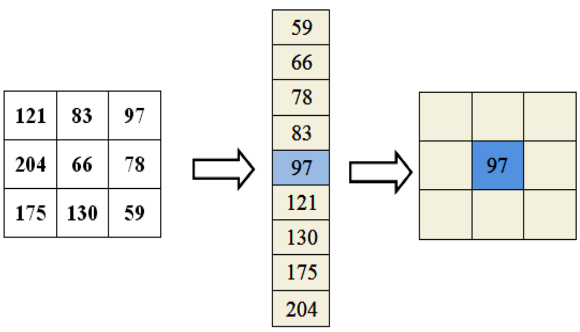


Fig. 2 An example of a median filter with a 3x3 window size

The main disadvantage of median spatial filtering is that it is damaging to thin lines and sharpens corners in the image. This problem can be avoided if another neighbourhood shape is adopted which increases the size of the window used to obtain a better result. In a 2D-echocardiographic image, the median filter of a 5x5 window size is preferred to eliminate the distortion effect of speckle-noise and low quality.

D. *Sharpen Laplacian Filter*

Most of the sharpening spatial filters are based on spatial differentiation. The Laplacian is one of the simplest sharpening filters and which is usually preferred to highlight fine detail by removing blurring from a noisy image and to highlight the edges. It is often defined as the second derivative operator:

$$\nabla^2 f = \frac{\partial^2 f}{\partial^2 x} + \frac{\partial^2 f}{\partial^2 y} \quad (2)$$

where the partial first-order derivative in the *x* direction is defined as follows:

$$\frac{\partial^2 f}{\partial^2 x} = f(x+1, y) + f(x-1, y) - 2f(x, y) \quad (3)$$

and the *y* direction is defined as follows:

$$\frac{\partial^2 f}{\partial^2 y} = f(x, y+1) + f(x, y-1) - 2f(x, y) \quad (4)$$

Therefore, the Laplacian can be used as a filter with 3x3 window size and applied to poor quality image.

III. Statistical Measures for Filter Effectiveness

In this section, we present the most common statistical quantity measures that are able to evaluate the performance of speckle-noise reduction filters for an output enhanced image by testing their effectiveness when applying these filters on an original speckled-noisy image. For this purpose, we used three major measures:

1) Root Mean Square Error (RMSE) is widely used to find the total amount of difference between two images. It indicates the root of average difference of the image pixels intensities. RMSE is defined as the following equation:

$$RMSE = \sqrt{\frac{\sum[f(i,j) - g(i,j)]^2}{MN}} \quad (5)$$

Where $f(i,j)$ is the original noisy image of M x N and $g(i,j)$ is the output image after filtering.

2) Peak Signal-to-Noise Ratio (PSNR) is the ratio between the maximum possible power of a signal and the power of the reduced noise that affects its representation. PSNR is defined as follows [15]:

$$PSNR = 20\, log_{10} \frac{255}{RMSE} \qquad (6)$$

A higher value of PSNR would normally indicate that the reconstruction quality is higher.

3) Signal-to-Noise Ratio (SNR) is a common statistical quantity measure to evaluate the speckle-noise reduction in the case of multiplicative noise by computing the ratio between the maximum possible power of a signal and the power of the reduced noise that affects its representation. The SNR can be calculated as follows:

$$SNR = 10\, log_{10} \frac{\sum f(i,j)^2}{\sum [f(i,j) - g(i,j)]^2} \qquad (7)$$

Here $f(i,j)$ is the original image and $g(i,j)$ is the output filtered image.

IV. Results and Comparative Analysis

This section discusses the experimental results that obtained by applying the previously described speckle-noise reduction filters on original 2DE images of 4-chamber (4-ch) and 2-chamber (2-ch) views with a resolution of 605 x 424 pixels. Each image belonged to an individual patient from off-line medical system (Philips) as shown in Fig. 3.

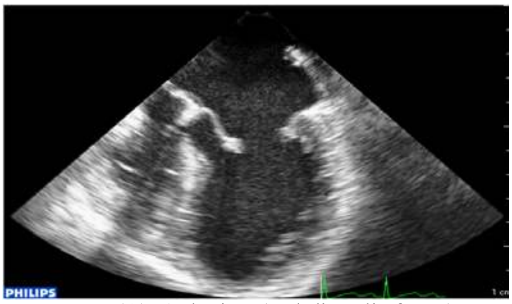


Image (A): 4-ch view (end-diastolic frame)

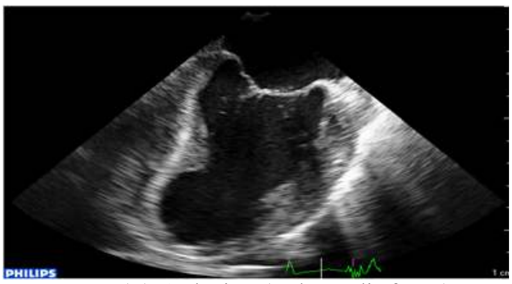


Image (B): 2-ch view (end-systolic frame)

Fig. 3 The original 2DE images

The performance measurement was done by comparing the filter effectiveness on the output enhanced image qualitatively and quantitatively. Fig. 4 shows the spatial filters; Mean, Gaussian, and Laplacian were applied to a 3 x 3 window size whereas the Median filter was performed using a 5 x 5 window sizes.

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

Mean

1	3	1
3	10	3
1	3	1

Gaussian

0	-1	0
-1	5	-1
0	-1	0

Laplacian

Fig. 4 Speckle-noise reduction filters

A. Qualitative Comparison

In echocardiography imaging, speckle noise reduction task has been proposed for enhancing the direct visualization of the cardiac structure and heart wall motion. Therefore, to evaluate the filters effectiveness qualitatively by comparing the results accuracy for automatic boundary detection after applying the proposed method in our previous published paper [5]. Fig. 5 and Fig. 6 shows the effect comparisons of filters were applied on the original 2DE images. filters have the same effect for myocardial wall segmentation. Whereas the Laplacian filters has better effect on speckled-image to obtain a more accurate segmentation results.

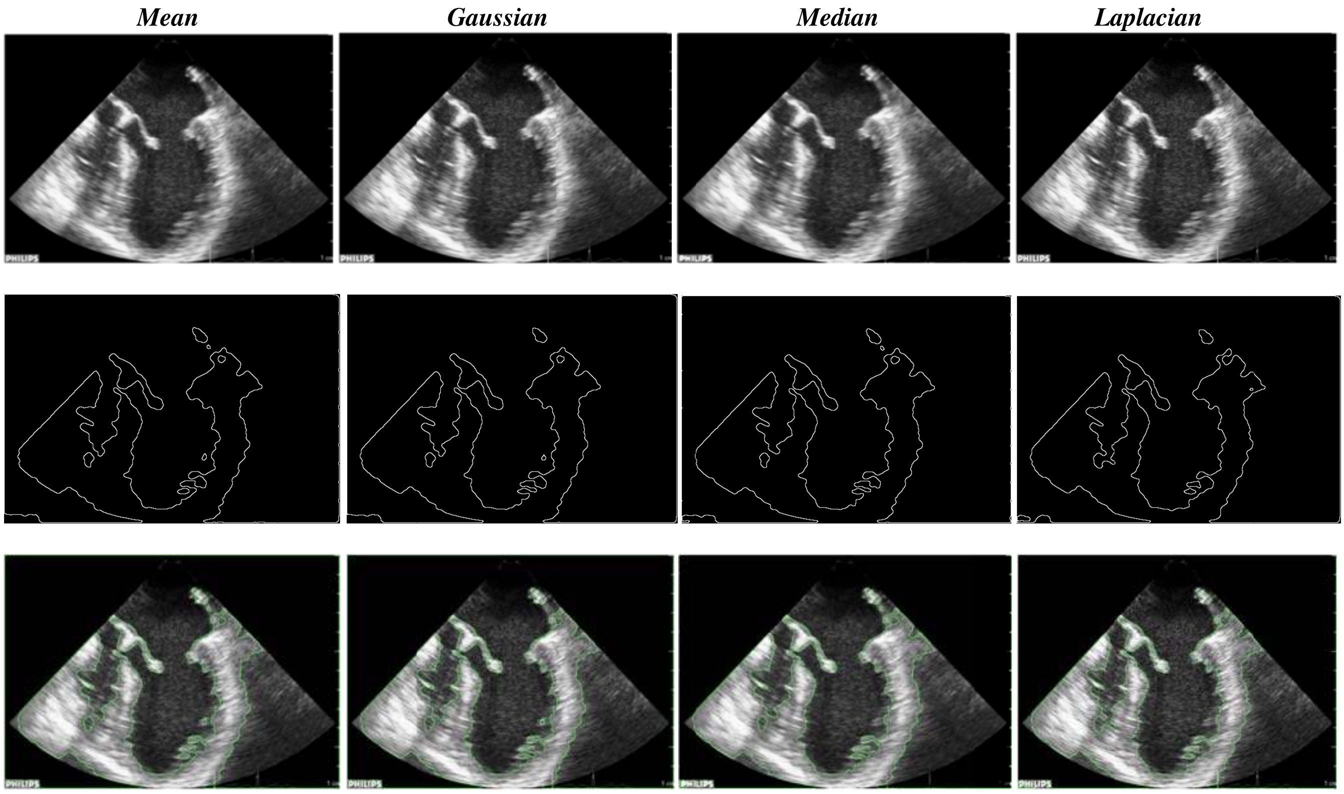


Fig. 5 The effect comparison of speckle-noise reduction filters on image (A)

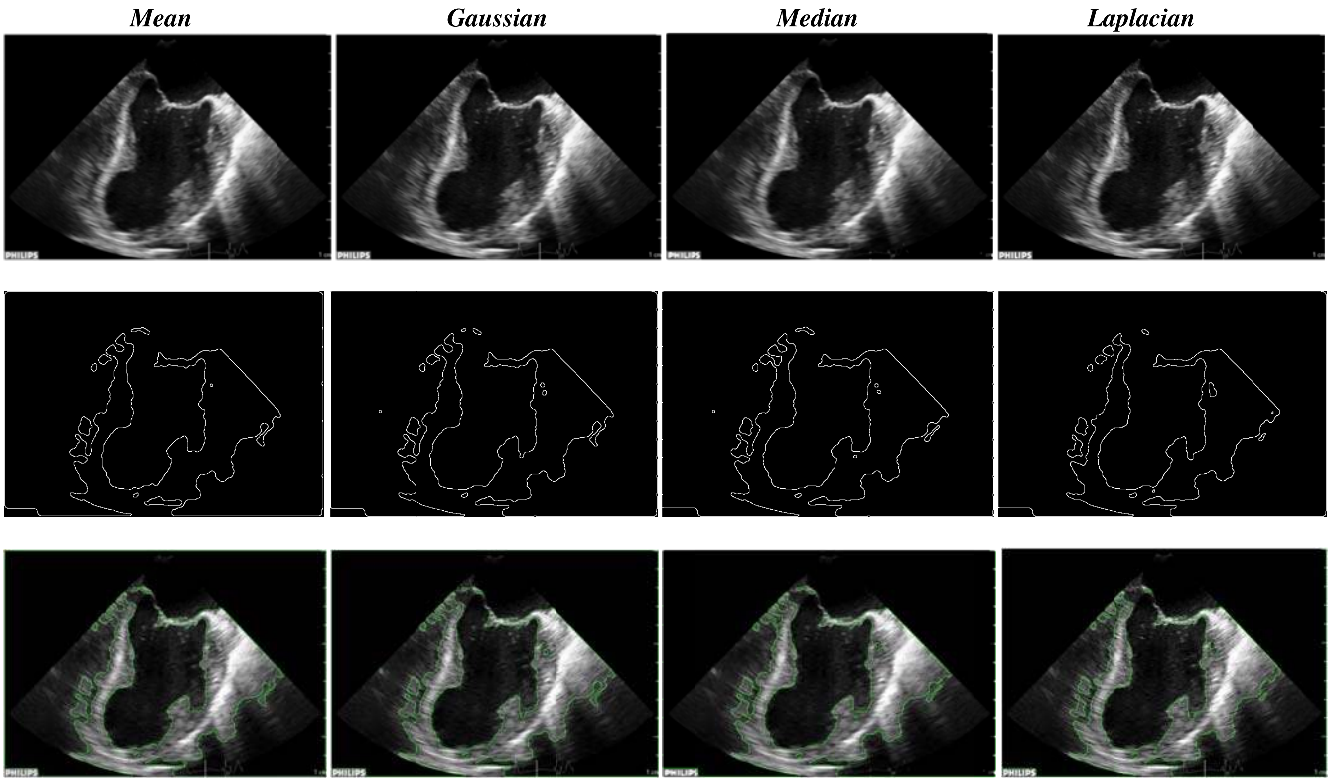


Fig. 6 The effect comparison of speckle-noise reduction filters on image (B)

B. Quantitative Comparison

To evaluate the filters effectiveness quantitatively, three main statistical measures were used: RMSE, PSNR and SNR. The comparative analysis based on the output values for these measures indicates which filter has better filtering results of speckle noise reduction. In more detailed, if the value of the RMSE is small and the values of the PSNR and SNR are high then the effect of that particular filter is better than the others. Table I presents a statistical comparison for filter effectiveness based on the different values of the three measures.

TABLE I
STATISTICAL COMPARISON FOR SPECKLE NOISE REDUCTION FILTERS

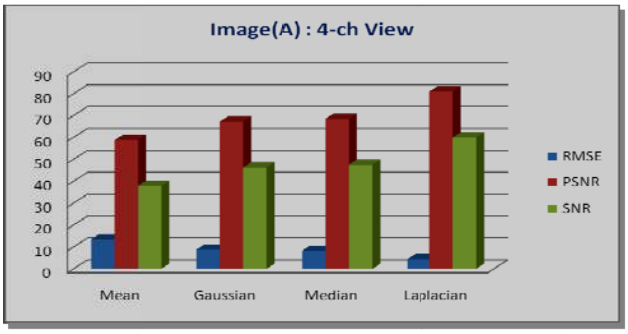
IMAGE (A)

	Mean	*Gaussian*	*Median*	*Laplacian*
RMSE	13.49	8.83	8.29	4.45
PSNR	58.78	67.27	68.52	80.96
SNR	37.83	46.31	47.56	60.01

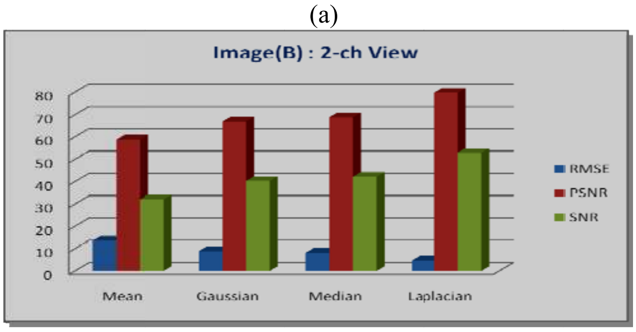
IMAGE (B)

	Mean	*Gaussian*	*Median*	*Laplacian*
RMSE	13.52	8.95	8.15	4.75
PSNR	58.74	66.98	68.86	79.68
SNR	32.04	40.28	42.16	52.97

Fig. 7 (a) and (b) shows the comparative analysis on original 2DE images respectively. The filters effectiveness was tested depending on the statistical measures results.



(a)



(b)

Fig. 7 The comparative analysis based on statistical measures

V. CONCLUSION

Spatial filtering is the most common technique which used for speckle noise reduction. A comparison of the effectiveness of these filters has been done to determine how their implementation could enhance an original speckled 2DE image in both qualitatively and quantitatively. The experimental results showed that the mean and median filters have very similar values for all statistical measures. On other hand, the Gaussian filter has an RMSE value less than the mean and median but the values of the PSNR and SNR are larger, so the Gaussian can be considered to have a better enhancement effect than the mean and median. Finally, the statistical comparative analysis indicates that the best filter is the Laplacian which gives the better effect for noise reduction and enhances the image quality for segmentation process because it has the smallest value of RMSE and the highest PSNR value.

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