Noise Reduction of Three Dimensional Echocardiography Images Using Voxel Connectivity Method

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Abstract : The removal of speckle noise in three-dimensional (3D) echocardiography is required for better analysis of the image and proper diagnosis and thus an important step in pre-processing. This paper proposes a new algorithm for removing the speckle noise which utilizes Von Neumann neighborhood concept. The application of three dimensional connectivity theories would reduce the noise to a certain extent. Here in this work Von Neumann neighborhood is applied for noise removal and is applied on three-dimensional echocardiographic images for the left ventricle region. The ultimate objective of this paper is to remove noise and preserve the edges of the region of interest qualitatively and quantitatively. The method is then compared with anisotropic diffusion filters such as Perona-Malik anisotropic diffusion (PMAD) and speckle reducing anisotropic diffusion (SRAD). The performance metrics such as Pratt's quality measurement and contrast is calculated, thus showing the new algorithm for removing noise is efficient when compared with diffusion filters. This method is satisfactorily tested on the slices taken from thirty four patient dataset.

Keywords : Three dimensional echocardiography (3DE), von neumann neighborhood, perona malik anisotropic diffusion (PMAD) filter, speckle reducing anisotropic diffusion (SRAD) filter.

1. INTRODUCTION

Among various imaging modalities, ultrasound technology is safe for the diagnosis of different types of diseases in human body. The application of this technology is extended to fetal imaging, cardiac, vascular, breast imaging, cyst identification and guiding surgical as well as therapeutic procedures. Thus ultrasound imaging remains to be a powerful tool in the medical industry because of its low cost, non-invasive, painless examination, portability and an instant diagnosis procedure. However, compared with other imaging modalities these images suffer from low contrast, low signal to noise ratio, signal dropout, shadowing of the structures and varying intensities between the structures.

The use of high-frequency sound waves generates the image of internal structures of human body. The principle is to send the high-frequency waves and convert back to sound echoes to form a picture of the organ. The two different processes such as specular reflections and scattering leads to echo formation [1]. The interference is caused by overlapping of scattering echoes which in turn leads to speckle (granular artifact). The randomly distributed scatters per resolution is more, it would lead to fully developed speckle pattern [2]. The detection of the lesion is reduced to eight-fold due to the presence of speckle and it affects the accuracy of human interpretation as well as automated diagnostic method [3]. Thus the speckle filtering is an important pre-processing step to remove the speckle without destroying the image features [4].

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Echocardiography is one of the applications of ultrasound technology and is routinely used for diagnosis of heart disease, but the image suffers from poor contrast and high level of noise. Many works have been reported in speckle reduction of two-dimensional (2D) echocardiography compared with 3D echocardiography. The speckle reduction of two-dimensional echocardiographic (2DE) images was made to reduce by anisotropic diffusion filters, wavelet denoising methods and other methods such as local statistics [5] and a comparison are made between these filters using performance metrics. In 3DE the anisotropic diffusion filters were used, among that SRAD filter showed good results in terms of performance metrics. The comparison of performance metrics in 2D and 3D shows that 3D SRAD is better than 2D SRAD [6]. Yet another approach for filtering noise is cellular automata method where local transition function using von Neumann or Moore neighborhood method [7]. The cellular automata method was first introduced by John von Neumann and later on John Horton Conway developed the game of life in the year of 1960's [8]. This method is used for noise filtering, as the image is considered to be a pixel in the case of 2D and voxel in the case of 3D. So far in 2D, cellular automata method used for noise filtering. In 3D, a set of rules and conditions makes the system more complicated. The theory behind this method requires regular lattice of cells where each cell has discrete state updated in discrete time steps.

In this paper, a new algorithm is proposed for removal of noise and to enhance the border of the region of interest using von Neumann neighborhood pixel connectivity on three-dimensional echocardiographic (3DE) images. The simple rules and conditions applied in this algorithm make the system less complicated compared to cellular automata method. Finally, the proposed algorithm is then compared with PMAD and SRAD filters in terms of performance metrics such as contrast and Pratt's quality measurement.

2. MATERIALS AND METHODS

The ultrasound data used for this work is taken from a database created by CETUS (Challenge on Endocardial Three-Dimensional Ultrasound Segmentation) MICCAI challenge 2014 [9,10]. The ultrasound data were acquired from three brands of ultrasound machine such as GE Vivid E9, Philips iE33 and Siemens SC2000 .This data consist of a set of healthy, dilated cardiomyopathy and myocardial infarction cases. These forty-five data are more challenging since it is acquired from different machines and there will be variation in noise level. The software used for filtering noise is Mat lab R2014b. Initially, 3D echocardiography images were made to display and histogram equalization on these images performed. The histogram equalization includes cumulative distribution function and its normalization followed by adaptive thresholding. The proposed filter applied on the threshold image and performance metrics such as Pratt's figure of merit and contrast are calculated. The pixel connectivity based noise filter is then compared with the existing filters such as PMAD and SRAD.

2.1. Filtering Method: Voxel Connectivity using Von Neumann Neighbourhood Concept

In digital image processing, the connectivity of the pixel in 2D or voxels in the case of 3D images is related to the neighbors. The most popular methods are von Neumann neighborhood and Moore neighborhood. In 2D Von Neumann neighborhood, four neighbor pixels are connected to every pixel that touched their edges. The horizontal and vertical connectivity to the center pixel is shown in Figure 1(a). Every pixel has the coordinate $(x \pm 1, y)$ or $(x, y \pm 1)$ which is connected to the center pixel (x, y). In 3D Von Neumann, the six face touching neighbor pixels are connected to every pixel. (Figure 1(b)). These pixels are connected along the one primary axes. So each pixel with coordinates $(x \pm 1, y, z)$, $(x, y \pm 1, z)$ or $(x, y, z \pm 1)$ is connected to center pixel (x, y, z). The corner pixels are excluded in both 2D and 3D case [11].

Neighborhood-based noise filtering : The echocardiograph images used in this work are 3D snapshots of grayscale data in unit time. Here pixels are cube shaped (voxels) unlike square in regular 2D images. The lateral and vertical connectivity help to filter the noise in a better way in 3D. Since voxel has six neighbors, the original data to be more connected or having useful information in its neighbors

and noise to be isolated. The original data are considered as the voxel and its neighbor having threshold value more than predetermined level. The pixels with less than four connected neighbors are considered as noise and are filtered out. This type of voxels is lesser in volume compared to original. The corner voxels are exceptional because they have only three neighbors by default. The 3D extended Von Neumann neighborhood method is used here to define the neighborhood and neighborhood-based noise filtering performed.
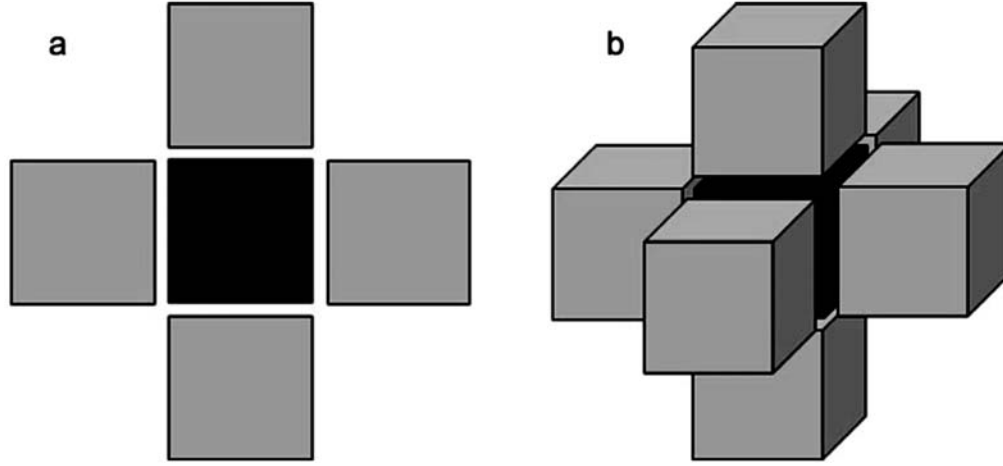

Figure 1: Von Neumann Neighborhood in (*a*) 2D and (*b*) 3D

Algorithm Flow

1. Consider an image of size $m \times n \times p$.
2. The algorithm scans all the voxels in an iterative process.
3. For each voxel I(i, j, k) ($1 < i < m$, $1 < j < n$, $1 < k < p$) the value of neighbour pixel in left $((i-1), j, k)$, right $((i+1), j, k)$, top $(i, (j-1), k)$, bottom $(i, (j+1), k)$, front$(i, j, (k-1))$, and behind $(i, j, (k+1))$ are observed if they are above the prefixed threshold.
4. The total number of voxel above this threshold is the connectivity of that central voxel. If the connectivity is greater or equal to four, then the voxel is considered as useful data, else, the voxel is considered as noise and filtered out.

2.2. Existing Methods

2.1.1 Perona and Malik Anisotropic Diffusion Filter (PMAD)

The filter developed by Perona and Malik and is selectively used for smoothing an image and preserving its edges [12]. The partial differential equation (PDE) of 3D is similar to 2D, by considering one more dimension in z direction [6, 13]. The diffusion takes place according to Equation 1 where I(x, y, z; t) is the image under diffusion and t is the artificial time dimension showcasing the progress of diffusion.

The above equation can be rewritten using finite difference method and finally arrive in a discrete realization of anisotropic diffusion for 3D images shown in Equation 2.

$$\frac{\partial I(x, y, z; t)}{\partial t} = \text{div}[c(x, y, z; t)\, \nabla I(x, y, z; t)]$$

$$= \frac{\partial}{\partial x}\left(c(x, y, z; t) \times \frac{\partial}{\partial x}I(x, y, z; t)\right) + \frac{\partial}{\partial y}\left(c(x, y, z; t) \times \frac{\partial}{\partial y}I(x, y, z; t)\right)$$

$$+ \frac{\partial}{\partial z}\left(c(x, y, z; t) \times \frac{\partial}{\partial z}I(x, y, z; t)\right) \quad (1)$$

$$
\begin{aligned}
I(x, y, z\,;t+1) \;=\; & I(x, y, z\,;t) + c(x+1, y, z\,;t)[I(x+1, y, z\,;t) - I(x, y, z\,;t)] \\
& + c(x, y, z\,;t)[I(x-1, y, z\,;t) - I(x, y, z\,;t)] + c(x, y+1, z\,;t)[I(x, y+1, z\,;t) - I(x, y, z\,;t)] \\
& + c(x, y, z\,;t)[I(x, y-1, z\,;t) - I(x, y, z\,;t)] + c(x, y, z+1\,;t)[I(x, y, z+1\,;t) - I(x, y, z\,;t)] \\
& + c(x, y, z\,;t)[I(x, y, z-1\,;t) - I(x, y, z\,;t)]
\end{aligned}
$$

where

$$
c(x, y, z\,;t) \;=\; \exp\left(-\left[\frac{|\nabla I(x, y, x, z\,;t)|}{k}\right]^2\right) \tag{3a}
$$

or

$$
c(x, y, z\,;t) \;=\; \frac{1}{1+\left[\dfrac{|\nabla I(x, y, z\,;t)|}{k}\right]^2} \tag{3b}
$$

The function C controls the level of diffusion at every image position in Equation. 2. The main problem is the choice of $C(x, y, z; t)$, Equation 3a or 3b, which is same as in 2D case. This PMAD noise filtering is performed by MATLAB codes [14].

2.2.2. Speckle Reducing Anisotropic Diffusion Filter (SRAD)

The 2D SRAD developed by Yu and Acton mainly focusses to remove the speckle or multiplicative kind of noise from the image and later on extended to 3D by another author [14, 15]. The diffusion takes place on the basis of PDE shown in Equation 1 and here C is the diffusion coefficient which depends on the instantaneous coefficient of variation (ICOV) given in Equation 4.

$$
c(q) \;=\; \frac{1}{1+[q^2\,(x, y, z\,;t) - q_0^2(t)/[q_0^2(t)\,(1+q_0^2(t))]} \tag{4}
$$

where $q(x, y, z; t)$ is called 3D instantaneous coefficient of variation and is defined in Equation 5.

$$
q(x, y, z\,;t) \;=\; \sqrt{\frac{(1/3)(|\nabla I|/I)^2 - (1/6)^2 (|\nabla^2 I|/I)^2}{(1+(1/6)(|\nabla^2 I|/I)^2}} \tag{5}
$$

here I is the input image. The partial differential equations are solved numerically by four stage iterative method with time step ∇t and spatial step h in all three directions. The final arithmetical approximation to the 3D SRAD filter differential equation is given in Equation 6[6, 16,17].

$$
I_{i,j}^{n+1} \;=\; I_{i,j}^{n+1} + \frac{\Delta t}{6} d_{i,j}^n \tag{6}
$$

2.3. Peformance Metrics

The voxel based connectivity method opted for filtering the noise is compared with other two existing filters in terms of performance metrics. The two different methods such as Pratt's Figure of merit and contrast were used in our experiments to measure the performance of the algorithm.

2.3.1. Pratt's Figure of Merit

Pratt's figure of merit was chosen to find the edges to compare the filtered image and original image. This provides the similarity between two contours and is defined in the Equation 7 where is the number of edge pixels and is number of ideal pixels. The di is the Euclidean distance between edge pixel and nearest ideal pixel and $\alpha = 1/9$ a constant optimal value established by Pratt [18].

$$
\text{FOM} \;=\; \frac{1}{\max(I_A, I_I)}\sum_{i=1}^{I_A}\frac{1}{1+ad_i^2}
$$

To detect the edges in the image Canny edge detection technique applied on 3D images and Pratt's figure of merit is calculated [18]. The Canny edge detection is a multistage algorithm which detects the wide range of edges in the image. The algorithm contains a Gaussian filter to remove noise and sigma is the smoothing parameter for Gaussian mask [19,20]. For 3D case the row, column and slice are taken into consideration and the process takes place. The intensity gradients of the image are calculated and non maximum suppression (edge thinning operation) performed on the image. Twice the threshold applied to track the edges, therefore the strong edge voxels will be highlighted and weak edge voxels will be suppressed. The values of the figure of merit varied between 0 and 1and the value 1 represent the perfect edge.

2.3.2. Contrast

The contrast refers to the difference in gray scale which exists between image features and is related with discrimination of objects within the region of interest[21].Here contrast measurement is performed using Michelson formula [22]. Here I (x, y, z) is the voxel value at the coordinates (x, y, z) and its $2n + 1$ neighborhood and hence local contrast at voxel (x, y, z) is given in eq (8)

$$C(x, y, z) \;=\; \frac{I_{max}\ (x,\ y,\ z) - I_{min}\ (x.\ y,\ z)}{I_{max}\ (x,\ y,\ z) + I_{min}\ (x.\ y,\ z)}$$

Where I max and I min are the maximum and minimum value of voxels in its $2n + 1$ neighborhood [6].Thus the contrast can be redefined as the separation between the darkest and the brightest areas of the image. When the contrast is increased the darker and brighter region separation increases making shadows darker and brighter side is highlited more. Upon decreasing the contrast shadowing effect more and speration will be more closer. The noise removal based on voxel connectivity increases the contrast with respect to diffusion filters. Moreover the diffusion filters has less contrast after filtering process.

3. RESULTS

The 3D echocardiography images from forty-five patient dataset are taken as the test images for the noise removal and the region of interest is the left ventricle of the heart. Initially, one slice from image volumes of different datasets comprised different planes such as axial (yz plane), coronal (xy plane) and sagittal (xz plane) were taken for processing. The end diastolic frame from different patients was tested and is plotted in terms of two different performance metrics. The qualitative evaluation of the result displayed in Fig (2) shows the slice image at $x = 81$, $y = 81$ and $z = 101$. The input image sliced from the image volume in the xy plane, xz plane and yz plane, are shown in Figure 2(a), 2(b) and 2(c) considered as noisy input data. To remove the noise from the input image, voxel connectivity filter discarded the unwanted voxels which are not connected to each other. The Figure 2(d), 2(e) and 2(f) show the noise filtered images corresponds to input images. This result shows the designed algorithm is capable of preserving the boundary of image and noise removal in certain extent without any blurring effect. The output of PMAD and SRAD filter is shown in Figure 2(g), 2(h), 2(I), and Figure 2(j), 2(k) 2(l) respectively. In PMAD and SRAD diffusion filters, speckle kind of noise is removed by the diffusion of similar edge region voxels with a high level of contrast. Both diffusion filters produce blurred output among which SRAD output has a high level of contrast. In SRAD filtered output the edge is not preserved properly and therefore the boundary of the left ventricle is distorted. The noise filtering was applied on all forty five dataset and out of which thirty four cases was working and remaining cases the gaps were more in the left ventricle cavity region so it was discarded.

The graphical representation of the performance metrics for best twenty four patient dataset is shown in Figure 3 and Figure 4 for quantitative evaluation. In Figure 3, the Pratt's figure of merit calculated for the different patient with denoising filter and traditional filters are compared. The range of figure of merit for voxel based connectivity filter lies between 0.113and 0.476, but in the case of SRAD, the minimum is 0.035 and the maximum value is 0.097 and in PMAD it is varied from 0.00029 to 0.026. These results

show trend line of Pratt's figure of merit of designed filter is better than traditional filters. In the case of contrast for implemented filter lie between 32.68 and 70.28 and for SRAD it is 28.04 to 45.6 and for PMAD filter the range lie between 27.39 to 41.41.
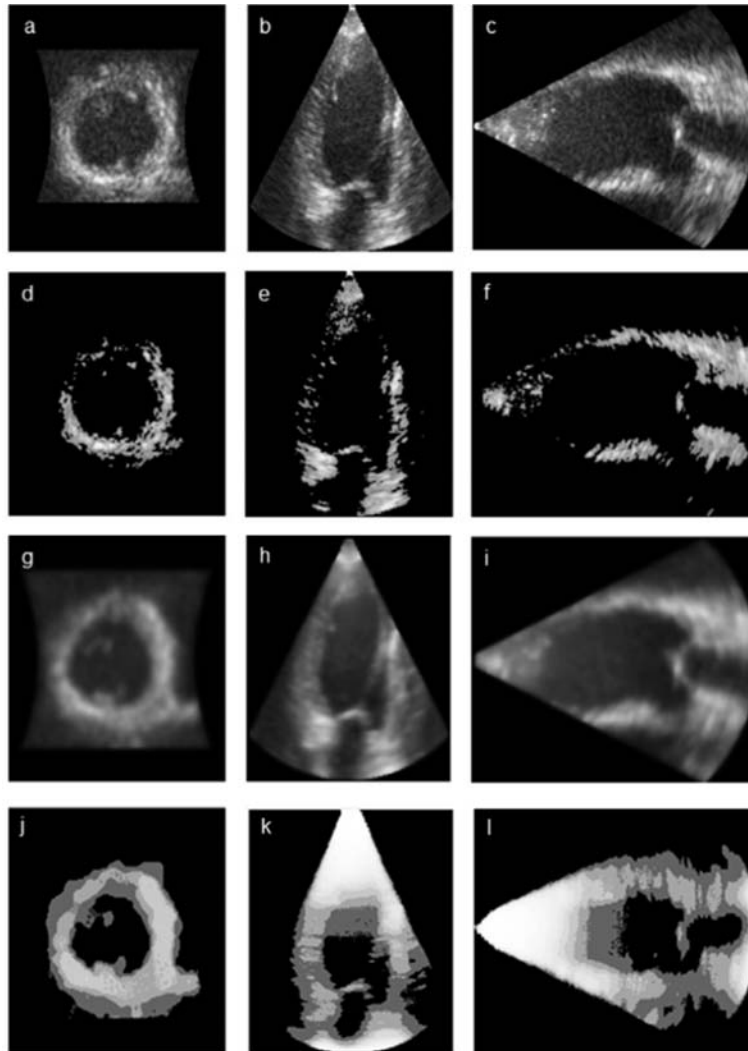

Figure 2: (*a*), (*b*) and (*c*) are the real input data sliced from image volume along different planes such as XY, XZ, YZ respectively. The output of the denoising filter in (*d*), (*e*) and (*f*). The output of PMAD filter in (*g*), (*h*) and (*i*) and the output of SRAD filter in (*j*), (*k*) and (*l*).
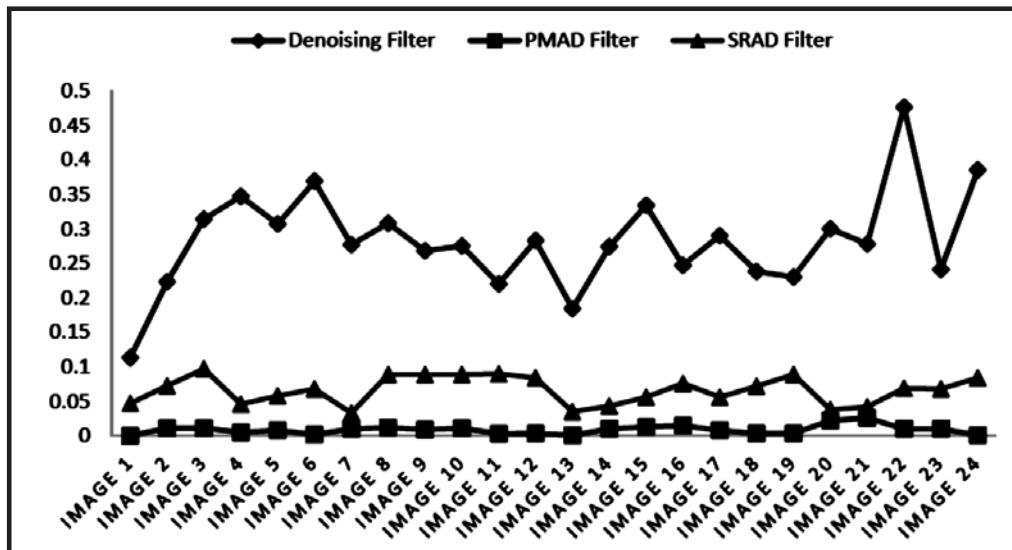

Figure 3: Comparison of Pratt's Figure of Merit for Twenty Four Images Taken from Different Patient Data

Theoretically, the figure of merit should be 1 to preserve the perfect shape in filtered image, even it is practically impossible, we acquired 48 % more compared to other two methods. The contrast wise also the pixel connectivity based filter shows better result when compared to the other two diffusion filters. This higher performance metrics results clearly indicates the performance of the filter is better than the traditional diffusion filters.
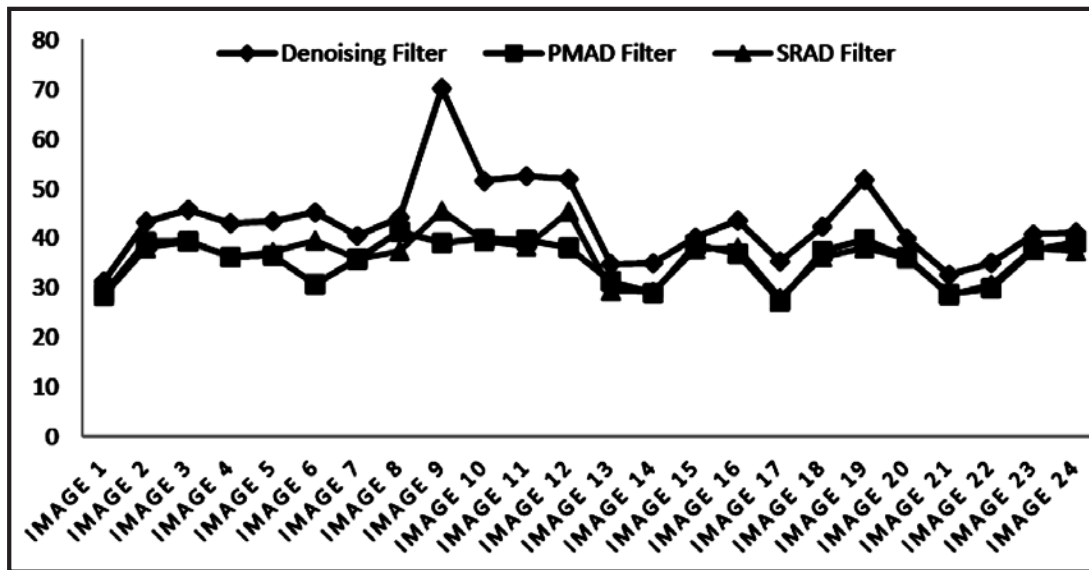

Figure 4: Comparison of Contrast for Twenty Four Images Taken from Different Patient Data

4. DISCUSSION

The voxel connectivity filter is developed to remove noise more effectively from echo cardio graphic images and provided better enhancement. The performance metrics calculated in this paper explained the quality of the developed filter. These results show the edge preservation and speckle filtering capabilities of this algorithm. The work reported for 3D echocardiography images for noise removal is very less when compared to 2D echocardiography, moreover, these work focussed on removing the noise of images taken from different patient using a single machine. In this work, we have focussed on noisy dataset taken from different patient with different echo cardio graphic machines and designed a filter for such a noisy datasets, which was the major challenge of this work. The algorithm of the filter is not too complex and instead of echo cardio graphic images, this can also be used for other form so medical images to remove the noise.

Although the algorithm performs well on noisy images, there are few limitations for the design. Due to the elimination of the corner boxes, there is a chance of losing information from the image. This may lead to lower the Pratts figure of merit values. The enhancement for the filter will help top reserve the edges and corners in a better way and that will increase the value of Pratts figure of merit in future.

5. CONCLUSION

The removal of speckle noise from an echocardiography image, enhance the quality and differentiate the boundary of regions for further process. So, noise removal is considered as an important preconditioning step in the image segmentation process. The reduction of speckle noise from the echocardiography image of the left ventricle region of the heart is done in this work using a voxel connectivity algorithm. A set of noisy clinical ultrasound image was used to test this algorithm and subsequent calculation of performance metrics quantifies the advantages of the new algorithm. Finally, these results compared with the existing filter called SRAD and PMAD reveals our denoising filter is far better than conventional filters in terms of quality and quantity.

6. ACKNOWLEDGMENTS

Conflict of interest

No conflict of interest

7. REFERENCES

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