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Cross Neighbourhood Kernel Filtering for Speckle Noise Removal in Ultrasound Images

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Abstract: *Ultrasound imaging is the most popular, non-invasive and inexpensive diagnostic tool in clinical imaging for treatment planning and therapy. Due to noise and artefacts present, pre-processing of these images is difficult which leads to poor image processing and analysis. In this paper, an improved frost filter with kernel of cross neighbourhood is proposed for denoising and performance analysis for different neighbourhood kernels is carried out using peak signal to noise ratio and mean square error.*

Keywords: Despeckling, frost filter, speckle noise, Ultrasound.

I. INTRODUCTION

Medical images are normally characterized by narrow distribution of gray-levels, thus suffered from high spatial redundancy and low contrast and further degraded by noises. Medical images are corrupted by various noises such as impulse noise, additive white Gaussian noise and speckle noise. These noises occur in imaging systems, storage devices, faulty sensors and transmission systems [1][1 a]. Various denoising methods have been proposed to restore medical images from these noises and do perform quite successfully, but despeckling proves difficult because of the multiplicative nature of speckle noise. Speckle noise affects all coherent medical imaging systems such as Ultrasound (US) and Optical coherence tomography. Among many medical imaging modalities, US imaging is the most popular, non-invasive and cheap method in clinical imaging. It finds wide application in monitoring fetus, the cardiovascular system, gynecology, abdomen, thyroid and [2][2a] has found increasing use in surgical and intravascular applications as a guide for interventional procedures [3][3a]. US images are most vulnerable to speckle noise because of coherent radiation in a medium containing many sub-resolution scatters. Speckle noise in US image lead to misinterpret mean image brightness, tiny high, low contrast objects and changes in image texture. Wide variety of linear and non linear filtering methods has been proposed for despeckling of ultrasound images and the most familiar filtering methods are Lee [4,5,6], Frost[7], Kuan[8] and Gamma MAP filter[9]. Both the Lee and Kuan filters restore a despeckled image by comprising a linear combination of the center pixel intensity in a filter window with the average intensity of the window. These filters achieve a balance between straightforward averaging and the identity filter. Frost filter uses an exponentially shaped filter kernel that can vary on a point wise and adaptive basis. Gamma maximum a posteriori (MAP) and extended versions of Lee and Frost filter strikes a balance between averaging and the identity filtering. All the filters are sensitive to the size and structure of the filter window and called as edge & feature preserving filters. Adaptive shape of filter window near edges does improve the edge preservation of images. In this paper, an improved frost filter with different shape kernels has been proposed and its performance is compared in terms of Peak-signal to noise ratio and mean absolute error. [10].

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II. FILTERING METHODS

A. *Speckle Filtering*

US despeckling is a pre-processing step provides clinicians with better diagnostic and therapy. Speckle filtering is implemented using a moving kernel over every pixel in the image. Central pixel is replaced by the calculated value which is derived by applying a mathematical calculation to the neighbourhood pixel values. This kernel is shifted along each pixel in the image till whole image is covered. Most of the speckle reducing filters achieve smoothing along the pixel values and reduces the presence of speckle noise. Some of the filters tend to reduce smoothing around edges to preserve edge details hence result in poor speckle removal. Carrying out Smoothing in homogeneous regions and preserving details around edges rely on neighbourhood pixels which are taken to determine local statistics of pixel of interest. Different neighbourhood pixels in the region of interest lead to different mean and variance and thus provide better speckle filtering. Frost filter is the one which adaptively changes its filtering based on image regions.

B. *Frost filter*

Frost filter is an adaptive filtering approach based on local statistic about the target pixel. Despeckled pixel value is estimated by the weighting co-efficient which decay from the filter centre when high contrast regions are filtered. In homogenous regions frost filter acts as a mean filter and at edges filtering is inhibited completely [10]. Thus despeckling is widely carried out by smoothing in homogeneous region and lesser smoothing or no smoothing in regions with high contrast pixels and edges. The filter output is determined by

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$$\hat{x}_s = \sum_{p\in\eta} k_p x_p \qquad (1)$$

where x_p is noisy pixel of interest in the window

k_p is given by

$$k_p = e^{(-KA_s^2 dis_{s,p})} / \sum_{p\in\eta} e^{(-KA_s^2 dis_{s,p})} \qquad (2)$$

where K, damping co-efficient, is selected such that $KA_s^2 \to 0$ at homogeneous regions and results in mean filter output and $KA_s^2 \to \infty$(so large) at edges and results in less or no despeckling or smoothing.

where $A_s^2 = (1/|\eta_s|)\sum_{p\in\eta}(x_p - \bar{x}_s)^2/(x_p - \bar{x}_s)^2$;

$\bar{x}_s$ is the mean value of the intensity within the filter window η_s

$$dis_{s,p} = \sqrt{(i - i_p)^2 + (j - j_p)^2} \qquad (3)$$

(i,j) - grid coordinates of pixel s and

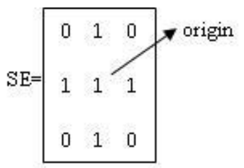
(i_p, j_p) - grid coordinates of pixel p

III. PROPOSED METHOD

Local characteristics such as mean and variance of target pixel rely on neighbourhood pixels of pixel of interest. Moving kernels of various shapes are used to carry out filtering over the image region. Coefficients of these kernels can be derived by structuring elements (SE) in MATLAB implementation. Structuring elements such as arbitrary, diamond, line, pair, periodic line, disk, square and rectangle are quite common. In this paper a structuring element based on horizontal and vertical neighbourhood, called cross neighbourhood ke is suggested. Kernel coefficients and local statistics are calculated based on these neighbourhood pixels. Some of the structuring elements which give different kernel coefficients help to remove speckle noise over the image region are given below.

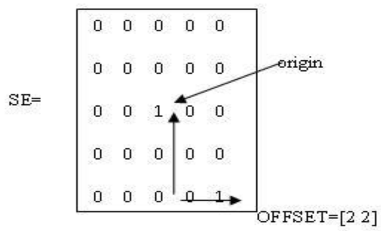
A. Cross Neighbourhood structuring element

This kernel is constructed using Cross structuring element which has all 1's in its horizontal and vertical neighbours as given below

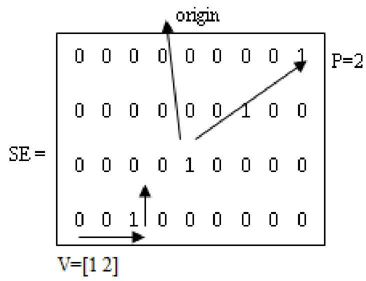


B. Other structuring elements

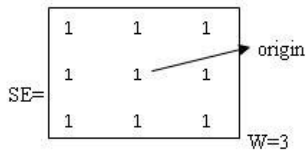
SE = strel('pair', OFFSET) creates a flat structuring element containing two members. One member is located at the origin. The second member's location is specified by the vector OFFSET. OFFSET must be a two-element vector of integers.



SE = strel('periodicline', P, V) creates a flat structuring element containing 2*P+1 members. V is a two-element vector containing integer-valued row and column offsets. One structuring element member is located at the origin. The other members are located at 1*V, -1*V, 2*V, -2*V, ..., P*V, -P*V.



SE = strel('square', W) creates a square structuring element whose width is W pixels. W must be a nonnegative integer scalar.



C. Simulation steps

1. Let x_s be the input image where s is the pixel coordinates (i,j)
2. Introduce speckle noise of variance ranging from 0.01 to 0.06
   Noisy image x_n=x_s+(speckle noise with variance η)
3. Apply filter with the kernels of different neighbourhood and the output image is given by
   $\hat{x}_s$ = cross neighbourhood kernel filter (x_s)

   a. Calculate local statistics of moving kernel with different neighbourhood as given by the structuring elements.
4. Calculate PSNR and MSE between restored image and the original image using equations 4 & 5 respectively.

IV. PERFORMANCE METRICS

The filtering methods are evaluated and compared in terms of Peak signal-to-noise ratio (PSNR) and mean square error (MSE). These quantitative measures are defined [11] as

$$PSNR\ in\ dB = 10\log_{10}\frac{255^2}{\frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n}(x_s(i,j) - \hat{x}_s(i,j))^2} \qquad (4)$$

$$MSE = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n}|(x_s(i,j) - \hat{x}_s(i,j)| \qquad (5)$$

where $x_s(i,j)$ and $\hat{x}_s(i,j)$ are the pixel values of original and restored images respectively at the location (i, j).

V. SIMULATION AND RESULTS

For simulation, breast US image of size 194 X 255 is taken. Input image is subjected to speckle noise of variance ranging from 0.01 to 0.06.

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Filtering is carried out by moving kernel of various neighbourhood pixels which determine the local statistics of pixel of interest. These local statistics decide smoothing over different regions of noisy image. Structuring elements are implemented using MATLAB morphological function. For arbitrary structuring element neighbourhood matrix is taken as [1 0 0;1 0 0;1 0 1]. Cross, Pair, Periodic line and square structuring elements are given in section II. Diamond and disk structuring elements use radius of 3. Size of rectangle structuring element is 3 X 5.

Denoising performance of the filter with different neighbourhood statistics are analyzed using PSNR & MSE and tabulated in Tab.1 & Tab.2. From the tables, it is evident that the proposed neighbourhood kernel outperforms others interms of PSNR & MSE. Pair structuring element based kernel gives high PSNR for noisy image with variance of 0.01. But for higher noise variances its PSNR decreases as compared to the proposed method. Fig.1 and Fig.2 also exhibits top four denoising performances. Subjective analysis also reveals that the proposed method results in better speckle removal as compared to other methods.

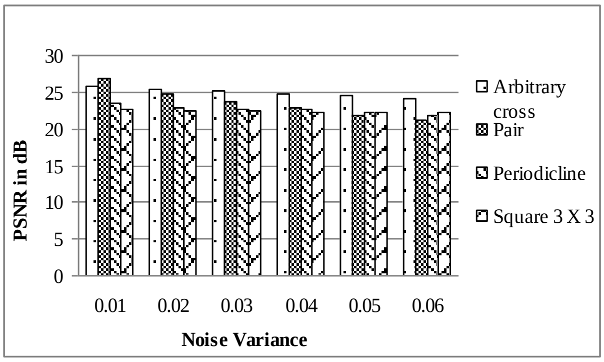

FIG.1 ANALYSIS OF PSNR IN DB FOR TOP FOUR METHODS

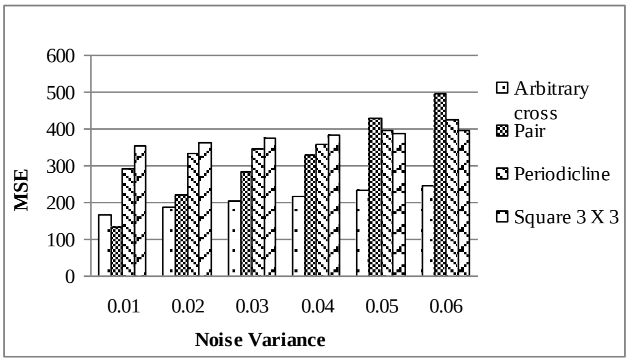

Fig.2 Analysis of MSE in dB for top four met

VI. CONCLUSION

Amount of filtering over homogeneous and edges of image regions are decided by the local statistics of moving kernel. These local statistics are calculated by different neighbourhood pixels as given above and the performance analysis clearly states that the proposed cross neighbourhood based kernel outperforms other neighbourhood kernels.

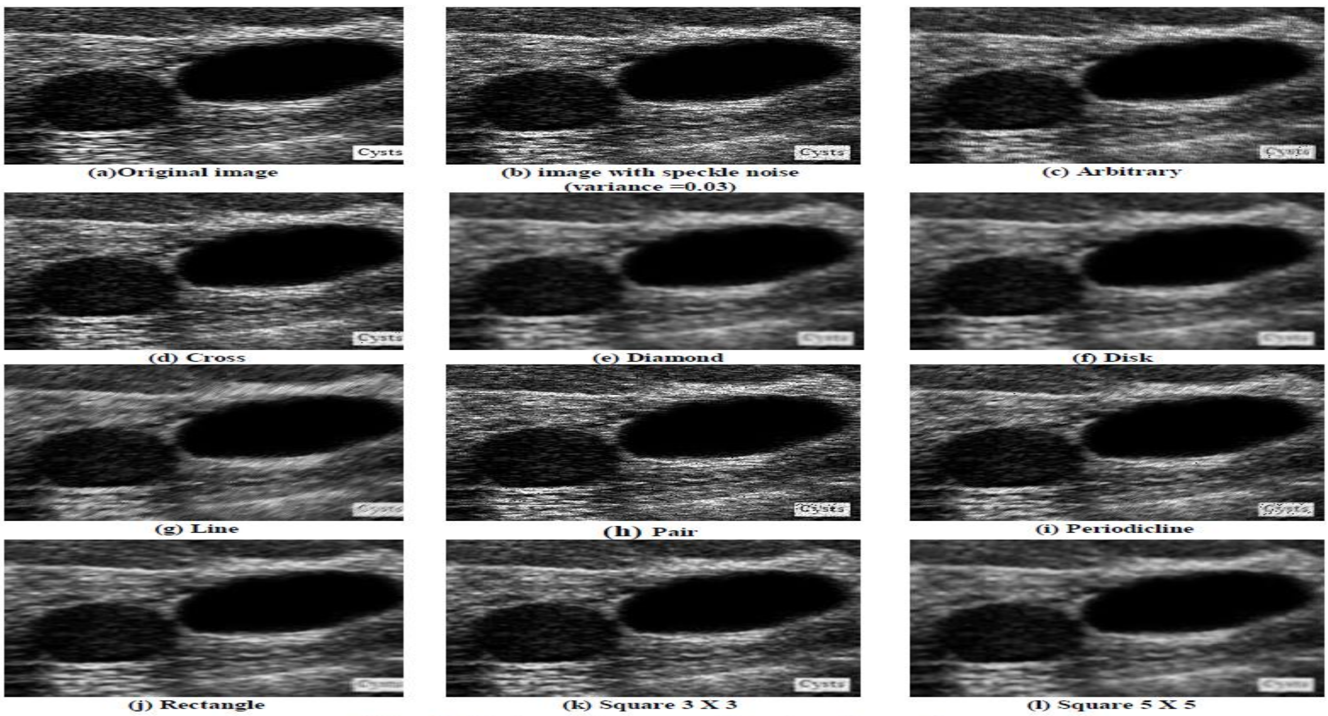

Fig. 3. Restored images of various kernels

Variance of noise / Structuring Element	0.01	0.02	0.03	0.04	0.05	0.06
Arbitrary	20.47315805	20.333551	20.21256	20.1176	19.97569	19.82538
Arbitrary cross	25.8776972	25.400985	25.07501	24.74964	24.44611	24.22239
Diamond	20.80587248	20.783649	20.72643	20.73022	20.68401	20.67643
Disk	20.38674334	20.374752	20.32959	20.34484	20.30322	20.30682
Line	21.7423793	21.64873	21.47273	21.41246	21.26005	21.16278
Pair	26.8442394	24.699611	23.61774	22.93112	21.78696	21.18356
Periodic line	23.50408849	22.913702	22.71932	22.59169	22.16928	21.83636
Rectangle	21.68559424	21.63318	21.54435	21.49709	21.44547	21.39215
Square 3 X 3	22.61446981	22.538916	22.39978	22.31135	22.22695	22.13451
Square 5 X 5	20.3675231	20.357257	20.31632	20.3299	20.29023	20.2931

Tab.1 PSNR values of filtering with kernel of different neighbourhood pixels.

Variance of noise / Structuring Element	0.01	0.02	0.03	0.04	0.05	0.06
Arbitrary	583.1288862	602.17853	619.1901	632.8789	653.9001	676.927
Arbitrary cross	168.0005256	187.49163	202.1062	217.8293	233.598	245.9471
Diamond	540.1235496	542.8945	550.094	549.615	555.4937	556.4649
Disk	594.8480291	596.4927	602.7277	600.6157	606.3988	605.8959
Line	435.3538912	444.8436	463.2417	469.7146	486.4917	497.5106
Pair	134.4796038	220.35316	282.6873	331.1073	430.9082	495.1356
Periodic line	290.1826966	332.4376	347.6551	358.0233	394.5957	426.034
Rectangle	441.0836264	446.43926	455.6647	460.6506	466.1582	471.9164
Square 3 X 3	356.1503537	362.40051	374.1985	381.8965	389.3904	397.7679
Square 5 X 5	597.4864362	598.90046	604.5719	602.6853	608.2154	607.814

TAB.2 MSE VALUES OF FILTERING WITH KERNEL OF DIFFERENT NEIGHBOURHOOD PIXELS.

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