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Speckle Noise Removal Methods in Ultrasound Medical Images: A Survey

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Abstract: Ultrasound images are used most popularly in medical image processing. The real time, low cost, non-invasive, no radiation features of ultrasound images make it useful for medical image processing applications. An ultrasound image provides the structural information of each organs of human body. Various techniques have been used for image acquisition and processing of ultrasound images. Visual content of ultrasound images are degraded due to a multiplicative type of noise called as speckle noise. This study deals with a detailed analysis of speckle noise removal techniques in ultrasound medical images.

Key words: Ultrasound images, image denosing, speckle noise, medical image processing, multiplicative noise

INTRODUCTION

Ultrasound imaging is one of the most popular medical imaging techniques since, it is inexpensive (Loizou *et al*., 2005). Ultrasound images are captured in real time with structural and/or organ movement of the body. Ultrasound imaging is done using ultrasonic waves in 3-20 MHz range. Ultrasound waves passes through the body and reflects back and the difference in time of reflection is converted into electric current which intern helps to identify the object with specific nature (Sutton, 1998).

There are different modes of ultrasound imaging. The most common modes are b-mode-the basic two dimensional intensity mode, m-mode-to assess moving body parts (e.g., cardiac movements) from the echoed sound and colour mode-pseudo colouring based on the detected cell motion using doppler analysis.

The ultrasound images are associated with a noise called speckle noise, hence they are not easy to interpret (Burckhardt, 1978). While applying traditional filters for denosing, the high intensity values associated with the images also get suppressed and this makes difficult for medical analysis.

The major adaptive filters for denosing ultrasound image include but limited to Lee Filter (Lee, 1981a, 1980), Forst Filter (Frost *et al*., 1982), Kuan Filter (Kuan *et al*., 1987), Median Filter (Huang *et al*., 1979), anisotropic diffusion (SRAD) (Yu and Acton, 2002), geometric filter (Crimmins, 1985), wavelet filter (Gupta *et al*., 2004), spatially varying frequency compounding, NL Mean algorithm (Buades *et al*., 2008), etc.

BASIC SPECKLE NOISE REDUCTION TECHNIQUES

Adaptive filters: Two forms of non adaptive filtering are based on mean and median and these non-adaptive filters are not able to preserve edges. Adaptive speckle filters is better at preserving edge/detail in densely textured region (higher texture areas) and hence widely used in ultrasound image analysis and restoration.

The major adaptive filters are proposed by Lee, Frost and Kuan. Lee filters uses linear approximation for speckle and Kuans filter uses nonlinear approximation. Lee filter deals with the multiplicative speckle noise by converting to additive one. Kuan is the generalization of Lee filter. Frost filter is a smoothing filter which is weighted exponential with some emphases on relative standard deviation (Lee, 1981b; Frost *et al*., 1982; Maini and Aggarwal, 2009).

Lopez *et al*. (1990) suggested adaptive speckle filters in which relative standard deviation is used for region based statistical filtering.

Yael Erez describes a method using compounding of frequencies stochastically rather than pixel wise averaging. In this stochastic denoising method, deep objects are reconstructed with no resolution loss and significant speckle reduction.

Median filter: Median filter was proposed by Richard for speckle reduction with preservation of boundary. Loupas *et al*. (1989) introduced Adaptive Weighted median filter (AWH) by assigning different weights to pixel for different regions.

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Wavelet filtering: Banazier A. Abrahim describes that speckle can be reduced by using Total Variation (TV) in the LL subband (containing low frequency components and less noise) of wavelet domain and shrinkage is used in other subbands to remove noise and preserve fine details.

Donoho L. David proposed a soft thresholding method using wavelet transform for unknown signals reconstruction from noise data (Donoho, 1995). Peng describes a modified soft-thresholding method that smoothens white noise and clean impulsive noise effectively.

Aleksandra and Philips proposed a correlation coefficient based noise reduction techniques using the image features (Pizurica *et al*., 2003). The preservation balance of the relevant features with the degree of noise reduction is done by using a single parameter. The method is applicable to various noises which are unknown during the studies which take very less time for implementation and execution.

Hui Chang and Wei Tang proposed a robust method for noise suppression using LS-SVR ("least square support vector regression") and wavelet transform which reduces speckle noise as well as preserve edge and real texture information.

Geometric filter: Geometric filter developed by Thomas R. Crimmins in 1985 is a non-linear filter based up on the concepts of Convex and 8 hulls (Crimmins, 1985). This filter is an iterative algorithm which reduces speckle noise and even preserves fine details in Ultrasound images.

The geometric filter operates on four different directions (vertical, horizontal and two diagonal directions). This filter calculates the maximum and minimum pixel values for every direction in every sliding window. The geometric filter algorithm (Loizou *et al*., 2005) works as follows:

1. Select the direction (N-S) and take the consecutive pixels that are being examined x, y and z
2. For each iteration
   a. Do dark pixel adjustments: if $((x\geq y+2)$ or $(x>y$ and $y\leq x)$ or $(z>y$ and $y\leq x)$ or $(z\geq y+2))$ then $y = y+1$
   b. Do light pixel adjustments: if $((x\leq y-2)$ or $(x<y$ and $y\geq z)$ or $(z<y$ and $y\geq x)$ or $(z\leq y-2))$ then $y = y-1$
2. Repeat step 1 and 2 from WE direction, NW-SE and SW-NE

Anisotropic diffusion: Anisotropic diffusion proposed by Perona and Malik in 1990 is a non-linear and space-variant transformation of the original image given by the nonlinear Partial Differential Equation (PDE) (Perona and Malik, 1990). The advantage of anisotropic diffusion is that, it enhances the speckle instead of eliminating the noise and good performance is obtained in image corrupted by additive noise with edge preservation and intra region smoothing.

Yu propose a Speckle Reducing Anisotropic Diffusion (SRAD), an extension of adaptive speckle filter, using PDE (Yu and Acton, 2002). A modified form of the above method is implemented by Scott. T. Action based on PDE, deconvolution and SRAD which gives low error rate which can be used for area estimation and improvement in fine features and for providing clarity in ultrasound image enhancement for quantitative analysis.

ADVANCED SPECKLE NOISE REDUCTION TECHNIQUES

NL Mean algorithm: NL Mean algorithm reduces redundancy for noise removal using weighted average of the pixel and uses the equation:

$$NLM(X(a)) = \sum_{\forall a\in X} \frac{1}{\sum_{\forall b} e^{-\frac{d(a,b)}{h^2}}} e^{-\frac{d(a,b)}{h^2}} X(a)$$

Where:
b's = Pixels, pixel 'a' needs to be filtered
d = Euclidean distance

Extensions of NL Mean algorithm includes modified NL Mean algorithm (Abrahim *et al*., 2011) and enhanced weights NL Mean algorithm (Chachada *et al*., 2011).

Bayesian non -local mean based speckle filtering: In this method, Pierric Coupe describes the patch comparison that uses NL-means filter with Pearson distance measure. High quality of denosing is achieved using this filter but this is computationally expensive. For computational complexity reduction they introduce a block wise approach. They use a weighted average of patches in block wise NL-mean filter.

IMAGE QUALITY EVALUATION METRICS

Different metrics are available for measuring the quality of ultrasound image denosing. Image quality measures can be of subjective and objective nature. Human Visual System (HVS) based on human judgment is an example of subjective measure. Objective quality measures includes but not limited to the following Mean Squared Error (MSE (p, q)) (Wang and Bovik, 2009; Winkler and Mohandas, 2008) is given by:

$$\frac{1}{n}\sum_{i=1}^{n}(p_i-q_i)$$

where, p_i and q_i are pixel intensities in the original and distorted image respectively. Peak signal to noise ratio (PSNR (p, q)) (Hore and Ziou, 2010) is given by $10\log_{10}$ 255^2/MSE (p, q) universal image quality index (Q) (Wang and Bovic, 2002) is given by:

$$\frac{4\sigma_{xy}\bar{x}\bar{y}}{\left(\sigma_x^2+\sigma_y^2\right)\left(\bar{x}^2+\bar{y}^2\right)}$$

where, $\bar{x}$, $\bar{y}$, σ_x, σ_y, σ_{xy} are the mean of the original image, mean of the test image, variance of the original image, variance of the test image and covariance respectively. Structural Similarity Image quality (SSIM (x, y)) (Wang *et al.*, 2003) given by:

$$\frac{\left(2\sigma_{xy}+c_2\right)\left(2\bar{x}\bar{y}+c_1\right)}{\left(\sigma_x^2+\sigma_y^2+c_2\right)\left(\bar{x}^2+\bar{y}^2+c_1\right)}$$

where, $\bar{x}$, $\bar{y}$, σ_x, σ_y, σ_{xy} are the mean of the original image, mean of the test image, variance of the original image, variance of the test image, covariance respectively and c_1, c_2 are constants.

EXPERIMENTAL RESULTS

Two different ultrasound images are used to compare the denoising methods like Median filter, Lee filter, Geometric filter, Anisotropic diffusion and NL Mean algorithm. Speckle noises are added to the images with standard deviation of 0.2, 0.3 and 0.4 before applying the denoising methods to see the benefits. The image quality measures like MSE, Root Mean Square Error (RMSE), PSNR and Q are calculated for each of the cases.

Figure 1 shows the original baby and bone ultrasound images used in this study. Figure 2 and 3 shows the results of applying various filter in the noisy images (standard deviation of noise added are 0.2, 0.3 and 0.4) using Median filter, Lee filter, Geometric filter, Anisotropic diffusion and NL Mean algorithm.

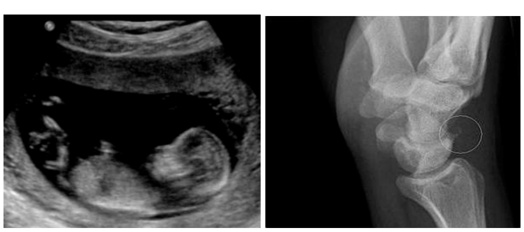

Fig. 1: Ultrasound images of baby (left) and bone (right)

Table 1 shows the image quality measures like MSE, Root Mean Square Error (RMSE), PSNR and Q for the baby images while denoising the noisy images (standard deviation of noise added are 0.2, 0.3 and 0.4) using

Table 1: The image quality measures for the baby image

Name of the filter	SD	Image quality measures MSE	RMSE	PSNR	Q
Median filter	0.2	0.0053	0.7307	70.8554	0.9400
	(0.3)	(0.0077)	(0.0881)	(69.2268)	(0.9147)
	[0.4]	[0.0100]	[0.0881]	[68.1042]	[0.8919]
Lee filter		0.0076	0.0873	69.3042	0.9164
		(0.0110)	(0.0104)	(67.7146)	(0.8817)
		[0.0140]	[0.1184]	[66.6566]	[0.8528]
Geometric filter		0.4403	0.6635	51.6933	0.1597
		(0.4370)	(0.6611)	(51.7251)	(0.1591)
		[0.4348]	[0.6594]	[51.7477]	[0.1564]
Anisotropic diffusion		0.0030	0.0550	73.3108	0.9643
		(0.0042)	(0.0650)	(71.8719)	(0.9504)
		[0.0053]	[0.0734]	[70.8114]	[0.9371]
NL mean		0.0036	0.0600	72.5636	0.9574
		(0.0069)	(0.0831)	(69.7290)	(0.9203)
		[0.0125]	[0.0125]	[67.9133]	[0.8829]

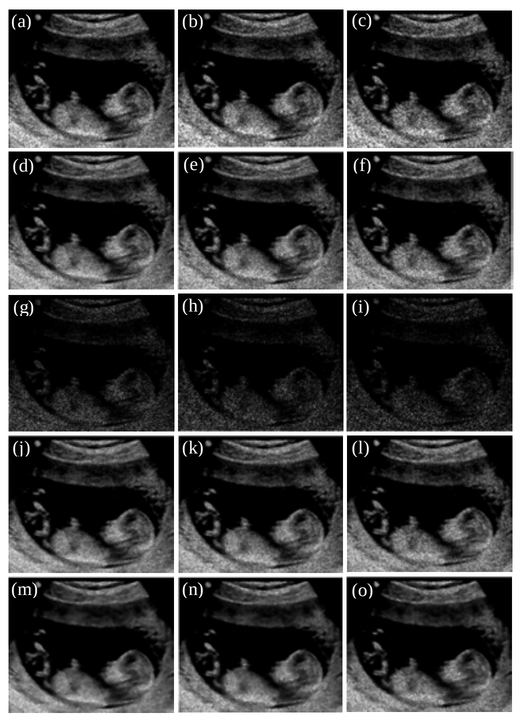

Fig. 2: For baby ultrasound image: a-c) result of median filtering on noisy image with SD = 0.2, 0.3, 0.4; d-f) result of Lee filtering on noisy image with SD = 0.2, 0.3, 0.4; g-i) result of Geometric filtering on noisy image with SD = 0.2, 0.3, 0.4; j-l) result of Anisotropic diffusion filtering on noisy image with SD = 0.2, 0.3, 0.4 and m-o) result of NL-mean filtering on noisy image with SD = 0.2, 0.3, 0.4

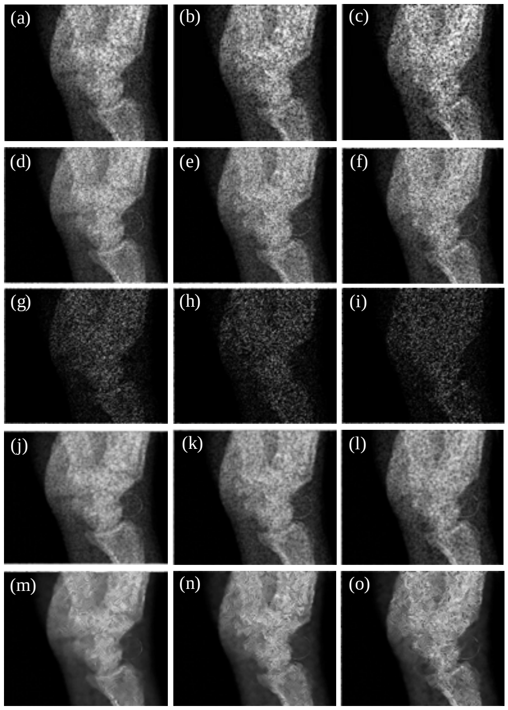

Fig. 3: For bone ultrasound image: a-c) result of median filtering on noisy image with SD = 0.2, 0.3, 0.4;d-f) result of Lee filtering on noisy image with SD = 0.2, 0.3, 0.4; g-i) result of Geometric filtering on noisy image with SD = 0.2, 0.3, 0.4 ; j-l) result of Anisotropic diffusion filtering on noisy image with SD = 0.2, 0.3, 0.4 and m-o) result of NL-mean filtering on noisy image with SD = 0.2, 0.3, 0.4

Table 2: The image quality measures for the bone image

Name of the filter	SD	Image quality measures MSE	RMSE	PSNR	Q
Median filter	0.2	0.0179	0.1340	65.5833	0.8529
	(0.3)	(0.2135)	(0.1461)	(64.8364)	(0.8305)
	[0.4]	[0.0244]	[0.1563]	[64.2478]	[0.8096]
Lee filter		0.0101	0.1009	68.0486	0.9187
		(0.0150)	(0.1227)	(66.3473)	(0.8818)
		[0.0187]	[0.1371]	[65.3897]	[0.8539]
Geometric filter		0.4224	0.6499	51.8726	0.2275
		(0.4233)	(0.6506)	(51.8640)	(0.2224)
		[0.4279]	[0.6542]	[51.8164]	[0.2182]
Anisotropic diffusion		0.0110	0.1052	67.6861	0.9048
		(0.0128)	(0.1134)	(67.0370)	(0.8898)
		[0.0141]	[0.1191]	[66.6107]	[0.8779]
NL mean		0.0059	0.0773	70.3573	0.9510
		(0.0110)	(0.1077)	(67.4800)	(0.9078)
		[0.0171]	[0.1311]	[65.7700]	[0.8672]

Median filter, Lee filter, Geometric filter, Anisotropic diffusion and NL Mean algorithm. Similarly, Table 2 shows the quality measures for bone image.

From these experimental results, it clear that NL Means algorithm removes the noise in the image better than other methods in the case of noise standard deviation is 0.2 and 0.3. The performance of NL means is comparable when the noise standard deviation is 0.4.

CONCLUSION

A quick survey of speckle noise removal methods are presented in this study. A comparative study of widely used speckle noise removal methods is done. Experimental results shows that the non-Local Mean (NLM) algorithm is better compared to other methods.

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