RESEARCH ARTICLE OPEN ACCESS

Speckle Reduction Techniques for Ultrasound Images

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Abstract:

Images of different body organs play very important role in medical diagnosis. Images can be taken by using different techniques like x-rays, gamma rays, ultrasound etc. Ultrasound images are widely used as a diagnosis tool because of its non invasive nature and low cost. The medical images which uses the principle of coherence suffers from speckle noise, which is multiplicative in nature. Ultrasound images are coherent images so speckle noise is inherited in ultrasound images which occur at the time of image acquisition. There are many factors which can degrade the quality of image but noise present in ultrasound image is a prime factor which can negatively affect result while autonomous machine perception. In this paper we will discuss types of noises and speckle reduction techniques. In the end, study about speckle reduction in ultrasound of various researchers will be compared.

Keywords **— Noise, Speckle, Gaussian, Spatial Filtering, Transform Filtering**

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I. INTRODUCTION

Ultrasound imaging is a medical diagnosis technique that uses sound waves of very high frequency and their echoes. In addition, ultrasound images have the advantage of being portable, versatile, and not requiring ionizing radiations [1]. The image generated using ultrasound waves is called Ultrasonogram. There are many modes of ultrasound imaging but b-mode and m-mode are most commonly used methods. Moreover the diagnosis procedure in ultrasound is of low cost and in order to diagnose an illness, person need not to go through dangerous invasive procedures. Ultrasound images are coherent images so speckle noise is inherited in ultrasound images which occur at the time of image acquisition. There are many factors which can degrade the quality of image but noise present in ultrasound image is a prime factor which can negatively affect result while autonomous machine perception [2]. Noise in a digital image is a very common problem. Noise can be introduced at all stages of Image acquisition. There could be noises due to the loss of proper contact or air gap between the Transducer probe and body; there could be noise introduced during the beam forming process and also during the signal processing stage. Even during the Scan conversion, there could be loss of information due to the interpolation. So we can say image gets corrupted with noise during acquisition, transmission, storage and the retrieval processes. Ultrasound imaging system overview is given below in fig.1.

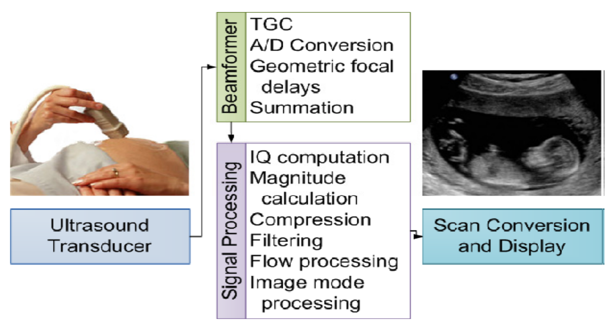

Fig.1 Ultrasound Imaging System

II. SPECKLE NOISE

Image noise is the random variation of brightness or color information in images produced by the sensor and circuitry of a scanner or digital camera [3]. Speckle is a particular kind of noise which occurs in images obtained by coherent imaging systems like ultrasound. The coherent imaging in simple terms is lensless imaging. Speckle noise is a multiplicative noise which occurs in the coherent imaging, while other noises are additive noise. Speckle is caused by interference between coherent waves that, backscattered by natural surfaces, arrive out of phase at the sensor. Speckle can be described as random multiplicative noise. This type of noise is an inherent property of medical ultrasound imaging. So, speckle noise reduction is an essential preprocessing step, whenever ultrasound imaging is used for medical imaging. The probability distribution function for speckle noise is given by gamma distribution,

$$P(z) = \frac{z^{\alpha-1}}{(\alpha-1)!a^{\alpha}} e^{-z/a}$$

Where z represents the gray level and variance is $a^2\alpha$. The probability density function of Salt and Pepper noise is graphically represented in figure-2

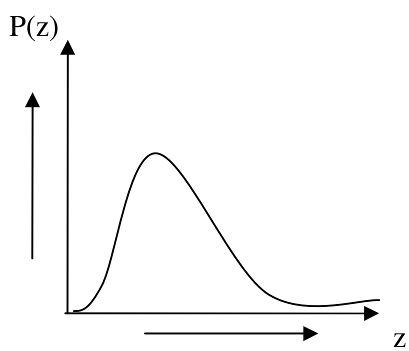

Fig-2 Probability density function of speckle noise

III. IMAGE QUALITY MEASURES

The quality of an image can be examined objectively evaluation as well as subjectively. For subjective evaluation, the image has to be observed by a human expert [4]. But The human visual system cannot do pixel by pixel evaluation of given image, So exact quality of image is difficult to determine. There are various metrics used for objective evaluation of an image [4].

- Mean square error
- Root mean square error
- Mean absolute error
- Peak signal to noise ratio

Let the original noise-free image F(m,n) , noisy image G(m,n), and the filtered image F'(m,n) be represented where m and n represent the discrete spatial coordinates of the digital images. Let the image size be M x N i.e m= 1,2,3………M and n= 1,2,3……..N

A. MEAN SQUARE ERROR:

For a given image F(m,n), the mean square error of the image is given as

$$MSE = \sum_{m=1}^{M} \sum_{n=1}^{N} (\tilde{F}(m,n) - F(m,n))^2$$

B. ROOT MEAN SQUARE:

For a given image F(m,n), the mean square error of the image is given as

$$RMSE = \sqrt{MSE}$$

C. MEAN ABSOLUTE ERROR:

For a given image F(m,n), the mean square error of the image is given as

$$MAE = \sum_{m=1}^{M} \sum_{n=1}^{N} \left| \tilde{F}(m,n) - F(m,n) \right|$$

D. PEAK SIGNAL TO NOISE RATIO:

Peak signal to noise ratio (PSNR) is another important image metric. It is defined in logarithmic scale. It is a ratio of peak signal power to noise power [8]. Since the MSE represents the noise power and the peak signal power, the PSNR is defined as:

$$PSNR = 10 * \log_{10} (\frac{1}{MSE})$$

There are some other metrics like, universal quality index (UQI) can be used to evaluate the quality of an image now-a-days. Further, some parameters, e.g. method noise and execution time are also used in literature to evaluate the filtering performance of a filter.

IV. SPECKLE REDUCTION TECHNIQUES

Filter has very important role in image de-noising process. Using filter technique, in order to decide particular value of pixel in output image the neighbor pixels also participate. The values in filter are known as coefficient rather than pixels. The filter which we use for denoising is also called as mask. There are two basic approaches to image de-noising, spatial domain filtering methods and transform domain filtering methods [3,5]. The spatial filtering process consists simply moving the filter mask from point to point in an image. At each point, the response of the filter at that point is calculated using a predefined relationship. The filters in frequency domain are more effective than in spatial domain while reducing noises because it is to identify noise in frequency domain [6]. When an image is transformed into the Fourier domain, the low frequency components usually correspond to smooth regions or blurred structures of the image, whereas high-frequency components represent image details, edges, and noises. Some standard speckle reduction filters like mean filter, median filter, lee filter, kuan filter, frost filter are given below.

A. Mean Filter

It is a traditional method of filtering. A mean filter [7,8] acts on an image by smoothing it. i.e., it reduces the variation in terms of intensity between adjacent pixels. The mean filter is used to suppress additive noise but edge preservation is not well with mean filter. The mean filter is a simple moving window spatial filter, which replaces the center value in the window with the average of all the neighbouring pixel values including that centre value. It is implemented with a convolution mask, which provides a result that is a weighted sum of the values of a pixel and its neighbour pixels. It is also called a linear filter. The mask or kernel is a square. Often a 3× 3 square kernel is used. If the sum of coefficients of the mask equal to one, then the average brightness of the image is not changed. If the sum of the coefficients equal to zero, then mean filter returns a dark image. Average filter method is also called neighbourhood average method. The essential idea of this method is to replace gray scale value of the center pixel by average value of neighbourhood pixel gray scale. It is used to reduce AWGN but it can cause blurring effect. Its filter features are analyzed as follows:

Suppose the noise model for any digital image is given as

$$G(x,y) = F(x,y) + N(x,y)$$

The image after neighborhood smoothing is

$$\hat{G}(x,y) = \frac{1}{M}\sum_{(x,y)\in S} F(x,y) + \frac{1}{M}\sum_{(x,y)\in S} N(x,y)$$

B. Median Filter

The Median Filter is performed by taking the magnitude of all of the vectors within a mask and sorted according to the magnitudes. The pixel with the median magnitude is then used to replace the pixel studied [9].The median filter is classified as a linear filter. It works well to suppress the Salt and pepper noise. A median filter comes under the class of nonlinear filter. It also follows the moving window principle, like mean filter. A 3× 3, 5× 5, or 7× 7 kernel of pixels is moved over the entire image. First the median of the pixel values in the window is computed, and then the center pixel of the window is replaced with the computed median value. Calculation of Median is done as first sorting all the pixel values from the surrounding neighbourhood and then replacing the pixel being considered with the middle pixel value. It is known as a rank filter [10]. Median filters exhibit edge-preserving characteristics unlike linear methods such as average filtering tends to blur edges, which is very desirable for many image processing applications as edges contain important information for segmenting, labelling and preserving detail in images. It is reasonable to assume that the signal is of finite length, consisting of samples from F(0) to F(L-1). If the filter's window length is N=2k+1, the filtering procedure is given by:

$$G(n) = Med[F(n-k)....F(n),......,F(n+k)]$$

Where G(n) and F(n) are the input and the output sequences, respectively.

Ultrasound images corrupted with speckle noise can be processed with mean and median filters. Results of median and mean filter on ultrasound images in matlab are given below

Fig.3 Ultrasound denoising using mean and median filter in matlab

C. Lee Filter

Lee Filter [11] is based on multiplicative speckle model and it can use local statistics to effectively preserve edges. This filter is based on the approach that if the variance over an area is low or constant, then smoothing will not be performed, otherwise smoothing will be performed if variance is high(near edges).

$$Img(i,j)=Im + W*(Cp-Im)$$

Where Img is the pixel Value at indices i, j after filtering, Im is mean intensity of the filter window, Cp is the center pixel and W is a filter window given by:

$$W = \sigma^2 /(\sigma^2 + \rho^2)$$

where σ^2 is the variance of the pixel values within the filter window and is calculated as:

$$\sigma^2 = 1/N \sum_{j=0}^{n-1} (Xj)^2$$

Here, N is the size of the filter window and Xj is the pixel value within the filter window at indices j.
The parameter ρ is the additive noise variance of the image given in following equation, where M is the size of the image and Yj is the value of each pixel in the image.

$$\rho^2 = 1/M \sum_{j=0}^{m-1} (Yi)^2$$

If there is no smoothening, the filter will output only the mean intensity value(Im) of the filter window. Otherwise, the difference between Cp and Im is calculated and multiplied with W and then summed with Im.
The main drawback of Lee filter is that it tends to ignore speckle noise near edges.

D. Kuan Filter

Kuan filter is a local linear minimum square error filter based on multiplicative order it does not make approximation on the noise variance within the filter window like lee filter it models the multiplicative model of speckle noise into an additive linear form [12]. The weighting function W is computed as follows:

$$W = (1 - C_u / C_i)/(1 + C_u)$$

The weighting function is computed from the estimated noise variation coefficient of the image, Cu computed as follows:

$$C_u = \sqrt{1/ENL}$$

And Ci is the variation coefficient of the image computed as follows:

$$C_i = S / \text{Im}$$

Where S is the standard deviation in filter window and Im is mean intensity value within the window. The only limitation with Kuan filter is that the ENL parameter is needed for computation.

E. Frost Filter

Frost filter is a spatial domain adaptive filter that is based on multiplicative noise order it adapts to noise variance within the filter window by applying exponentially weighting factors M as:

$$M_n = \exp(-(DAMP * (S / \text{Im})^2) * T)$$

The weighting factor decrease as the variance within the filter windows reduces. DAMP is a factor that determines the extent of the exponential damping for the image [13]. The larger the damping value, the heavier is the damping effect. Typically the value is set to 1. S is the standard deviation of the filter window, Im is the mean value within the window and T is the absolute value of the pixel distance between the center pixel to its surrounding pixels in the filter window. The value of the filtered pixel is replaced with a value calculated from weighted sum of each pixel value Pn and the weights of each pixel Mn in the filter window over the total weighted value of the image as:

$$\operatorname{Im} g(i,j) = \sum P_n * M_n / \sum M_n$$

The parameters in the Frost filter are adjusted according to the local variance in each area. If the variance is low, then the filtering will cause extensive smoothing.

F. Wiener Filter

The wiener filter is a spatial domain filter and it generally used for suppression of additive noise. Wiener filters are a class of optimum linear filters which involve linear estimation of a desired signal sequence from another related sequence. The wiener filter's main purpose is to reduce the amount of noise present in a image by comparison with an estimation of the desired noiseless image [14]. This filter is the mean squares error-optimal stationary linear filter for images degraded by additive noise and blurring. due to linear motion or unfocussed optics Wiener filter is the most important technique for removal of blur in images. Wiener filter can be applied in two ways (a) spatial domain by using mean squared method (b) fourier transform method. Wiener filter in fourier domain can be used for deblurring and denoising whereas in spatial domain Wiener filter cannot be used for deblurring. Wiener filter is based on the least-squared principle, i.e. the this filter minimizes the mean-squared error (MSE) between the actual output and the desired output. Thus, both global statistics (mean, variance, etc. of the whole image) and local statistics (mean, variance, etc. of a small region or sub-image) are important [12]. Wiener filtering is based on both the global statistics and local statistics and is given as

$$\hat{F}(x,y) = \bar{g} + \frac{\sigma f^2}{\sigma f^2 + \sigma n^2}(g(x,y) - \bar{g})$$

And $$\bar{g} = \frac{1}{L}\sum_{s=-m}^{M}\sum_{t=-n}^{N} g(s,t)$$

Where $\hat{F}(x,y)$ denotes restored image, σ_f^2 is the local variance and σ_n^2 is the noise variance [14]. In statistical theory, Wiener filtering is a great land mark. It estimates the original data with minimum mean-squared error and hence, the overall noise power in the filtered output is minimal. Thus, it is accepted as a benchmark in 1-D and 2-D signal processing.

G. Soft Computing for Ultrasound Despeckling

Soft computing principles like Artificial Neural Networks (ANN), Genetic Algorithms (GA) and Fuzzy Logic (FL) are also be used in designing algorithms for speckle noise reduction in medical ultrasound images. Hyunkyung Park et al shows that a cellular neural network which is a kind of recurrent neural network can deal with images by the weight of neurons called a cell. It could obtain more detail image recognition compared with other methods. In the study [15], they discuss determination template parameters of the cellular neural network for ultrasound image processing. Their experimental results show effectiveness of applying the proposed method to boundary enhancement and the speckle noise reduction of medical ultrasound image. In [16] Maruyama Kenjiro et al presents a neural Network based nonlinear 2D filtering technique for adaptive speckle reduction in ultrasound images. Then use ultrasound speckle model and back propogation for training the Neural Network. They confirmed the efficiency of the approach with simulated results.

V. SPECKLE REDUCTION TECHNIQUES AND RELETIVE FINDINGS

Year	Author	Title	Approach	Relevant Findings
1980	Lee	Digital Image enhancement and noise filtering	Single scale	It uses the approach that if the variance over an area is low or constant, then smoothing will not be performed, otherwise smoothing will be performed if variance is high.
1982	Frost et al	A model for radar image & its application to adaptive digital filtering for multiplicative noise	Single Scale	It belongs to spatial domain adaptive filter that works on multiplicative noise , it adapts to noise variance within the filter window by using exponentially weighting factors.
1989	T.Loupas et al	An adaptive weighted median filter for speckle suppression in medical ultrasonic images	Single Scale	They do the adaptive filtering by adjusting the weight coefficients of the median filter according to the local statistics of the image.
1995	Richard N. Czerwinska et al	Ultrasound speckle Reduction by Directional Median filtering	Single Scale	A technique is presented which uses novel adaptation of the median filter to the problem of speckle reduction by preserving boundary in ultrasonic imaging.
2001	Chedsada Chinrungrueng et al	Fast Edge-Preserving Noise Reduction for Ultrasound Images	Single Scale	It describes a non linear filtering technique which is based on the least squares fitting of a polynomial function to image intensities.
2004	Yu and acton	Generalized speckle reducing anisotropic diffusion for ultrasound imagery	Single Scale	PDE for speckle reduction from minimizing a cost functional of instantaneous coefficient of variation was developed.
2006	Badawi et al	Speckle Reduction in Medical Ultrasound: A Novel Scatterer Density Weighted Nonlinear Diffusion Algorithm Implemented as a Neural-Network Filter	Single scale	They Proposed a novel algorithm for speckle reduction in medical ultrasound imaging while preserving edges with added advantage of adaptive noise filtering and also speed.

2007	Ricardo G. Dantas et al	Ultrasound speckle reduction using modified gabor filters	Single Scale	It describes a method for speckle reduction in ultrasound medical imaging, which uses a bank of wideband 2-D directive filters, based on modified Gabor function.
2009	Shankar	Contrast enhancement and phase-sensitive boundary detection in ultrasonic speckle using Bessel spatial filters	Single Scale	A class of spatial filters based on cylindrical Bessel functions of the first kind for speckle reduction was proposed.
2011	Babak Mohammadzadeh et al	Contrast Enhancement and Robustness Improvement of Adaptive Ultrasound Imaging Using Forward-Backward Minimum Variance Beamforming	Single Scale	They used forward/backward spatial averaging for array covariance matrix estimation, which is then employed in minimum variance weight calculation.
2011	Paul liu and dong liu	Filter-based compounded delay estimation with application to strain imaging	Single Scale	They developed an approach using a filter bank to create multiple looks to produce a compounded motion estimate.
2003	Pizurica et al	A versatile wavelet domain Noise filtration technique for medical imaging	Multi scale	They Proposed a robust wavelet domain method for noise filtering in medical images. The proposed method adapts itself to various types of image noise as well as to the preference of the medical expert.
2004	S. Gupta et al	Wavelet based statistical approach for speckle reduction in medical ultrasound images	Multi Scale	The threshold is calculated using simple standard deviation of noise and the sub band data of noise free image . K is also used as a scale parameter.
2007	Zhang et al	Nonlinear diffusion in laplacian pyramid domain for ultrasonic speckle reduction	Multi Scale	They presents a Laplacian pyramid-based nonlinear diffusion (LPND), approach for reducing speckle noise in medical Ultrasound imaging .
2010	Maryam Amirmazlaghani	Two Novel Bayesian Multiscale Approaches for Speckle Suppression in SAR Images	Multi Scale	They developed two new bayesian speckle suppression approaches in this paper. They introduced 2D GARCH model and GARCH- M model

2014	S. Kalaivani et al	Condensed anisotropic diffusion for speckle reduction and enhancement in ultrasonography	Multi Scale	In this scheme, diffusion matrix is designed using local coordinate transformation and the feature broadening correction term is derived from energy function.

Table 1 Speckle reduction techniques and relative findings

VI. CONCLUSION

This paper presents a detailed survey of research on speckle removal methods. We have focused only on speckle noise which occurs most frequently in ultrasound images. Speckle Noise with various noise intensity range from low to high. We have analysed noise removal algorithms for these noises. The parameters for this analysis were high level of noise detection, preserving features and edges, over smoothness, high contrast image, high density noise, and mixture of noises. There is lack of uniformity in how methods are evaluated so it is imprudent to declare which methods indeed have lowest error rate with highest noise ratio. Therefore, our analysis has produced relative performance of methods. Noise can be removed using single scale filters as well multi scale filters. Single scale possesses mathematical simplicity but have the disadvantage that they introduce blurring effect. To reduce this blurring effect we can use multi scale filters like wavelet filter etc because of their multi resolution property. So, keeping in view, a robust system should fulfil all the above parameters with multiple noises removal in a single ultrasound image and in multiple images.

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