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Speckle Denoising Filters – A Survey

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ABSTRACT

Medical images are most commonly corrupted by various types of noises during the process of image acquisition and transmission. It is very important to get precise images to obtain exact information for the particular application. Removal of Noise from medical images is remarkably hard without knowing the prior information of noise types, causes, and removal procedures. This becomes the main reason to analyze the various noises removing process. Until now numerous researchers have working to remove noise using spatial, adaptive and fuzzy filtering approaches. This paper presents a study of various denoising procedures available in the literature.

KEYWORDS: Medical Images, Speckle Noise, Fuzzy Logic, Denoising Filters.

I. INTRODUCTION

Currently, digital image capturing and processing techniques have become an important part in medical diagnosis. Living object images are using the various modalities like ultrasound, X-ray, magnetic resonance imaging and computed tomography. During the capturing process there may occur some image distortions, which would affect the accurate diagnosis of the image. This illustrates the significance of using Innovative Medical Image Processing Approaches for developing the feature by eliminating noise facts present in the input image to obtain an accurate diagnosis. Even though we have different medical image capturing modalities, ultrasound has become the most popular because of its cost effectiveness and non-invasive nature. However, ultrasound image has more noise components when compared to other modalities like MRI and CT. The capabilities such as real time imaging and harmlessness are the two main important reasons for ultrasound imaging becoming more utilized modality in the last two decades. Ultrasound image is obtained by using ultrasonic waves in the range 3 to 20 MHz. Once transducer produces the ultrasound waves, it travels throughout the human body tissues until it reaches a surface or an object with acoustic nature or different texture and it reflects back. The transducer array receives the reflected echoes and changes into electric current. Consequently, these signals are conditioned, amplified and shown on a digital device in real time [1]. The above described imaging process which uses ultrasonic waves is commonly known as ultrasound scanning or ultra sonogram. The image resolution will become better utilizing high frequencies; however there is a limitation for the depths to penetrate. Ultrasound imaging has different types of modes. The most common used modes are B-mode, M-mode and Colour mode. B-mode is basically a two-dimensional intensity mode. M-mode is used to analyze the movements of human body parts. Colour mode is a pseudo colouring which bases the detection cell action utilizing Doppler analysis. Main benefits of ultrasound imaging are (i) in expensive (ii) no radiation (iii) obstetric and liver imaging (iv) effectiveness for cyst and (v) real time image formation [2]. But, by nature, it contains lot of noise components, than other imaging modalities. For example speckle noise. The original and the speckle noisy images are illustrated in fig 1.

Fig. 1: (i) Original Image

(ii) Speckle Noise Image

Noise is introduced at every stage of image acquisition process. That is, due to the air gap among the body and transducer probe and proper contact failure. And also it introduced during the process of beam forming and the stage of signal processing. Even at the time of scan conversion, information may be lost by interpolation. Ultrasound image filtering techniques and analyzing methods have been led to a deep review. These reviews particularly focus one type of noise called speckle. The most speckle noise affected imaging system is coherent which includes medical ultrasound images. Speckle noise distorts, the edge definition and fine particulars, and creates a limitation for contrast resolution. These issues create a difficulty in detecting low and small contrast lesions in human body. Ultrasound noise image reduction techniques come under the two divisions namely during acquisition process and after acquisition process. The primary refers unique processing components included to the acquisition process to reduce the noise content and as well to develop the characteristics in the input image. The secondary includes noise filtering techniques employed to suppress the noise and also enhances the acquired ultrasound image qualities. Our aim is to focus the latter one. Nowadays researchers have been publishing numerous articles related to the application of various techniques in medical image frameworks for developing the characteristics of the image obtained through an ultrasound scanner. This article tries to discuss the various denoising approaches and categorize them into several groups.

II. SPECKLE NOISE MODEL

Speckle noise is a multiplicative noise that occurs in all coherent real time images such as synthetic aperture radar images and medical ultrasonic images. The mathematical model for speckle noise is given as follows.

$$g(x,y) = f(x,y) \times \eta(x,y) + \gamma(x,y) \qquad (1)$$

Where, $g(x,y)$ and $f(x,y)$ denotes resultant corrupted image and original image.

$\eta(x,y)$ and $\gamma(x,y)$ indicates multiplicative and additive noise component present in the image.

The effectiveness of additive noise is very low when compared with multiplicative noise. Hence the above equation can be rewritten as

$$g(x,y) = f(x,y) \times \eta(x,y) \qquad (2)$$

III. SCALAR FILTERING APPROACH

Depending on local statistics ratio, scalar filters develop homogeneous areas smoothness where noise is totally increased and decreases the noise significantly in the remaining regions to protect the important particulars of the image. Mean and median filters are the most commonly used scalar filters.

In 1984, Pomalaza Raez discovered the mean filter which is simple and instinctive. This filter replaces centre pixel by calculating the mean value of the neighboring pixels. It removes speckle noise to some extent. After that it starts to produce the blurring effect significantly. This filter works well for additive Gaussian noise whereas speckle affected image minds a multiplicative Non-Gaussian noise model [3]. This method is otherwise commonly known as slightest acceptable method because of its poor performance in detail preservation, resolution and blurring effect. Its mathematical representation is given as follows.

$$h[k,l] = \frac{1}{M} \sum_{(i,j)\in N} f(i,j) \qquad (3)$$

Where M represents the number of pixels in the surrounding N. f (i, j) and h (k, l) indicates new and old image pixels.

In 1990, Pitas invented a new filter called Median filter [4]. It is also known as order statistics and non-linear filtering technique. Its standard model is directly used as a preprocessing method. Because of its robustness in reducing impulse noise, preserving edges and maintaining image characteristics, it can be more widely used as a digital image preprocessing technique.

The advantages of this filter are less blurring and edge preservation, however disadvantage is it consumes more computation time in calculating median value for sorting N pixels. The mathematical model for median filter with window length N=2k+1 is given by.

$$F(n) = Median[G(n-k),..G(n),\ldots\ldots.F(n+k)] \qquad (4)$$

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

IV. ADAPTIVE FILTERING APPROACH

In 1982, Frost found a new filtering technique which is linear, convolution and more suitable to preserve the De-speckling images [5]. It has adaptive nature when compared with scalar filtering approaches and also it is otherwise known as exponentially weighted mean filter. This filter depends on the co-efficient of variation which is the ratio among the mean and standard deviation of the degraded image. The significant filtering model for frost filter is given as follows:

$$DN = \sum_{n \times n} K\alpha e^{-\alpha|t|}, \qquad (5)$$

$$\alpha = \left(\frac{4}{n\sigma^2}\right)\left(\frac{\sigma^2}{\bar{I}^2}\right)$$

Where, K and $\bar{I}$ represents normalized constant and local mean. σ *and* $\bar{\sigma}$ denote the local variance and image co-efficient of variation value. n is the moving kernel size and $|t| = |x-x_0|+|y-y_0|$.

Based on local statistics, Jong Sen Lee developed a new filtering method in 1981 [6]. It depends on multiplicative speckle noise model and preserves edge and details using local statistics.

This filter performs well for the region which has low variance whereas for high variance it fails. Lee filter's Mathematical model is given below.

$$W(x,y) = 1 - \left(C_B^2 / \left(C_I^2 + C_B^2\right)\right) \qquad (6)$$

Where, W(x, y) represents co-efficient of adaptive filter. C_B and C_I denote the co-efficient of variation of the noise and noised image.

In 1987, Kaun developed a new filter which is considered to be more superior to Lee filter. This filter changes the multiplicative noise into signal dependent additive noise model [7]. Kaun filter has the structure similar to Lee filter with slight difference on weighting function. The weighted function W for Kaun filter is given by,

$$W = \left(\frac{1 - \frac{C_u}{C_i}}{1 + C_u}\right) \qquad (7)$$

Where C_i denotes variation co-efficient and C_u is the estimated noise variation co-efficient of the image.

By Enhancing Frost and Lee filter, in 1990, Lopes proposed a new filter based on threshold value [8]. This filter induces pure averaging until the value of local co-efficient of variation reaches minimum threshold value. It performs a strict all pass filter when the value of local co-efficient of variation exceeds maximum threshold value. When the co-efficient of variation lies between the two thresholds, a balance between averaging and identity operation is computed.

Gamma map filter is proposed by Lopes in 1993. It utilizes contrast and coefficient variation. It performs better than Lee and Frost filter and also decreases the loss of texture details. Working procedure for Gamma map filter is same as the enhanced Frost filter except a slight difference that is, the pixel value depends on the Gamma estimation of the contrast ratio if local coefficient of variation lies between minimum and maximum threshold values.

During 1940s, Norbert Wiener proposed a filter named by Wiener filter or Least Mean Square filter [9]. It has the capability to restore the blurred or corrupted images. It reduces speckle noise through the comparison of desired noiseless image. Its working procedure is depending on the local image variance computation. Hence, larger the local variance of the image, lesser the smoothing amount and vice versa. In this Wiener has an edge over the Liner Filtering. Further wiener takes less time for commutation. Wiener filter has the following mathematical formula.

$$f(x,y) = \left[\frac{G(x,y)^*}{G(x,y)^2 + \frac{S\eta(x,y)}{Sf(x,y)}}\right] H(x,y) \qquad (8)$$

Where, $G(x,y)^*$ and $G(x,y)$ denotes conjugate complex and degradation function. $H(x,y)$ represents degraded image and $S\eta(x,y)$ and $Sf(x,y)$ indicates power spectra of noise and original image.

V. FUZZY FILTERING APPROACH

Recently, fuzzy filtering approach has achieved a tremendous development in medical image processing. It can easily overcome the issues such as vagueness, contrast resolution and ambiguity. In addition to that it turns the human facts into fuzzy if–then rules. This approach gives an alternate solution for the issues created by classical based filtering approaches. Fuzzy image processing has the following steps (i) Image fuzzification, (ii) Modification of membership values and (iii) Defuzzification process. The advantages of using fuzzy filtering approaches are preservation of texure, edge and fine details. In general, these approaches are constructed by membership function and facts based fuzzy rules. Its characteristics adaptness is based on image noise and features. Since ultrasound images have various degree of fuzziness, the fuzzy approach has proven to be an alternate choice for the classical approaches.

Based on fuzzy logic and morphological filter, L.Jiang et.al [10] proposed a speckle noise removing filter for coherent images. In this method, two operations such as directional close-open and morphological open- close are used for noise removal for each modified pixel, fuzzy rule based membership function has defined by employing morphological operator. Also this operator plays an important role in preserving image edges. A neuro fuzzy Despeckling filter is developed in [11] for sonography images. This technique merges neural, fuzzy and genetic algorithm for filtering process. The structure of neural network integrates fuzzy reasoning for image characteristics and genetic algorithm executes neural network training. Time consumption for network training and poor filtering performance are the drawbacks occur in utilizing this filtering method. For the removal of multiplicative noise in SAR images, Mario Mastriani et.al [12] introduced a method in wavelet domain which uses fuzzy thresholding technique. Noise variance is calculated from median deviation method and by using resultant noise variance estimation of initial threshold has done. An adaptive fuzzy controller is implemented to develop the threshold processing. This controller helps the filter to obtain better denoising as well as edge preservation. Using adaptive fuzziness, Aneesh Agarwal et.al [13] proposed a filter which found fuzzy derivative from direction features. Depending on neighboring pixels contribution, this filter applies fuzzy weighted smoothing operator to the current pixel. This filter improves denoised image contrast; however it fails in noise reduction. Implementing fuzzy logic concepts, an additive noise reducing filter is proposed in [14]. This filter has two steps, from the former, fuzzy Gaussian membership functions is calculated using gradient of central and neighboring pixels of a selected window and in the latter, membership values are used as an each pixel weight to estimate weighted mean in the selected window. A diffusion filtering algorithm based on fuzzy rules is designed by C.Elmas et.al [15] for image despeckling. This method has a difficulty in arranging diffusivity parameters for real time imaging. To defeat this issue, it implements fuzzy adaptive diffusion utilizing extended neighborhood. Depending fuzzy rules frame, similarity matrix was computed. Depending the binning procedure and fuzzy inference system, a despeckling method for ultrasound images is introduced in [16]. In this method, fuzzy logic detects the speckle noise and fuzzy rule classifies the pixels as degraded or non-degraded and applies binning procedure to denoising the affected pixels. Finally it is concluded that most of the fuzzy filtering approaches have done better performance in denoising as well as in preserving significant image particulars.

VI. PERFORMANCE METRICS

Measurement metrics	**Mathematical Expression**
Mean Square Error (MSE)	$MSE = \frac{1}{ij}\sum_{\eta_1=1}^{i}\sum_{\eta_2=1}^{j}[I'(\eta_1,\eta_2)-I(\eta_1,\eta_2)]^2$
Root Mean Square Error (RMSE)	$RMSE = \sqrt{\frac{1}{ij}\sum_{\eta_1=1}^{i}\sum_{\eta_2=1}^{j}[I'(\eta_1,\eta_2)-I(\eta_1,\eta_2)]^2}$
Normalized Mean Square Error (NMSE)	$NMSE = \frac{\sum_{\mu_1=1}^{m}\sum_{\mu_2=1}^{n}[I'(\mu_1,\mu_2)-I(\mu_1,\mu_2)]^2}{\sum_{\mu_1=1}^{m}\sum_{\mu_2=1}^{n}I^2(\mu_1,\mu_2)}$
Signal-to-Noise Ratio (SNR)	$SNR = 10\log_{10}\left[\frac{\sum_{\sigma_1=1}^{j}\sum_{\sigma_2=1}^{k}I^2(\sigma_1,\sigma_2)}{\sum_{\sigma_1=1}^{j}\sum_{\sigma_2=1}^{k}[I'(\sigma_1,\sigma_2)-I(\sigma_1,\sigma_2)]^2}\right]$
Contrast to Noise Ratio (CNR)	$CNR = \frac{\lvert\mu'-\mu''\rvert}{\sqrt{\sigma_1^2+\sigma_2^2}}$
Peak Signal-to-Noise Ratio (PSNR)	$PSNR = 20\log_{10}\left[\frac{255}{\sqrt{\frac{1}{ij}\sum_{\omega_1=1}^{i}\sum_{\omega_2=1}^{j}[I'(\omega_1,\omega_2)-I(\omega_1,\omega_2)]^2}}\right]$
Structure Similarity Index Map (SSIM)	$SSIM = \frac{(2\mu_a\mu_b+D_1)(2\sigma_{ab}+D_2)}{(\mu_a^2+\mu_b^2+D_1)(\sigma_a^2+\sigma_b^2+D_2)}$

Geometric Average Error (GAE)	$GAE = \left(\prod_{m=1}^{I} \prod_{n=1}^{J} \sqrt{g_{m,n} - f_{m,n}} \right)^{\frac{1}{IJ}}$
Image Fidelity (IF)	$IF = 1 - \left(\frac{\sum_{\gamma_1=1}^{P} \sum_{\gamma_2=1}^{Q} \left[F(\gamma_1,\gamma_2) - \hat{F}(\gamma_1,\gamma_2) \right]^2}{\sum_{\gamma_1=1}^{P} \sum_{\gamma_2=1}^{Q} [F(\gamma_1,\gamma_2)]^2} \right)$
Structural Content (SC)	$SC = \frac{\sum_{\rho_1=1}^{P} \sum_{\rho_2=1}^{Q} [F(\rho_1,\rho_2)]^2}{\sum_{\rho_1=1}^{P} \sum_{\rho_2=1}^{Q} \left[\hat{F}(\rho_1,\rho_2) \right]^2}$

VII. CONCLUSION

An extensive study of various Despeckling methods was carried out in this paper. Every existing filtering approach has certain boundaries. Local statistics based spatial filtering approaches are very simple to execute and fast in calculation, however its efficiency is limited by selected windows size and shape and also by proper threshold selection. Adaptive filtering approaches are beneficial compared to scalar filtering approaches as they remove noise efficiently and preserve image edges and fine details significantly. However the algorithm intricacy is increased as further conversion processes require to be completed. To protect image particulars, there must be a superior trade-off among edge preservation and noise reduction. This can be achieved by fuzzy filtering approaches as it can provide an efficient output although the input image is ambiguous, vague, noisy or imprecise. Hence, by using fuzzy logic in spatial and adaptive filtering approaches, the future work might focus on developing speckle denoising filters with detail and edge preservation as well as efficient noise reduction to defeat the disadvantages of the existing filters.

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