International Journal of Engineering & Technology, 7 (4.10) (2018) 685-689

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Fractional Calculus and Fuzzy Rule Based Filter for Despeckling the Medical Images

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Abstract

Medical ultrasound imaging plays an important role in diagnosis of various complicated disorders. But, these ultrasound images are intrinsically degraded with speckle noise which harshly affects the image visual qualities and essential particulars. Hence, denoising is an unavoidable process in medical image processing. In this paper, a new despeckling technique is presented for denoising the medical ultrasound images by employing fuzzy technique on co-efficient of variation and fractional order integration filter. The proposed technique has two steps. During first step, the noisy image pixels are classified into three regions by using fuzzy technique on co-efficient of variation and consequently, the proposed technique adaptively employs appropriate filters on the grouped pixels to reduce noise in the ultrasound image. In the second step, to obtain an effective denoising image, the fractional order integration filter is applied on the resulting image of step 1. The performance of the proposed technique is tested on various medical images in terms of Peak signal to noise ratio and speckle suppression index quality measures. Experimental results reveal that the proposed despeckling technique can efficiently reduce the speckle noise, protect the edges and preserves any other important structural details of an image. It is suggested that the proposed technique is employed as a preprocessing tool for medical image analysis and diagnosis.

Keywords: *Denoising, Fractional order integration filter, fuzzy sets, Ultrasound imaging and speckle noise*

1. Introduction

Ultrasound is predominantly utilized for imaging compared to the CT, MRI and X-rays, because of its safety aspect and cost efficiency. However, the main drawback of ultrasound imaging is that they are severely affected by the noise due to background echo signals named as speckle noise [1]. This speckle noise creates a difficulty for an expert or a physician to take an accurate decision about the disease of a particular patient. Hence, denoising the ultrasound image is one of the main aspects in medical image processing. The key objective of speckle noise reduction algorithm is to reduce the noise together as preserving the images significant features [2].Several denoising methods have been proposed by many researchers including mean filtering [3], median filtering [4],bilateral [5], total variation [6], wavelet [7] and LSMV [8]. Generally, these methods provide a better denoising when the image models match to the algorithm steps. But, they are commonly unsuccessful and provide artifacts or poor image visual quality. Hence, poor visual quality, loss of well particulars and assortment of suitable window shape and size are the fundamental issues which necessitate to be sorted out in fundamental techniques [9]. Currently, fuzzy logical system is utilized in various fields but they are broadly utilized for denoising the medical and synthetic aperture radar images. An image with the presence of uncertainty and vagueness can be easily handled by using fuzzy logic. Fuzzy logical system provides an alternative decision for the classical logical system.

In recent years, fractional calculus has been widely used in signal and medical image processing. Fractional differential and integral filters are capable to reduce the noise as well as protecting the significant image features. He et al. created an image despeckling model based on an Improved Fractional-order Differential (IFD) [2]. A despeckling algorithm called generalized fractional integral algorithm along with two parameters has been introduced by Jalab et al. [10]. Image enhancement and image denoising based on adaptive fractional calculus of small probability strategy has been also presented by LI et al. [11]. Tomasi et al. [12] introduced a bilateral filter which discovers the value of the pixels by evaluating mean values of all the pixels which have same intensity value along with spatial distance. Zhou et al. proposed a technique, which can decide an optimal threshold and neighboring window size for each subband by the Stein’s unbiased risk estimate (SURE) [13].Y.Wang et al .generated a noise removal method by modifying the total variation model [14].Four fuzzy filters with triangular membership function along with center median and moving average center have been developed for image filtering by H.K.Kwan [15]. Ayesha Saadia and Adnan Rashdi produced an Echocardiographic Image denoising method based on fuzzy and fraction order integration filter (FFIF) [16]. Sometimes, most of the existing fractional differential and integral based filters are unsuccessful to eliminate significant quantity noise from medical images. To resolve this problem, a new speckle noise reduction technique is introduced by using fuzzy technique on co-efficient of variation and fractional order integration filter.

2. Proposed Method

Speckle noise which corrupts the ultrasound image regions and pixels are classified into edge, detail and homogeneous regions. Each classified region has different quality features . On the basis of these quality features, every pixel can occupy various membership degrees. Hence, a suitable reasoning technique is required to classify every pixel in the ultrasound images. Since ultrasound images include fuzziness originate by speckle noise, fuzzy technique can be accepted as a right way to achieve at an efficient result from vague, blurred or noisy input image with important features. Hence, fuzzy technique is employed to group every pixel into edge, detail and homogenous regions based on the degree of membership.

The proposed method has two steps: In the first step, the noisy image pixels are classified into three regions by using fuzzy technique on co-efficient of variation and consequently, three appropriate filters are employed on the grouped pixels to reduce noise in the ultra sound image. In the second step, to get an effective image quality, fractional order integration filter is applied on the resulting image from step1.The working process of the proposed method is shown in fig.1

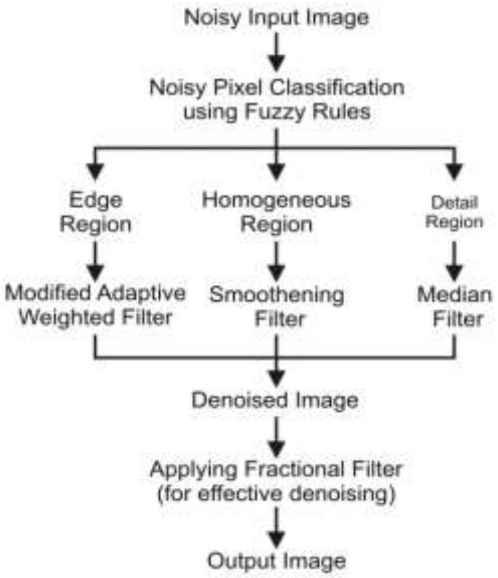


Fig.1 Flow diagram of the proposed method

2.1. Noise Model

Let $X(p,q)$ be the observed ultrasound image of size $P \times Q$. Since the speckle noise is multiplicative in nature, it can be modeled as:

$$X(p,q) = y(p,q)\alpha(p,q) + \delta(p,q) \quad (1)$$

Where $y(p,q)$ is noise free image and $\alpha(p,q)$ and $\delta(p,q)$ are the multiplicative and additive noise respectively. When compared with multiplicative, the effect of additive noise is very low. So the equation (1) can be rewritten as

$$X(p,q) = y(p,q)\alpha(p,q) \quad (2)$$

The logarithmic transformation process is performed for converting the above multiplicative noise model into an additive noise model and is given as follows:

$$\log X(p,q) = \log[y(p,q)\alpha(p,q)] \quad (3)$$

$$X' = \log[y(p,q)] + \log[\alpha(p,q)] \quad (4)$$

X' is a logarithmic transformed image.

2.2. Noisy Image Pixel Classification Using Fuzzy Logic Once-Efficient of Variation

The ratio between the standard deviation and mean is represented as the co-efficient of variation. As a pixel have maximum value of co-efficient of variation, variation corresponds to edges. Also, a pixel with minimum co-efficient of variation value represent that it is contains to homogeneous region. The values belong to intermediate represents the detail region. On the basis of this idea, the pixels in the noisy image have been classified into edges, detail and homogeneous regions. Next, Gaussian membership function is used for representing the membership degree in a fuzzy system. The most important advantage to utilize this Gaussian membership function in the proposed method is that, it is non zero and symmetric about its mean over the whole real axis. Hence, using Gaussian membership function, the calculated co-efficient of variation values of noisy image are mapped into the fuzzy domain.

The Gaussian membership function is defined as follows:

$$\mu_f^k(v) = e^{\left((v-m_i)^2/2\sigma_i^2\right)}, \quad i = 1,2,3. \quad (5)$$

Where μ_f^k represents the fuzzy set for the sort of pixels NxN with mean m_i and σi^2 denotes the three classified regions of the noisy images.

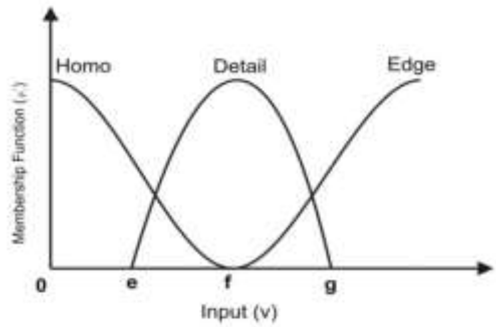


Fig.2 Fuzzy membership function

Furthermore, we need to determine the threshold values e, f, and g for define the three regions such as edge, detail and homogeneous. The values of e, f, and g are given as follows:

$$\mu_f^k(v) = \begin{cases} edge & v > f \\ detail & v \geq, e \; and \; v \leq g \\ homogeneous & v < f \end{cases}$$

Where $e = Max.Value\left[co\text{-}efficient of\ variation\left[X'(p,q)\right]\right]$

$$g = Max.value\left[Co\text{-}efficient of\ variation\left[grad\left(X'(p,q)\right)\right]\right]$$

f = average value of e and g

The pixel which has minimum co-efficient of variation value corresponds to homogeneous region. So, the threshold value of 'e' is required to describe the detail region. Since, gradient calculation is effective in differentiating edges; the threshold value 'g' is determined by the maximum value of coefficient of variation

$\left[grad\left(X'(p,q)\right)\right]$. Finally, the threshold value 'f' is considered as the average of e and g. Figure 2 demonstrates the fuzzy membership function for the edge, homogeneous and detail regions. Hence, the variation of the threshold values and classification in the input noisy pixel are depending on the quantity of noise included to the image.

2.2.1. Fuzzy Rules for Noisy Image Pixel Classification:

The three regions such as edge, detail and homogeneous are described by means of the co-efficient of variation value. 'Low' and 'high' denotes the membership function degree in every class. The following rules which are based on co-efficient of variation are used to classify the noisy pixels.

1. If $\mu_f^1(v), \mu_f^2(v)$ is small and μ_f^3 is large then noisy pixel belongs to edge region.
2. If μ_f^1 is small and $\mu_f^2(v)$, μ_f^3 is large then noisy pixel belongs to edge region.
3. If, $\mu_f^1(v), \mu_f^3(v)$ is small and $\mu_f^2(v)$ is large then the noisy pixel belongs to detail region.
4. If μ_f^1, $\mu_f^2(v)$ is large and μ_f^3 is small then the noisy pixel belongs to detail region.
5. If μ_f^1 is large and $\mu_f^2(v)$, μ_f^3 is small then the noisy pixel belongs to homogeneous region.

In order to ignore the computational difficulty of the presented method, utilize of fuzzy rules is probable decreased to five. It is probable that the proposed method can effectively differentiate all the likely regions by using these five fuzzy rules.

2.2.2. Appropriate Filters for Classified Regions:

Case (i)
A simple smoothening filter is sufficient for filtering the pixels which are belongs to the homogeneous class. This filter catches the average value of pixels in a window of size (2Q+1) x (2Q+1) and is given as follows:

$$F(p,q)=\frac{1}{(2Q+1)^2}\sum_{S=-Q}^{Q}\sum_{t=-Q}^{Q}X'(p+s,q+t) \qquad (5)$$

Where k = 1, 2…….

Case (ii)
Since the image structural details are requires to be protected, a simple average filter is not enough for filtering the pixels belong to the detail class. Therefore, the median filter which keeps the attractive features of the images safely is given for the window of size (2Q+1) x (2Q+1) and is defined by

$$F(p,q)=MED\left(X'(p+s,q+t)\right) \qquad (6)$$

Case (iii)

Since the main aim of the proposed method is to preserve the edge of denoised image, an efficient filter is required to protect edges without destroying the original feature of the image. Hence, a modified adaptive weighted filter is designed and defined as follows.

$$F(p,q)=\frac{\sum_{S=-Q}^{Q}\sum_{t=-Q}^{Q}X'(p+s,q+t)\times W(p+s,q+t)}{\sum_{S=-Q}^{Q}\sum_{t=-Q}^{Q}W(p+s,q+t)}\times\left(1-W(p,q)\right)+W(p,q)\times X'(p,q)$$

Where $X'(p,q)$ and $X'(p+s,q+t)$ are the centre pixel and its neighboring pixel in a window of size (2Q+1) x (2Q+1), *W (p, q)* denotes the weight corresponds to each pixel in that window. Finally we obtained the denoised image $\hat{F}(p,q)$.

2.3 Fractional Integration Filter

During the process of second step of the proposed method, fractional integration filter is employed on the image $\hat{F}(p,q)$, for further denoising and improving the image quality. We know that there is no unique definition to describe fractional calculus. Two definitions such as Grunwald-Letnikov and Riemann-Liouville are the most commonly used definitions in the field of digital and medical image processing.

0	0	0
$\frac{-v+v^2}{2}$	$-v$	1
0	0	

0	$\frac{-v+v^2}{2}$	0
0	$-v$	0
0	1	0

Fig.3: (a) 3 × 3 fractional integral mask

$\frac{-v+v^2}{2}$	0	$\frac{-v+v^2}{2}$	0	$\frac{-v+v^2}{2}$
0	$-v$	$-v$	$-v$	0
$\frac{-v+v^2}{2}$	$-v$	8	$-v$	$\frac{-v+v^2}{2}$
0	$-v$	$-v$	$-v$	0
$\frac{-v+v^2}{2}$	0	$\frac{-v+v^2}{2}$	0	$\frac{-v+v^2}{2}$

Fig.3: (b) 5×5 fractional integral mask

Let $f(s),\in[a,b]$ be the period of a unitary signal. By considering the size of interval h=1, split the signal $f(s)$ into equivalent intervals. Then we have, $n=\left[{(b-a)}/{h}\right]=b-a$ and the difference of $f(s)$ is given as

$$\frac{d^v f(s)}{ds^v}\approx f(s)+(-v)f(s-1)+\frac{(-v)(v+1)}{2}f(s-2)+....+\frac{\Gamma(-v+1)}{n!\,\Gamma(-v+n+1)}f(s-n)$$

$$\frac{d^v s(x,y)}{dx^v}\approx s(x,y)+(-v)s(x-1,y)+\frac{(-v)(v+1)}{2}s(x-2,y)+....+\frac{\Gamma(-v+1)}{n!\,\Gamma(-v+n+1)}s(x-m,y)$$

$$\frac{d^v s(x,y)}{dy^v}\approx s(x,y)+(-v)s(x,y-1)+\frac{(-v)(v+1)}{2}s(x,y-2)+....+\frac{\Gamma(-v+1)}{n!\,\Gamma(-v+n+1)}s(x,y-n)$$

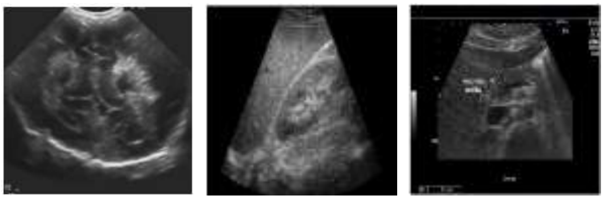
On the basis of first 3 non-zero terms of the above equation, a 3 x 3 mask (Shown in Fig.3 (a)) is acquired as clarified in [17]. To achieve a 5 x 5 fractional integration mask (Shown in Fig.3 (b)), applying this 3 x 3 fractional mask in eight directions such as 0^0, 90^0, 135^0, ...315^0. Combine the resulting image $\hat{F}(m,n)$ from step-1 with the 5 x 5 mask, by setting $v=-0.9$. The value v has been checked on various despeckling images and established the noise reduction capability.

$$R = F * mask$$

Where R is the filtered image and * is the convolution operator.

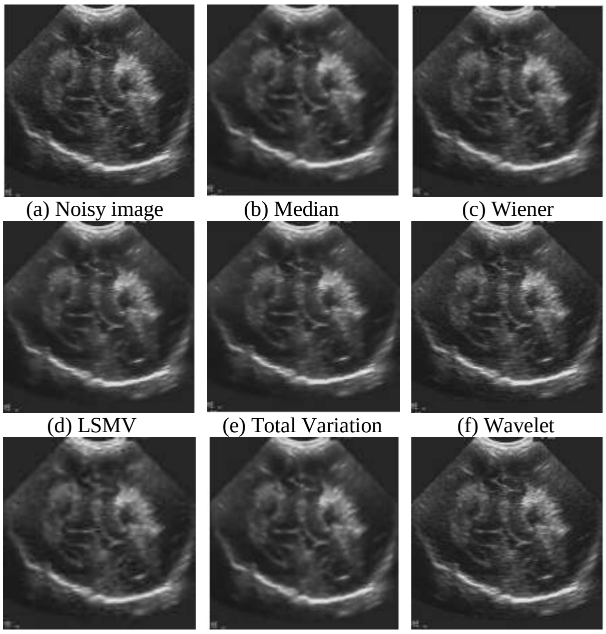
3. Experimental Results

The proposed despeckling method is implemented in MATLAB 12 and investigational results are presented. The performance of the proposed method is compared with median filtering, bilateral, total variation, wavelet, LSMV, IFD, and FFIF. The ultrasound images "Liver"," Pancreas" and "Kidney" images were adopted as the test images with noise variance $\sigma_n = 0.1$ and $\sigma_n = 1.0$. Speckle Suppression Index (SSI) and Peak Signal to Noise Ratio (PSNR) between the restored image and the original image were selected as the performance index. The SSI and PSNR are defined as follows:



(a) **(b)** **(c)**

Fig.5 Original images (a) Liver (b) Kidney (c) Pancreas



(a) Noisy image (b) Median (c) Wiener
(d) LSMV (e) Total Variation (f) Wavelet
(g) IFD (h) FFIF (i) Proposed

Fig.6 Image despeckling by various filters

Figure.6 shows the result of proposed despeckling method when the standard deviation of the noisy image is equal to $\sigma_n = 0.5$. Table 1, 2 and 3 shows the quantitative investigation of different methods discussed. From this, we observed that the proposed method executes well than the other methods in terms of SSI and PSNR.

Table 1: Comparison of PSNR and SSI for Liver Image with Noise Variance σ_n is 0.1 and 1.0

Methods	σ_n = 0.1		σ_n = 1	
	PSNR	SSI	PSNR	SSI
Median filtering	16.89	1.06	10.55	0.80
Bilateral	22.15	0.78	15.45	0.50
Total variation	10.88	0.81	12.55	0.65
Wavelet	16.03	0.95	8.77	0.99
LSMV	20.52	0.89	15.58	0.52
IFD	22.71	0.79	13.23	0.64
FFIF	24.40	0.70	17.58	0.42
Proposed	25.45	0.46	22.18	0.38

Table 2: Comparison of PSNR and SSI for Kidney Image with Noise Variance σ_n is 0.1 and 1.0

Methods	σ_n = 0.1		σ_n = 1	
	PSNR	SSI	PSNR	SSI
Median filtering	14.68	0.88	10.74	0.81
Bilateral	19.15	0.77	15.15	0.60
Total variation	16.21	0.80	12.52	0.70
Wavelet	13.12	0.98	8.94	0.99
LSMV	18.22	0.71	15.07	0.53
IFD	18.90	0.79	13.30	0.71
FFIF	21.56	0.70	17.37	0.54
Proposed	22.64	0.62	19.41	0.51

Table 3: Comparison of PSNR and SSI for pancreas Image with Noise Variance σ_n is 0.1 and 1.0

Methods	σ_n = 0.1		σ_n = 1	
	PSNR	SSI	PSNR	SSI
Median filtering	18.76	0.95	11.67	0.76
Bilateral	16.15	0.73	14.23	0.72
Total variation	17.88	0.86	12.01	0.78
Wavelet	14.72	0.88	7.79	0.97
LSMV	17.43	0.64	12.47	0.46
IFD	19.56	0.69	16.23	0.49
FFIF	21.34	0.78	16.98	0.38
Proposed	21.67	0.61	18.44	0.37

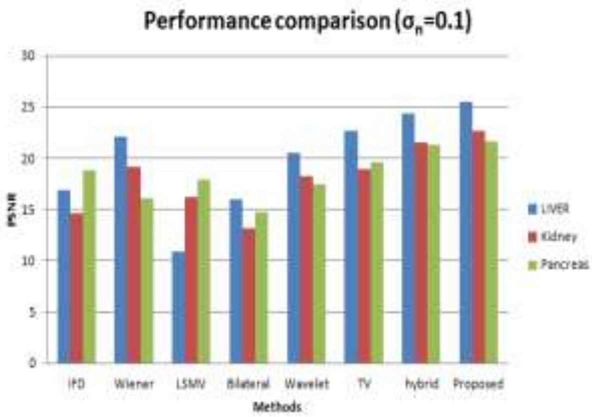


Fig.7 Performance comparison of proposed method with existing methods (σ_n=0.1)

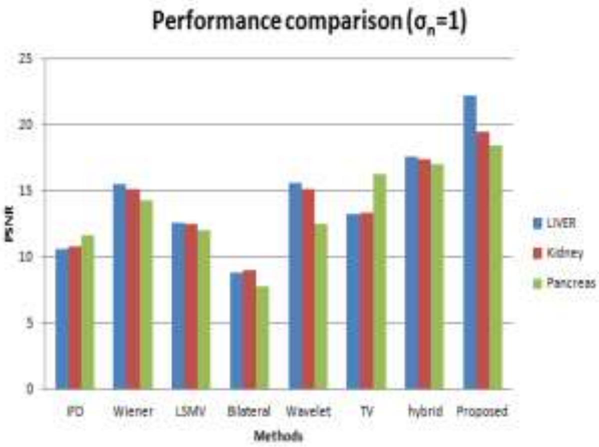


Fig.7 Performance comparison of proposed method with existing methods (σ_n=1)

4. Conclusion

In this paper, a new despeckling technique is presented for denoising the medical ultrasound images by employing fuzzy technique on co-efficient of variation and fractional order integration filter. The proposed technique has two steps. During first step, the noisy image pixels are classified into three regions by using fuzzy technique on co-efficient of variation and consequently, the proposed technique adaptively employs appropriate filters on the grouped pixels to reduce noise in the ultrasound image. In the second step, to obtain an effective denoising image, the fractional order integration filter is applied on the resulting image of step 1.Experiments are conducted on different images such as liver, kidney and pancreas ultrasound images. From experimental results, it is observed that the proposed method outperforms the existing methods and preserves important particulars for further diagnostics of medical ultrasound images.

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