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A Novel Filter Selection for Efficient and Robust Segmentation in MR Human Brain Images Through Comparative Analysis of Various Spatial and Transform Domain Filters

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***Abstract*— Medical imaging is the non-invasive visualization of internal organs of the human body. Medical image processing deals with the processing of medical images by image processing algorithms for the diagnosis of anomalies in human body. Image denoising is the preliminary process which provides efficient image segmentation, image registration, fusion of different image modalities. This paper deals with the comparative study of research work done in the field of medical Image denoising. A detailed study of the research is required in order to design a filter which will fulfill the desire aspects along with handling most of the image filtering issues. Image denoising can be considered as a component of processing or as a process itself. The image denoising is used to improve the accuracy of various image processing algorithms. Magnetic resonance images are usually corrupted by rician noise. Different types of spatial domain and transform domain filtering approach are discussed in this paper for the removal of noise from magnetic resonance images of brain. The filtering algorithms are evaluated in terms of various performance metrics and statistical parameters.**

Keywords—Medical Imaging; Filter;Noise; Denoising; Magnetic Resonance Imaging.

I. INTRODUCTION

Medical imaging is the technique and process used to create images of the human body for clinical purposes. Medical imaging techniques have revolutionized the modern medicine. Along with the advances in the field of medical imaging, the need for substantial quality of digital images for accurate and efficient diagnosis has become a necessity. The medical images are obtained from different type of sensors and are affected by different type of noise such as additive white Gaussian noise, Speckle noise and Rican noise[1][2]. In general MRI images are corrupted by Rican noise and ultra sound image is corrupted by speckle noise [1]. Depending on the imaging source the filter or morphological operator will be selected which reduce the effect of the noise [3].The magnetic resonance (MR) system[4] acquire data by sampling the object of interest in the frequency domain and after computing the inverse fourier transform ,the data can be decomposed in to signal and noise component .

$$Y[m, n] = S[m, n] + N[m, n] \qquad (1)$$

Where S[m,n] is the complex signal of interest and N[m ,n] is the additive complex Gaussian white noise. Because of phase errors, the magnitude of Y [m,n] is typically used to form the image reconstruction [5]. The magnitude image is defined at the m, nth pixel as

$$X[m, n]=|Y[m, n]|=[(S[m, n]\cos\Theta+Nr[m, n])^2 +(S[m, n]\sin\Theta+Nr[m, n])_2]^{1/2} \qquad (2)$$

The magnitude image X [m, n] obeys a rician distribution. At high SNR the rician distribution is very close to Gaussian distribution and at low SNR the rician distribution tends to the Rayleigh distribution [4]. Magnetic Resonance Imaging (MRI) is a notable imaging technique to provide highly detailed images of tissues in the human body and is primarily used to demonstrate the pathological or other physiological alterations of living tissues [6]. MRI, like ultrasound and computed tomography (CT) is used to generate two dimensional images of sections of the body. Low field MRI is vital for sensitive surgery to allow real-time imaging in the operation theatre [7]. An open low-field system has number of advantages over its conventional counterpart, including low-cost, reduced fringe fields and the relative ease of movement and usage; however the main problem with low-field MRI is its low resolution images [7]. To achieve the best result in diagnosing disease, medical images must have good quality and be free from noise and artifacts [6]. There are two basic approaches to image de-noising, spatial filtering methods and transform domain filtering methods [8]. Commonly used filters for denoising are median filter, Gaussian filter, wiener filter [9]. Section II describes about the different types of filtering approach and finally conclusions are drawn in section III.

II. LITREATURE SURVEY

The basic problem in image processing is to suppress the noise in corrupted image. Firstly the spatial domain approach has been adopted. One of the biggest gain of this filter domain approach is speed but the demerit is that this method was unable to preserve edges, which are identified as discontinuities in the image, On the other hand transform domain approach are able to preserve the edges. Denoising techniques are aimed at removing noise or distortion from images while retaining the original quality of the image. The goal of denoising is to remove noise and/or spurious details from a given possibly corrupted digital picture while maintaining essential features such as edges. Different types of denoising approaches are discussed in this paper. The denoising algorithms are evaluated in terms of performance metrics like Peak to signal noise ratio (PSNR), Mean square error (MSE), Mean absolute error (MAE) etc.

A. Spatial domain filtering approach

Spatial domain filters can be classified into two types, linear filter and nonlinear filter. In linear techniques noise reduction formula is applied for all pixels of image linearly without classifying pixel into noisy and non-noisy pixels. Nonlinear Noise reduction is a two-step process 1) noise detection and 2) noise replacement. In first step, location of noise is detected and in second step, detected noisy pixels are replaced by estimated value. Mean, Wiener, Median filters comes under the category of linear filter [10].Min-Max Median Filter (MMF), Center Weighted Median Filter (CWMF), Adaptive Median Filter (AMF), Decision Based Algorithms (DBA) etc. comes under the category of nonlinear filter [10].Manohar Annappa Koli applied linear and nonlinear filters on MR images of brain [10]. Among the linear filters the median filter and among the nonlinear filters the decision based median filter gives best result [10].

TABLE I FEATURES OF SPATIAL DOMAIN FILTERS

Serial Number	Type Of Filter	Features	Comments
1	Mean filter [10]	Simple optimal linear filter for Gaussian noise removal	Large kernel size makes the image blurred
2	Median Filter [11][12] [13]	Preserves sharp edges than the mean filter.	Alters the pixel gray values not disturbed by noise.
3	Kuan Filter [[17][18]	Edge information is retained	Leaves noise in the vicinity of edges and lines
4	Wiener Filter [19][21] [20]	Considers the global statistics and local statistics of the image.	Requires the information about the spectra of the noise and the original signal
5	Spatial Frequency Filter [54]	Low pass filters using Fast Fourier Transform (FFT).	Time consuming and artificial frequencies are produced
6	Wavelet Denoising (Based on DWT transform /Thresholding technique) [25][26] [29][30]	Haar wavelet, Daubeschies wavelet,Bior wavelet/ Hard thresholding-Keep or Kill rule Soft thresholding-Shrink or Kill rule	Wavelet transform based denoising introduces artifacts during denoising of images containing smooth curves, curved edges.
7	Curvelet Transform [44][46]	Curvelet has directional elements and better ability to represent edges and other singularities along curves of image	Conventional curvelet transform will be computationally heavy

Sonali Patil et al [11] proposed a preprocessing technique in which the morphological operator is used after median filtering for the removal of skull portions from the MR brain images. Morphological erosion operation is done with square shaped structuring element and the satisfactory results were also obtained for CT images of thorax and abdomen [11]. Jaya et al [12] applied different filters like Median filter, weighted median filter, Adaptive median filter on MR images of brain and the weighted median filter showed better results in removing the salt and pepper noise and maintaining the edges. GnanambalIlango et al [13] used Hybrid filtering techniques like hybrid cross median filter, hybrid minimum filter, hybrid maximum filter for removing Gaussian noise from images of brain tumor and hybrid maximum filter gives best result. Lalitha Y et al [14] proposed modified spatial median filter for the removal of impulse noise from the MR images and its performance outperforms the standard filters.

Nicolas Wiest Daessle et al. [15] have proposed non local means filtering technique to remove rician noise from both conventional magnetic resonance images and diffusion tensor images. E. Ben George et al [16] apply median, weighted median and center weighted median filter on MR images of brain and Centre weighted median filter gives best result. K.Kothavari et al [17] applied Lee and Kuan filter applied on MR brain image and Kuan filter shows better result. Kuan filter [18] is considered to be more superior to the Lee filter, since it does not make approximation on the noise variance within the filter window. Vivek Venugopal et al [19] applied different types of spatial filters for the removal of speckle noise on MR brain images and for low values of noise variance, Median filter and Wiener filter exhibit good performance and for higher values of noise variance, Geometric filter and first order linear filter provided better performance. J.Mohan et al [20] apply neutrosophic set (NS) approach of wiener filter on MR brain image for rician noise removal and NS wiener filter gives best result while comparing with other spatial filtering techniques.

B. Transform domain filtering approach

The transform domain filtering methods can be subdivided according to the choice of the basic functions. Depending upon the type of basic functions the transform domain filtering approach can be data adaptive or non-adaptive [21]. The non-adaptive transform includes spatial frequency filtering, wavelet filtering and data adaptive transforms include independent component analysis (ICA) [21].The Discrete wavelet transform (DWT) of image produce a non-redundant image representation, which provides better spatial and spectral localization of image [22]. DWT is widely used for image restoration, blurring, noise removal owing to its sparisity and multi resolution properties by preserving the important details of the image [22] [23].

The Fourier transform deals with the frequency- amplitude representation of the raw signal alone by dropping the time information [24].The discrete wavelet transform is considered to be better than the Fourier transform because it gives frequency representation of raw signal at any given time interval [24]. Shashikant Agrawal et al [25] proposed different wavelet thresholding based denoising scheme, out of which the Haar wavelet with global thresholding yield a respectable outcome on MR brain images. Nowak [26] proposed threshold-based wavelet de-noising scheme for the removal of rician noise from MR brain image and thereby corrects the bias introduced by the noise. Weaver proposed soft and hard thresholding techniques for the denoising of brain images, and observed that a small value of threshold results in noisy coefficients in the denoised image [27]. H. Zhang [28] suggested a wavelet-domain spatially adaptive FIR Wiener filtering for image denoising however wiener filtering is performed only within each scale and intrascale filtering is not allowed. Pizurica et al. [1] proposed a wavelet domain algorithm which outperforms the homomorphic wiener filter in the removal of rician noise from MR brain image.Kanwaljot Singh Sidhu et al [29] apply hard and soft thresholding algorithms on MR brain image for the removal of speckle noise and db3 wavelet outperforms harr wavelet.

TABLE II DIFFERENT TYPES OF SPATIAL DOMAIN FILTERING TECHNIQUES

Filtering Methodology	Noise handled/ Filtering technique	Robust filtering Technique	Performance Metrics
"Impulse noise reduction" [10]	Speckle noise Linear filters: Average, Mean, Median Nonlinear filters: MMF ,CWM,AMF,TS MF, PSMF,DBA	Linear filter-Median filter Nonlinear filter-DBA	PSNR, SNRI
"Preprocessing for MR/CT" [11]	Median filter and Morphological operator	Median filter	PSNR
"Tracking Algorithm" [12]	Salt and pepper noise Median filter, Weighted median filter, Adaptive median filter	Weighted median filter	PSNR, ASNR, Contrast
"Hybrid filtering" [13]	Gaussian noise Hybrid cross median, minimum, maximum filter	Hybrid maximum filter	RMSE, PSNR
"Novel noise filtration" [14]	Random noise Mean, Spatial median, Modified spatial median filter	Modified spatial median filter	RMSE
"Brain image enhancement" [15]	Removal of film artifacts Median, Weighted median, Centre weighted median Filter	Centre weighted median filter	PSNR, RMSE
"Hybrid approach' [17]	Speckle noise Average, Median ,Lee, Kuan filter	Kuan filter-Noise removal Median filter-image enhancement	PSNR, RMSE
"Speckle noise removal" [19]	Speckle noise Median, Weiner, First order linear, Geometric filter	Low noise variance-	PSNR,MSE ,AD,SC,NK, LMSE,NAE, MSSIM

TABLE III DIFFERENT TYPES OF TRANSFORM DOMAIN FILTERING TECHNIQUES

Filtering Methodology	Noise handled/ Filtering technique	Robust filtering Technique	Performance Metrics
"Wavelet Thresholding" [25]	Random noise Haar,db,sym,bior wavelet with global thresholding	Haar wavelet with global thrsesholding	PSNR, MSE, MAE
Versatile wavelet domain filtering" [1]	Rican noise Homomorphic wiener filter,wavelet domain filtering	Wavelet domain filtering	SNR
"Haar and db3 filtering"[29]	Speckle noise Haar,db3 , wavelet with soft and hard thresholding	db3 wavelet with soft thresholding	PSNR, MSE
"Complex ridgelet" [35]	Guassian white noise Visu shrink,wiener2, ridgelet,complex Ridgelet shrink	Complex ridgelet shrink	PSNR
"Wavelet denoising using Gaussian scale mixture models" [32]	Rican noise Wiener filter in Wavelet domain, Multicomponent denoising	Multicomponent denoising	PSNR
"Wavelet using bivariate laplacian mixture model" [38]	Guassian noise Hard thresholding, soft thresholding, Wiener filter, Bivariate laplacian mixture model	Bivariate laplacian mixture model	PSNR, CNR
"Multireslotion bilateral filter(MRBF)" [39]	Guassian noise Bilateral,non local means,total variation, MRBF	MRBF	PSNR, RMSE
"Waveatom shrinkage" [47]	Rican noise Wavelet,Curvelet Waveatom shrinkage	Waveatom Shrinkage	SNR

Shashikant Agrawal et al [30] obtain satisfactory results for the removal of additive random noise from cardiac MR images by bior 1.3 wavelet and optimum thresholding scheme. The advantage of haar wavelets is that it is fast, memory efficient and conceptually simple [31]. Paul Scheunders et al [32] proposed bayesian wavelet based denoising which is used to denoise the images in which the Gaussian scale mixture are used as prior models and a noise free image is used for extra prior information.Daubechies wavelets are useful in compression and noise removal process because of its property of overlapping windows [32]. DWT suffers from two serious disadvantages viz. shift-sensitivity [33] and no phase information; hence to overcome this disadvantage, complex Daubechies Wavelet can be used for image denoising [34].G.Y. Chen et al [35] proposed a methodology in which the shift invariant properties of dual-tree complex wavelets with the high directional sensitivity of ordinary ridgelet transform which made it a very virtuous choice for image denoising. Multiwavelets which incorporate neighboring coefficients give improved results than the single wavelets [36]. Based on a combination of the total variation minimization scheme and the wavelet scheme a denoising algorithm for medical images has been proposed by Yang Wang et al., while maintaining sharpness of objects, they have showed that their scheme offers effective noise removal in real noisy medical images [37].

Hossein Rabbani et al [38] apply discrete complex transform to the noisy 3D data and then laplacian probability density functions in wavelet domain were applied for noise removal in MR images. Bilaplacian Gaussian minimum mean square error estimator is preferred especially for CT image, which has high SNR [38]. ZeinabA.Mustafa et al [39] proposed an extension of the bilateral filter that is multi resolution bilateral filter (MRBF), with wavelet transform (WT) sub-bands mixing for MR images. Again V.Loganayaagi et al [40] proposed adaptive bilateral filter in discrete wavelet transform for the denoising of MR images and the adaptive bilateral filter overcomes the drawback of bilateral filter that is tuning of the parameter. Jaya et al [12] proposed a fusion model of total variation approach (PDE method) and Complex Dual Tree wavelet transform (Multi resolution analysis) method is used to reduce gaussian noise in the MR images.

S.Satheesh et al [41] proposed contourlet transform constructed by Laplacian pyramid (LP) and directional filter banks (DFB) for the removal of Gaussian noise from MR Images. The contourlet transform is found to be more efficient than the wavelet methods (hard threshold, soft threshold, wiener filter in wavelet domain)[41]. Toprak et al proposed rule based fuzzy adaptive median filter for denoising medical images, which can preserve image details efficiently than the adaptive median filter by suppressing additive salt and pepper or impulse type noise [42]. Again I. Guler et al [43] used fuzzy adaptive median filter with adaptive membership parameters (FAMFAMP) for the noise reduction of magnetic resonance images corrupted with heavy impulse (salt and pepper) noise, while maintaining image edges and details.

The curvelet transform (CT), like the wavelet transform, is a multiscale transform, with frame elements indexed by scale and location parameters [44][45]. A combined algorithm of curvelet transform and morphological filter (CASF algorithm) is used for the removal of noise from coronal MR images [46].The transform was designed to detect singularities and edges along curves much more efficiently than old transforms, hence fewer coefficients are required for reconstruction [44]. J.Rajesh et al [47] apply waveatom shrinkage, a variant of wavelet packet and obey the parabolic scaling of curvelet for rician noise removal from MR brain image. Curvelets uses the ridgelet transform and implements curvelet sub bands using a filter bank of wavelet filters [48]. From the survey table it is seen that depending upon the type of noise in the image, the performance of the filter varies. Hence choosing a denoising algorithm for an application depends on i) modality of the image, ii) nature of noise. From the table i and table III it is clear that in most of the papers the performance metrics used are PSNR, MSE. However Some other metrics like structural similarity index (SSIM), structural content (SC), normalized cross correlation (NK), maximum difference (MD), laplacian mean square error (LMSE), normalized absolute error (NAE) etc. can also be used to evaluate the filtering techniques.

III. CONCLUSION

The different types of spatial and transform domain denoising algorithms for MR images of brain are discussed in this paper. The survey table provides a clear picture of features of different types of spatial and transforms domain denoising approach. On the basics of the performance metrics and the statistical parameters the transform domain algorithms are providing better results than spatial domain algorithms. In the case of transform domain approach, the wavelet atom shrinkage and Curvelet provides better result than wavelet domain techniques especially in the case of images with smooth curves and curved edges. The denoising is the preliminary process for segmentation, registration, hybrid fusion of different medical image modality. An efficient denoising algorithm based on the modality of the image and nature of noise has to be selected with appropriate performance metrics and statistical parameters to yield good results.

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