Denoising of MRI based on Wavelet Domain: A Review

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Abstract— Magnetic Resonance Imaging (MRI) is useful and effective diagnostic tool in basic research, clinical investigation, and disease diagnosis since it provides both chemical and physiological information about the tissue under investigation. But when noise get introduced in MR images it decreases the image quality, image analysis and becomes difficult to diagnose it accurately. A trade off between noise reduction and preservation of actual image features has to made in such manner that enhance the diagnostically relevant image content. Thus noise reduction is still challenging task. There are varieties of techniques for denoising of MR images. In this paper, different techniques have been presented along with its assumption, advantages and disadvantages.

Index Terms—MRI, denoising

I. INTRODUCTION

MRI is imaging technique used in radiology for visualizing the internal structure of tissues and organs in the body. It is used for assessing the pathological or physiological alternations of living tissues. It differs from other imaging modalities such as X-ray, computed Tomography in such manner that it can characterise and discriminate among tissues using their biochemical and physical properties. Also, without moving patient it can produce sectional image of equivalent resolution. This adds to its versatility and diagnostic utility which gives it special advantage for surgical treatment planning. One more advantage is that it does not causes the harmful radiations to the patient[19]. For clinical diagnosis, the visual quality of magnetic resonance images plays an important role. But during acquisition or transmission these images are corrupted with noise, which hinder the medical diagnosis based on these images. Thus, denoising of image is necessary and foremost step to be taken before the image data to be analysed. Image denoising is still challenging as removal of noise causes artifacts and image blurring. Different algorithms are used for denoising which depends on noise model and modelling of noise depends on many factors like data capturing instrument, transmission media, quantization of image. This paper explains different methods of denoising and also gives us the insight in to the methods to determine which method will give accurate and reliable estimate of original one.

MRI is very effective tool for diagnosis and analysis of the disease so how is it body can be analysed by magnetic resonance? Well as body is largely composed of fat and water molecule and each water molecule has two hydrogen nuclei or protons which are imaged to detect any physiological or pathological alterations of human tissues. MRI is based on the principle of Nuclear Magnetic Resonance (NMR). It is used to map spatial location and associated properties of specified nuclei or protons in patient using interaction between electromagnetic field and nuclear spin. It detects and process the signal generated when hydrogen atoms are placed in strong magnetic field and excited by resonant magnetic excitation pulse. The nuclei of H atom align themselves to magnetic field after magnetic pulse will raise their energy level, further when pulse ends they will relax and during this energy is transmitted from atom. The transmitted signal will be detected by the equipments and processed further in to pixels which make it MR image.[19]

A brief survey of representative techniques denoising of MRI is now presented. S. kalavthy proposed a sub band adaptive thresholding technique based on wavelet coefficients along with neighbourhood pixels filtering algorithm [NPFA] for noise suppression of MRI. This stastical model describes a new method for denoising by fusing the wavelet denoising technique with optimized thresholding function. This technique has given significantly superior image quality by preserving edges, producing better PSNR value.[6] Image denoising using contourlet transform is proposed by S. Satheesh. Based on qualitative and quantiative analysis it shows that this algorithm is more efficient than the wavelet methods in image denoising particularly for removal of Gaussian noise. This method can obtain high PSNR than wavelet based denoising algorithm using MR images in the presence of AWGN.[10] Rohini Majan proposed wavelet domain denoising for the removal of Rician noise from MR images and this method depends on the selection of threshold value which in turn predicts the efficiency of denoising method. Symlet filter (sym6) is used for
denoising purpose which tends to preserve the shape of reflectance peak and smoothness value of data point. [16] S. Jakhade introduced an algorithm that uses wavelet based multiresolution analysis and adaptive filtering which can efficiently remove noise from image. By doing comparative study it has been proved MRI with Rician and speckle type of noise, adaptive bilateral filter is best suitable for MRI denoising in wavelet domain.[18] For image denoising, Kanwaljot Singh et al worked on Haar and Daubechies transform. Initially, image is decomposed using Haar and Daubechies transform then the level of hard and soft threshold is selected and then by calculating and comparing the PSNR of an image for every wavelet, desired wavelet is assigned which gives more PSNR of respective image. From this comparison it is found that DB3 wavelet is more efficient which enhance the visual quality of images and thus it helps in effective diagnosis.[24] Neelabh Sukatme used UDWT for diagnosis of MRI which is based on idea of no decimation. It omits the down sampling at the decomposition step and up sampling at the synthesis step. It gives more precise information. Comparing with DWT on the basis of PSNR values it has been proved that UDWT found to be good in terms of quality metrics.[14]

Rupindrapal Kaur et al presents a wavelet based technique for detection and removal of noise in MRI images. Though the set of wavelet has some common properties but each has certain unique properties of image decomposition denoising and reconstruction. Result obtained by quantitative and qualitative comparison of daubechies wavelet and malit wavelet transform for Gaussian noise shows that image denoising using fast wavelet transform has better results compared to daubechies wavelet with less processing time. Also it reduces memory requirement, complexity and increases the flexibility. Also it enhances the visual quality of MRI by achieving high PSNR and low MSE.[1] Shashikant Agrawal et al proposed a medical image denoising algorithm using DWT. They have presented the generation of DWT methods for 2-D case. From the result it shows that the bio orthogonal wavelet (bior1.3) gives best result compared to other and also optimal thresholding gives better denoised result among the three thresholding techniques.[2] A new approach introduced by zuvria to enhance denoising of MRI that exploits the sparseness and self similarity properties of images. This is based on three dimensional moving window discrete cosine transform hard thresholding and rotationally invariant version of non-local means filter. This proposed method run in reasonable time and can be used for most research and clinical settings. [3] Paul Bao proposed MRI image denoising using an adaptive wavelet thresholding. This scheme multiplies the adjacent wavelet subbands to amplify the significant feature and then applies thresholding to the multiscale scheme which gives high SNR and also preserves edges of the image. [4] A new filtering method based on neutrosophic set approach of weiner filter is presented by J. Mohan to remove rician noise from MRI. By applying neutrosophic set into image domain and image is transformed to NS domain, the entropy of this set is employed to measure the indeterminacy. The wiener filter is used to decrease the set of indeterminacy and remove noise. [5] Devande bhosle implemented bilateral filtering for denoising of MRI which is corrupted by additive white Gaussian noise. It gives better performance to remove noise in high frequency area but fails to remove noise to low frequency area. [7]

Hossein Rabbani (2009) proposed novel noise reduction algorithms that can be used to enhance image quality in various medical imaging modalities such as magnetic resonance and multi detector computed tomography. The noisy captured 3-D data are first transformed by discrete complex wavelet transform. Using a nonlinear function, he model the data as the sum of the clean data plus additive Gaussian or Rayleigh noise and use a mixture of bivariate Laplacian probability density functions for the clean data in the transformed domain. [22].

Zeinab A. Mustafa (2011) proposed an extension of the bilateral filter: multi resolution bilateral filter (MRBF), with wavelet transform (WT) sub-bands mixing. The proposed wavelet sub-bands mixing is based on a multi resolution approach for improving the quality of image denoising filter. The MRBF algorithm is also proven to be asymptotically optimal under a generic statistical image model. [20]

Henkelman R.M demonstrated that the corresponding noise in magnitude MR images is Rician not Gaussian. A Maximum-likelihood (ML) method for the parameter estimation procedure is used. Further discrimination between edge- and noise-related coefficients is achieved by updating the shrinkage function along consecutive scales and applying spatial constraints. [21]

II. NOISES IN MRI

During acquisition or transmission MRI images are mostly corrupted by noise. Also, noise may be produced because of imperfect instrument used during processing, interference and compression [7]. Image noise can be defined as random variation of brightness or color information image produced by the sensor and circuitry of the scanner. Noise in MRI poses a lot of problem to medical personnel by interfering with interpretation of MRI for diagnosis and treatment of human. Image noise in large measures contributes high hazards faced by human [8]. MRI, cancer and brain images often consists of random noise which is not because of tissues but from other sources in electronic instrumentation during acquisition. Noise exist in MRI may be of two types additive or multiplicative. Noises present in MRI are of different of types like thermal noise, RF noise, Gaussian noise, pepper and Salt noise and rician noise.
Thermal noise is caused by motion of free electrons which may be occurred due to eddy current losses in patient which is inductively coupled to RF coil or by ohmic losses in RF coil itself. RF noise is produced due to excessive electromagnetic emissions from medical devices that interfere with proper operation of MR scanner.[18] Salt and pepper noise is an impulse type of noise, which is mainly occurred due to errors in data transmission. The corrupted pixels are set alternatively to the minimum or to the maximum value, giving the image a “salt and pepper” like appearance. For an 8-bit image, the typical value for pepper noise is 0 and for salt noise 255. This type of noise is mostly caused by malfunctioning of pixel elements in the camera sensors, faulty memory locations, or timing errors in the digitization process. Gaussian noise is evenly distributed over the signal. Each pixel in the noisy image is the sum of the true pixel value and a random Gaussian distributed noise value. [14] Rician noise is nothing but the error between underlying image intensity and the observed data. Magnetic resonance magnitude image data are usually modelled by rician distribution.

III. DENOISING METHODS

Noise like Rician noise. Gaussian noise affects the image in both quantitative and qualitative manner and thus it hinders image analysis, interpretation and feature detection.[16]. So denoising method is required which removes this noise. Denoising is nothing but the removing noise from image while retaining the original quality of the image. The great challenge of image denoising is how to preserve the edges and all fine details of an image while suppression of noise.

In a diagnostic image, edge preservation is important in maintaining the original clinical significance[7]. It is also important to reduce noise without introducing artifacts. So to denoise image while retaining the edges of the image and to reduce noise without introducing artifacts is very fundamental problem in Image processing. Depending on this, there are different techniques are developed. Some are explained here.

Transform Domain

This transform domain mainly consists of three types which are as:

1. Curvelet transform

The concepts of curvelet transform based on the theory of multiscale geometric analysis. It possess directionality and anisotropy for representing directions of the edges in image. Curvelet transform is useful to detect, represent and process high dimensional data. In this, the frame elements are indexed by scale, position and orientation parameters. A curve is represented as a superposition of functions of various lengths and width obeying the scaling law width = \text{Length}^\text{2}$. This can be obtained by first decomposing the image into subbands i.e., separating the object into a series of disjoint scales. Each scale is analyzed by means of a local ridgelet transform which is also a multiscale transform to describe signal with straight line singularity. Curvelets are based on multiscale ridgeslets combined with a spatial bandpass filtering operation to obtain different scales. Main disadvantage is that it does not works well in smooth areas produces curvelet like artifacts.[19]

2. Contourlet Transform

The wavelet transform is effective in representing images containing smooth areas separated with edges but it can not perform well when the edges are smooth curves. The contourlets have the property of capturing contours and fine details in images. The Contourlet transform by Do and Vetterli is a geometrical image transform, which represents images containing contours and textures, provides sparse representation at both spatial and directional resolutions. It gives a flexible multiresolution and directional decomposition for images. It is constructed by combining two distinct and successive decomposition stages: a multiscale decomposition followed by a multidirectional decomposition. The first stage uses a Laplacian pyramid (LP) scheme to transform the image into one coarse version and a set of LP bandpass images. The second stage use directional filter bank (DFB) and critical subsampling to decompose each LP bandpass image into a number of wedge shaped sub-bands, thus capturing directional information. Finally, the image is represented as a set of directional sub-bands at multiple scales[19].

3. Wavelet Domain

Wavelet means a “small wave”. A wave is an oscillating function of time or space and is periodic, whereas wavelets are localized waves. Wavelets have their energy concentrated in time. The wavelet transform is better than fourier transform as it gives frequency representation of raw signal at any given interval of time, but fourier transform gives only the frequency-amplitude representation of the raw signal, but the time information is lost. So we cannot use the Fourier transform where we need both time as well as frequency information at the same time[24]. While Fourier Transform and STFT use waves to analyse signals, the Wavelet Transform uses wavelets of finite energy.

In wavelet analysis the signal to be analyzed is multiplied with a wavelet function and then transform is computed for each segment generated. Wavelets are functions that are generated from the single function called the prototype or mother wavelet. These functions are generated by dilations (scaling) and translations (shifts) in time frequency domain [10]. In wavelet analysis, approximations are the high-scale, low-
frequency components of the signal and details are the low-scale, high-frequency components.[14]

In practise, the wavelet transform is implemented with reconstruction bank using wavelet families. The use of wavelet transform as filter bank called discrete wavelet transform (DWT). The DWT provides better spatial and spectral localization of signal formation.[12]. Also it provides non-redundant and unique representation of signal. Due to this, signal and noise are easily separated in wavelet domain. Here, the signal is decomposed into sub-signals corresponding to different frequency content. The result of DWT is a multilevel decomposition which will generate wavelet coefficients. These coefficients include various approximation and detail coefficients at various levels and it leads to four different sub-bands as HH, HL, LH and LL at each level. Typically the content of each scale is divided into three orientations. Thus, sub-bands are characterised by horizontal, vertical and diagonal direction. The approximation sub-band consists of the so called scaling coefficients (LPF) whereas the detail sub-band (HPF) are composed of wavelet coefficients.

These coefficients are useful for texture categorization of image. Very small wavelet can be used for isolating finer details whereas large wavelets identify coarse details. The digital transformation of image for computer processing requires digitization, so here we are using 2-D discrete wavelet transform which decompose image several sub-bands. In case of two dimensional image after DWT the image is divided into four corners, upper left of the original , lower left of corner of vertical details upper right of the horizontal details and lower right corner of the image detail.[23].

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![Two level 2-D DWT of image](image)

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IV. WAVELET THRESHOLDING

The most important way of distinguishing information from noise in the wavelet domain consists of thresholding the wavelet coefficients. Thresholding is a non-linear technique, which operates on one wavelet coefficient at a time. During thresholding, a wavelet coefficient is compared with a given threshold and is set to zero if its magnitude is less than the threshold; otherwise, it is retained or modified depending on the threshold rule. Thresholding distinguishes between the coefficients due to noise and the ones consisting of important signal information. The choice of a threshold is an important point of interest. It plays a major role in the removal of noise in images because denoising most frequently produces smoothed images, reducing the sharpness of the image.

Thresholding is mainly divided into two categories:

Hard Thresholding

The In this approach, wavelet coefficients below threshold value are set to zero and keeps the other unchanged .it does not affect the detail coefficients that are greater the threshold value.

$$\begin{align*}
C(K) &= \text{sign}(C(K)) \cdot |C(K)| \quad \text{if } |C(K)| > \lambda \\
&= 0 \quad \text{if } |C(K)| \leq \lambda 
\end{align*}$$

where $\lambda$ is threshold.

Soft Thresholding

In this approach, coefficients under the threshold are set to zero but scales the ones that are left. It can be defined as

$$\begin{align*}
\tilde{C}(k) &= \text{sign}(C(K)) \cdot |C(K)| - \lambda \quad \text{if } |C(K)| > \lambda \\
&= 0 \quad \text{if } |C(K)| \leq \lambda 
\end{align*}$$

The important point thresholding method is to find the appropriate value for threshold. The threshold value is estimation of noise level .It is generally calculated from the standard deviation of the detail coefficients. Donho proposed a good estimator for the wavelet denoising, which is given as
Where L is number of decomposition levels. This median selection made on the detail coefficients of signal to be analysed.[12]

Mean Square Error (MSE)

This is one of the error criteria used in this work. MSE is the squared difference between the original and the denoised image. This gives us the difference between original image and the denoised image. It is given by:

\[ MSE = \frac{1}{MN} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} (y(m,n) - y'(m,n))^2 \]

between Where \( y(m,n) \) is the original image and \( y'(m,n) \) is denoised image with respect to image dimension (m,n).[8]

Signal To Noise Ratio (SNR)

SNR is very useful way of comparing the relative amount of signal and noise. Signal to noise ratio estimates the quality of a reconstructed image compared with an original image. High measures will have very little amount of noise and opposite is true for low ratios.[16]

\[ SNR = \frac{\sigma_s}{\sigma_n} \]

Where \( \sigma_s \) and \( \sigma_n \) are the variance of the original image and recorded image.

This gives us the difference between original image and the denoised image

Peak Signal To Noise Ratio (PSNR)

It is the ratio between maximum possible power of a signal and the power of corrupting noise that affects the quality and reliability of its representation. PSNR is calculated as

\[ PSNR = 10 \cdot \log_{10} \left( \frac{MAX^2}{MSE} \right) \]

Where MSE is mean square error and MAX is the maximum pixel value of image.[8]

V. CONCLUSION

In this paper, numerous amounts of Image Denoising Techniques are discussed. The selection of Denoising technique depends on what kind of denoising is required. Wavelet thresholding offers high quality and flexibility for noise problem of signal and images. Wavelet thresholding is very useful technique for denoising of MRI images, as it preserves the edges of images which is very important for clinical investigation.

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