

Comparative Analysis of Denoising Methods in CT Images

Tarandeep Chhabra, Geetika Dua and Tripti Malhotra

Abstract: In CT Scan there is a scope to adapt patient image quality and dose. Reduction in radiation dose (i.e the amount of X-rays) affects the quality of image and is responsible for image noise in CT. However, several denoising algorithms can be used to improve the image quality. This paper contains the comparative analysis of a number of denoising algorithms namely median filtering, wavelet decomposition, wave atom decomposition, wiener filtering, anisotropic diffusion and NL-means filtering. We compute some quantitative performance metrics like PSNR, SNR, MSE,S/MSE and MAD. This comparison helps in the assessment of image quality and fidelity.

Keywords: *computed tomography, noise reduction, filtering, denoising, SNR, MSE.*

I.INTRODUCTION

CT Scan stands for Computed tomography. It basically uses X-rays to obtain structural and functional information about the human body. In CT, the image quality is influenced by many technical parameters. One of the most important parameter is the radiation dose. The quality of image increases with the significant amount of radiation dose [1]. But an increased amount of X-rays being absorbed by the human body increases the chances of cancer. So we need to reduce the radiation dose which is responsible for image noise in CT. So for proper analysis and diagnosis it is required to reduce the image noise and filtering is thus applied to clear such images. Any noise reduction algorithm aims to enhance the fidelity of an image which actually means removing the random and uncorrelated structures and retaining the resolution. Denoising of image data has been an active area of research and different methods such as median filtering, wiener filtering, use of NLM filter, wavelets decomposition, wave atom, bilateral filtering, isotropic, anisotropic diffusion, etc have been used.

II.METHODS TO REDUCE NOISE IN CT SCAN IMAGES

A. Median Filter

Linear filters are generally used to reduce noise in CT images. Here, the neighboring pixels represent the additional samples of the same value as that of reference pixel. In linear filters the convolution process is used for implementing the neighboring kernels as neighborhood function. But this may lead to the blurring of edges. To overcome such a problem non-linear filters are used for noise reduction. These filters help to preserve edges. Median filter is an example of non-linear filters. In median filter, the ranking of the neighboring pixels is done according to the intensity or brightness level and value of the pixel under evaluation is replaced by the median value of surrounding pixel values.

123	125	126	130	140
122	124	126	127	135
118	120	150	125	134
119	115	119	123	133
111	116	110	120	130

Neighborhood values:

115,119,120,123,124,125,126,127,150

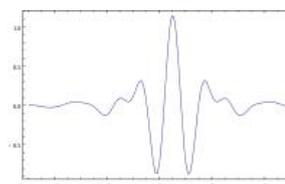
Median value= 124

Median filter can therefore effectively denoise medical images. The images distorted or blurred by shot or impulse noise can excellently denoised using this filter. Median filters have many advantages over smoothing filters[9]:

- In median filter the output values consist of only those present in the neighborhood (median value) so there is no reduction in contrast across the steps.
- The boundaries are also not shifted when median filter is used.
- The edges are minimum degraded and hence median filter can be repeatedly applied.

B. Wavelet Decomposition

The term Wavelet means a short wave like oscillation. Its amplitude value starts from zero, increases, again degrades to give zero value.



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Figure 1: Wavelet

Wavelet transform is actually a mathematical technique which is used to synthesize a signal in time domain. It can be combined with any unknown signal to analyze that signal[8]. Then the transform of each segment is computed. At high frequencies this transform gives poor frequency but good time resolution, and vice-versa.



Figure 2: wavelet characteristic.

In wavelet transform the analysis of data variables is done in both time and frequency domain. In DWT a signal is represented in terms of displacement functions ϕ and scale functions ψ .

In DWT the signal can be decomposed into several levels and then these levels are analyzed independently. Signal decomposition (using orthogonal wavelets) can be shown by the equation:

$$s(l) = \sum_k C_{j,k} \Phi_{j,l}(k) + \sum_{j=i}^k \sum_x w_{j,k} \Psi_{j,k}(k) \tag{1}$$

where, $\Psi_{j,k}(x) = 2^{-j}\psi(2^jx - l)$ and $\Phi_{j,k}(x) = 2^{-j}\phi(2^jx - l)$.

Threshold is applied to the wavelet coefficients for noise reduction. Threshold is further of two types:

- (i) Soft threshold
- (ii) Hard threshold

Soft and hard threshold can be given as:

$$\rho_{hard}(x) = \begin{cases} x, & |x| < \lambda \\ 0, & otherwise \end{cases} \tag{2}$$

$$\rho_{soft}(x) = \begin{cases} x - \lambda, & x \geq \lambda \\ x + \lambda, & x \leq -\lambda \\ 0, & otherwise \end{cases} \tag{3}$$

Further, there are a number of basis functions that can be used as mother wavelet for wavelet transformation. Commonly used wavelet functions are haar, daubechies, coiflet, symmlet,etc. the wavelets are chosen based on their shape and their ability to analyze the signal in a particular application.

C. Wave atom Transform

Wave atoms are used for harmonic computational analysis. These are a variant of 2D wavelet packets that retains an isotropic aspect ratio [6]. They have a sharp frequency localization that cannot be achieved using a filter bank based on wavelet packets. Wave atoms obey the parabolic scaling law: wavelength \sim (diameter)². The name “wave atom” comes from the property that they provide an optimally spars representation of wave propagator with applications to fast numerical solvers for wave equation.

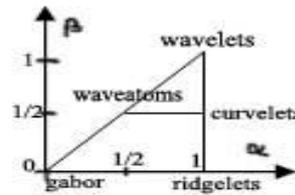


Figure 3: Identification of various transforms as (α, β) families of wave packets.

D. Wiener Filter

Wiener filters are basically the optimum linear filters which involves linear estimation of a desired signal sequence from another related sequence while solving the linear filtering problem certain important parameters like mean and correlation functions of useful signal and unwanted additive noise are assumed. Now the aim is to design a linear filter whose input is the noisy data and output is required to minimize the effect of noise[10]. The filter optimization problem is to minimize the value of MSE that is defined as mean square value of error. It is the difference between the desired and the actual filter output. The resulting solution (for stationary inputs)is called the wiener filter. However, wiener filter is inadequate for non stationary inputs because in such a case the optimum filter has to assume a time varying form.

In wiener filter, the performance function is given as:

$$x = E[|e(n)|^2] \tag{4}$$

This is called “mean square error criterion”

E. Anisotropic Diffusion

Diffusion filtering of an image is similar to the physical diffusion process which provides equilibrium while following the law of conservation of mass. The image intensity can be seen as ‘concentration’. The noise can be seen as noise inhomogenities. The inhomogenities can be smoothened by ‘diffusion’. Diffusion filtering is digital image processing is mainly of two types: linear and non linear. Since the diffusion process relates a concentration gradient with a flux, linear *isotropic diffusion* is that in which these quantities are parallel[2]. Linear isotropic diffusion is used for image smoothening. The main disadvantage is that it blur the important features like edges. In *nonlinear* diffusion the concentration gradient and flux are not parallel and the filter coefficients change in response to differential structures within the image[3].

The first inhomogeneous diffusion model(*anisotropic diffusion*) was given by Perona and Malik[7]. Their idea was to vary the noise removal in nearly homogeneous regions while avoiding any alteration of the signal along significant discontinuities. The discontinuities are edges in images that arise due to the sharp changes in image intensity. The change in intensity I over time was defined as[7]:

$$I_t = \text{div}(g \|\nabla I\|) \nabla I \quad \text{with: } g(x) = \frac{1}{1 + \frac{x^2}{a}} \quad (5)$$

where g is the conduction function.

F. NLM Filter

The aim of any denoising method is to recover the original image from a noisy environment,

$$v(i) = u(i) + n(i) \quad (6)$$

where v(i) is the observed value, u(i) is the actual or the true value and n(i) is the noise perturbation at a pixel i.

Several methods can be used to denoise and recover the true image u. One such method is to use NLM (non- local means) filter[4]. The NL- means algorithm is defined by the formula:

$$NL[u](x) = \int_{\Omega} e^{-\frac{(G_a * |u(x+) - u(y+)|)^2}{h^2}} u(y) dy \quad (7)$$

where $x \in \Omega$,

$C(x) = \int_{\Omega} e^{-\frac{(G_a * |u(x+) - u(y+)|)^2}{h^2}} dz$ is normalizing constant, G_a is the Gaussian kernel and h acts as a filtering parameter.

According to this formula the denoised value at x is the mean of all the values at all the points whose Gaussian neighborhood is as the neighborhood of x.

III. COMPARISON PARAMETERS

The final step is to compute comparison parameters to compare the results of all above described techniques.

A. Mean Square Error (MSE)

Mean square error is a dominant quantitative performance metric in the field of image processing. It is used for the assessment of image quality and fidelity. The cumulative squared error that occurs between compressed and original form of image is termed as MSE. It is mathematically defined as:

$$MSE = \frac{1}{m * n} \sum_{i=1}^m \sum_{j=1}^n (N(i, j) - DN(i, j))^2 \quad (8)$$

where m is the number of rows in the image, N(i,j) is noisy image and DN(i,j) is denoised image.

B. Peak Signal To Noise Ratio

PSNR is mathematically described as:

$$PSNR = 10 \log_{10} \left(\frac{R^2}{MSE} \right), \quad (9)$$

where R is the maximum fluctuation in the input image data type. For example, if the input image has a double precision data type, R=1[6]. The PSNR value approaches infinity as the MSE approaches zero. Higher value of PSNR represents higher image quality. Small value of PSNR represents high numerical differences between images.

C. Signal To Noise Ratio

The signal-to-noise ratio is a technical term used to characterize the quality of the signal detection of a measuring system. It is mathematically described as:

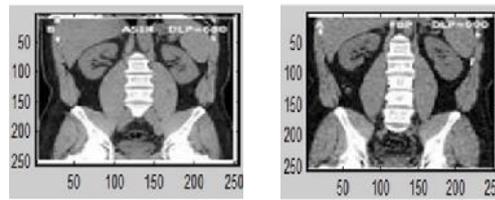
$$SNR = 10 \log_{10} \left(\frac{\text{var}(x)}{\text{var}(\hat{x} - x)} \right), \quad (10)$$

where x is the noise free simulated images and \hat{x} is noisy or denoised image.

IV. RESULTS AND DISCUSSION

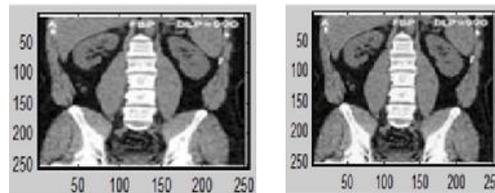
This paper contains the results, obtained after following the median filter, wiener filter, wavelet, wave atom, anisotropic and NLM denoising algorithms.

Further, comparison parameters like PSNR, MSE, SNR, S/MSE are calculated and compared.



(a) (b)

Comparison parameters	PSNR	MSE	SNR
Median Output	11.6844	0.06852	-0.1239
Wavelet denoised image	11.6216	0.068839	-0.2075
Wave atom denoised image	11.6154	0.068939	-0.2135
Wiener output	11.9619	0.063652	0.2135
Anisotropic diffusion output	11.6216	0.060561	0.7143
NLM filter Output	11.7771	0.066419	-0.0069



(c) (d)

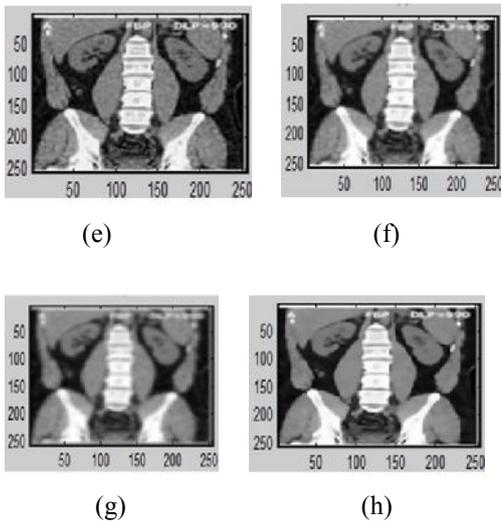


Figure 4: (a) Original image, (b) Noisy image, (c) Image filtered by median filter, (d) Wavelet denoised image, (e) Waveatom denoised image, (f) Wiener filter output, (g) Image filtered by anisotropic diffusion, (h) Output of NLM filter.

V. CONCLUSIONS

In this paper, we demonstrated the image denoising results obtained from various denoising algorithms namely median filtering, wavelet decomposition, waveatom decomposition, anisotropic diffusion, weiner filtering and NL-m filtering. By investigating the comparison parameters, it is clear that anisotropic diffusion technique is promising. This method smoothes the noise while preserving the important features like edges. This technique provides the maximum SNR (i.e. 0.7143), S/MSE (i.e. 7.1733) and minimum MSE (i.e. 0.060561). So, from the comparative analysis of all the above described denoising algorithms it is clear that anisotropic diffusion method is best among all discussed above.

Table 1: Comparison parameters

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