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A Novel Image Reconstruction Technique Using Steerable Wavelet Transform and Modified Morphological Approach

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Abstract

This paper proposes a promising high resolution image reconstruction algorithm with the blend of spatial and transform domain techniques for biomedical images. The actual content of an image can be recovered by the proposed unique combination of Steerable Wavelet Transform (StWT) and Modified Morphological Approach (MMA) under noisy environment. This method relies on StWT for edge detection by which marker image is obtained and morphological operation for obtaining mask image. By superimposing the marker and mask image, the original image can be reconstructed from noise. The performance measures such as Correlation Co-efficient (CC), Peak Signal to Noise Ratio (PSNR), Mean Absolute Error (MAE), Structural Similarity Index Measure (SSIM) and Universal Image Quality Index (UIQI) are evaluated for the obtained reconstructed image. This StWTMMA yields better performance and proves to be superior and outperforms other existing techniques. Moreover the performance comparison of Classical operators, Morphology based approach and StWT approach for edge detection and corresponding image reconstruction techniques are analyzed.

Keywords: Classical Operators, Morphology based approach, Steerable Wavelet, Mean Absolute Error, SSIM and UIQI.

Introduction

The rapid development and proliferation of medical imaging technologies is revolutionizing medicine. Medical imaging allows scientists and physicians to glean potentially lifesaving information by peering non-invasively into the human body. The role of medical imaging has expanded beyond the simple visualization and inspection of anatomic structures. It has become a tool for surgical planning and simulation, intra-operative navigation, radiotherapy planning, and for tracking the progress of diseases. Image reconstruction is a powerful mathematical operator provided by morphology and it is a sub process of digital image processing. In this paper, salt & pepper noise, speckle noise, Gaussian noise and Poisson noise are considered for analysis [3].For the last two decades classical operator were dominating the edge detection techniques. Recently morphological based edge detection techniques were implemented [1] [5]. We impose a combination of Modified Morphology Approach[MMA] with an advanced transform domain technique StWT.

Classical Operators And Modified Morphological Approach

Classical edge detectors like Sobel, Roberts, Prewitt, Canny and Laplacian were developed and they fail to perform under noisy circumstances [4]. A modified morphology approach based on the set of morphological operators are proposed in [6] to eliminate the noise from the gray image and to reconstruct the image in order to obtain a clear image without any feature loss from the processed image.

$$[(((M\bullet B) \oplus B)-(M\bullet B) \circ B) \bullet B] \tag{1}$$

$$M= (F\bullet B) \circ B \tag{2}$$

Where $\circ$ - open operation, $\oplus$ - dilation operation, $\bullet$ - close operation

The F,B and M in the equation (2) represent the noisy image ,Structural Element (SE) and reconstructed image respectively. The equation (1) gives the edge detected image and is taken as marker image in this modified morphological approach.

Image Reconstruction:

Morphological based image reconstruction is repeated dilations of an image, called the marker image, until the contour of the marker image fits under a second image, called the mask image. In morphological reconstruction, the peaks in the marker image "spread out," or dilate. Each successive dilation is constrained to lie underneath the mask. When further dilation ceases to change the image, process should be stopped and the final dilation is the reconstructed image [3].

The original image is reconstructed by creating a mask using image erosion and dilation operation of the noisy image [5]. Noisy image should be dilated using the SE B and the obtained image should be eroded using the same SE. It acts as pre-processing step in elimination of noise and the resultant image is considered as mask image. By using the mask and the marker, the original image is reconstructed by imposing the mask image on marker image. The degree of equality between original input image and reconstructed image is analyzed with image parameters such as CC, PSNR, MAE, SSIM and UIQI. The same algorithm can be implemented using different SEs [6]. The overall results are presented in simulation results and analysis.

Classical Operators With Modified Morphological Approach

Classical operators are used for detecting edges in an image and the original image can be reconstructed from a noisy image.It can be done by pre-processing the noise image with Gaussian filter with sigma 2.25 to suppress the noise. It does not blur the edge information to some extent, but fails in reducing the noise content of an image. Gaussian filter gives the best compromise between noise reduction and prevention of edge information loss. The pre-processed image is taken as mask image and the edge detected image is considered as marker image. Original image can be reconstructed by imposing mask image on marker image. But the degree of equality between original image and reconstructed image is very poor in this case and is discussed in Table.1. In classical operators with mathematical morphology approach, difference is made in preparing the mask image. Instead of using basic filters in pre-processing of noisy image, dilations and erosion operators are used. Noisy image is dilated and then it is eroded using any type of structural element, as discussed. The resultant image is used as mask and reconstruction operation should be performed. The degree of similarity is better in this approach than purely mathematical morphology approach. Mask preparation can be done by using different structural elements.

STWT With Mathematical Morphology Approach (Proposed Algorithm)

StWT based edge detection provides fine edges of an image without false edge detection and this property is very essential for biomedical images. Steerable wavelet filter has a property of rotation at different angles and different orientation under adaptive control and it is a linear combination of set of basis kernels. It provides components at each scale and orientation separately and its non- aliased subbands are good for texture and feature analysis. The StWT of a two dimensional function is written as linear sum of rotated versions of itself, and is given by the expression as [4],

$$f^{\theta}(x_1x_2) = \sum_{j=1}^{n} k_j(\theta) f^{\theta_j}(x_1x_2) \tag{3}$$

where, $k_j(\theta)$ represents interpolation function and 'n' is the number of terms required for summation. The design of quadrature pair of steerable filter is given by frequency response of 2nd derivative of a Gaussian function G_2 and its Hilbert transform pair is H_2. For edge detection, the quadrature pair set G_2 and H_2, dominant orientation, Θ_d are utilized. The squared magnitude of the quadrature pair filter response steered everywhere in the direction of dominant orientation and it is given by [4],

$$E_2(\theta_d) = \left[G_2^{\theta_d}\right]^2 + \left[H_2^{\theta_d}\right]^2 \tag{4}$$

$$\varphi = \arg[G_2^{\theta_d}, H_2^{\theta_d}] \tag{5}$$

The steerable pyramid constitutes four band pass filters form a steerable basis kernel set at each level of pyramid. The orientation of these basis filters were at

0°,45°,90°,135° and the coefficients of these filters were obtained at any orientation and at any linear combination of these basis filters. The original image with perfect reconstruction can be obtained, when these basis filters are applied again at each level and the pyramid collapses to the original version [4] [2].

In this paper, Steerable wavelet filter bank technology is combined with morphology operators to get noise free refined image and these filters are used for finding the edges. The edge detected image is used as marker image and mask is made using morphology operators as discussed in proposed algorithm as depicted in Figure.1. The noise image is dilated using structural element and it is eroded with the same structural element. The resultant image is used as a mask image and eventually reconstruction operation is performed. The degree of similarity in this approach is better when compared to classical operators with morphology approach. Mask preparation can be done by using various structural elements. The overall results are discussed in simulation results and analysis.

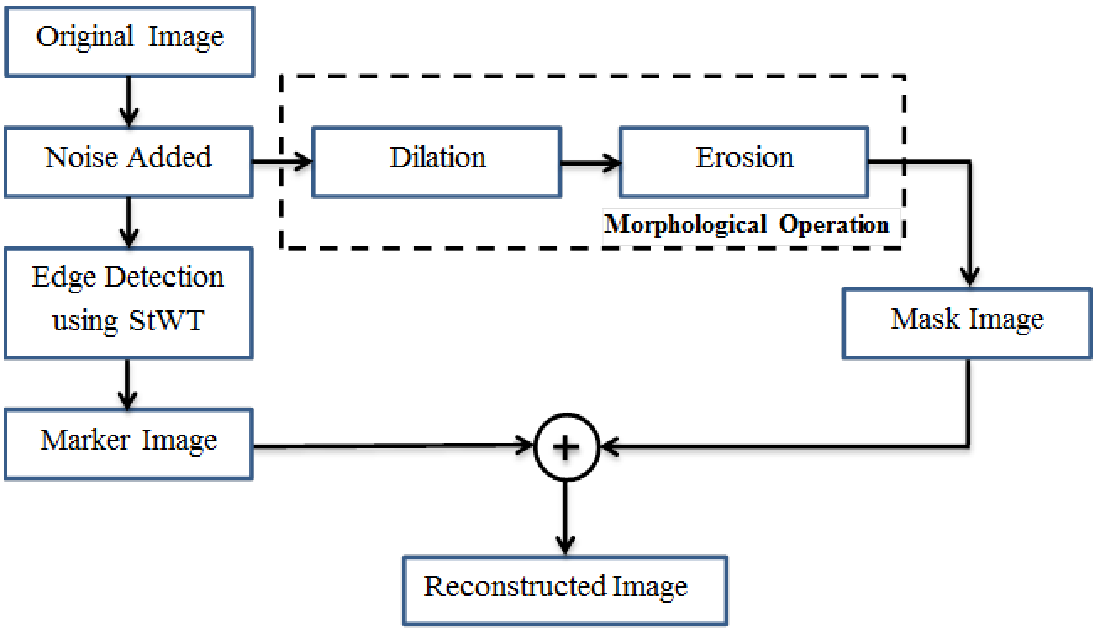


Figure 1: Flow Chart of the proposed method

Simulation Results and Analysis

Certainly automatic interpretation of medical images is a desirable, challenging, long-term goal, since it can potentially increase the speed, accuracy, consistency and reproducibility of the analysis.Medical images such as lung image and brain image are taken into consideration and are represented in Figure.2. and Figure.3. respectively. The effectiveness of this image processing algorithm developed is evaluated by different edge detection and reconstruction approaches. The comparison between all these approaches are made with the help of below mentioned parameters. The degree of similarity between original input image and reconstructed image can be analyzed with image quality assessment parameters. Some of the performance parameters discussed are CC, PSNR, MAE, SSIM and UIQI and among which CC is considered as an important parameter and is briefly discussed [7].

The appropriate range of CC is closer to 1, PSNR greater than 20dB, SSIM and UIQI are between the range of 0 and 1 and MAE of less value between original image and reconstructed image. All these approaches are tested with different structural elements and the results are discussed.

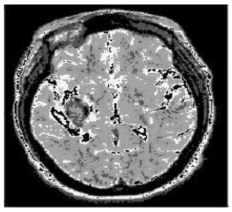


Figure 2: CT Lung Image **Figure 3:** CT Brain Image

Modified Morphology Approach

Modified Morphology Based Approach are evaluated on images namely CT Lung Image & CT Brain Image and are represented in Figure.4. and Figure.5.respectively, and the SE arbitrary [1,0,1;0,1,0;1,0,1] gives better result for Salt & Pepper noise, the SE arbitrary [0,1,0;1,1,1;0,1,0] gives better result for speckle noise. SE disk of size 1 or SE diamond of size 1 can be used in the place of arbitrary SE for Speckle Noise. The performance measures for Modified Morphology Approach for CT Lung Image and CT brain Image are illustrated in Table.1. and Table.2. respectively. For the image which was impregnated by Gaussian noise or Poisson noise, the SE square of size 2*2 gives better result. It is shown in the Table 3. and Table 4. for lung and brain image respectively.

4a. Noise Image

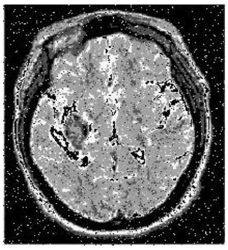
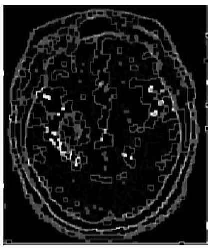
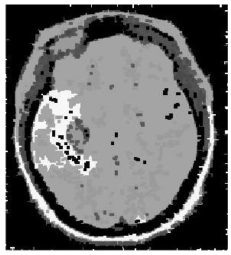
4b. Edge detected image

4c. Reconstructed image

Figure 4: Modified Morphology Approach - CT Lung Image.

Table 1: Modified Morphology Approach - CT Lung Image

Noise Type	Structural Element	CC	PSNR (dB)	MAE	SSIM	UIQI
Salt & Pepper	Arbitrary	0.9624	15.4236	4.9846	0.9583	0.9614
Speckle	Arbitrary	0.9519	11.6907	5.0993	0.8984	0.9012
Gaussian	Square	0.9445	12.9568	8.7131	0.9149	0.9210
Poisson	Square	0.9600	11.2802	2.0156	0.8890	0.8888

5a.Noise Image 5b.Edge detected Image 5c. Reconstructed image

Figure 5: Modified Morphology Approach - CT Brain Image

Table 2: Modified Morphology approach - CT Brain Image

Noise Type	Structural Element	CC	PSNR (dB)	MAE	SSIM	UIQI
Salt & Pepper	Arbitrary	0.9237	18.7383	4.8633	0.7141	0.8278
Speckle	Arbitrary	0.9334	18.8320	3.3828	0.9401	0.9019
Gaussian	Square	0.9417	19.3358	9.2181	0.7959	0.7554
Poisson	Square	0.9379	18.0715	1.4518	0.9704	0.8012

Classical Operators with Modified Morphological Approach

In pure classical operators approach, it is seen that Prewitt operator gives better results for salt and pepper noise and speckle noise. And Log operator gives better results for Gaussian noise and Poisson noise. The Table 4. shows the results of reconstructed lung mage which was impregnated with Salt & Pepper Noise. Here the noisy image was edge detected using Canny edge detection method and it was reconstructed by morphology based approach using different structural elements. It is seen that SE rectangle of size [1, 2] shows better result than any other structural element. By using rectangle as SE of size [1, 2], four different noise images were reconstructed using five different classical edge detectors such as Canny, Robert, Prewitt, Sobel and Log. And it is seen that for the images which were impregnated with Salt & Pepper noise and Gaussian noise, Sobel operator gives better results. But for speckle type of noise, Prewitt operator gives better result, and canny operator gives better result for Poisson noise.

Table 3: Comparison of Classical operators – CT-Lung Image

Noise Type	Operator Type	CC	PSNR (dB)	MAE	SSIM	UIQI
Salt & Pepper	Prewitt	0.9571	18.8667	9.1284	0.9792	0.9851
Speckle	Prewitt	0.9592	16.6417	6.8036	0.9745	0.9799
Gaussian	Log	0.9579	19.1209	7.5524	0.9852	0.9905
Poisson	Log	0.9588	19.3496	7.4493	0.9865	0.9914

Table 4: Comparison of Classical operators – CT-Brain Image

Noise	Classical Operator	CC	PSNR (dB)	MAE	SSIM	UIQI
Salt & Pepper	Canny	0.9886	25.3859	3.6232	0.9976	0.9983
	Robert	0.9889	25.5474	3.4337	0.9976	0.9983
	Prewitt	0.9895	25.7965	3.3487	0.9980	0.9987
	Sobel	0.9896	25.8297	3.3805	0.9980	0.9987
	Log	0.9870	24.8456	3.7060	0.9972	0.9982
Gaussian	Canny	0.9826	23.5845	6.9578	0.9932	0.9957
	Robert	0.9826	23.6110	6.6242	0.9939	0.9963
	Prewitt	0.9837	23.8839	6.5743	0.9941	0.9965
	Sobel	0.9837	23.8727	6.5587	0.9941	0.9965
	Log	0.9828	23.6302	7.0011	0.9933	0.9959
Speckle	Canny	0.9776	22.3345	4.6778	0.9972	0.9981
	Robert	0.9774	22.2855	4.5074	0.9971	0.9980
	Prewitt	0.9789	22.5635	4.4170	0.9971	0.9981
	Sobel	0.9788	22.5449	4.4100	0.9971	0.9981
	Log	0.9783	22.5443	4.7289	0.9972	0.9982
Poisson	Canny	0.9966	30.1403	2.0496	0.9992	0.9995
	Robert	0.9962	29.8644	2.0963	0.9988	0.9992
	Prewitt	0.9964	29.6708	1.9227	0.9988	0.9993
	Sobel	0.9965	29.6812	1.9218	0.9988	0.9993
	Log	0.9964	30.2624	2.1563	0.9991	0.9995

Steerable Wavelet Filter With Modified Morphology Approach:
The steerable filters are translation invariant (i.e. subbands are aliasing-free) and rotation-invariant (i.e., the subbands are steerable) and over complete. Any image function f(x,y) steers and it can be rotated as linear sum of rotated versions, and 1st order and 2nd order derivatives are represented in Figure.6. and Figure.7. In Steerable Wavelet Filter Bank Technology, for the image impregnated with Salt & Pepper

noise, 1st order filter of Gaussian width(σ) of two with zero mean(μ) gives better result by using SE rectangle of size [1, 2], Since in the process of image reconstruction, morphology operations are used in finding mask. For all other types of noises, second order filter of σ=4 with μ=2 gives better result. But different SE should be taken. SE arbitrary [1,1,1;1,0,1;1,1,1] should be used to get better result for speckle and Gaussian types of noise. And SE rectangle for Poisson type of noise and is shown in the Table. 5 and Table. 6. Lung Image impregnated with salt & pepper noise, speckle noise,Gaussian noise, Poisson noise and the performance of StWT of varying orders are shown in Figures.8.9.10.11. respectively.

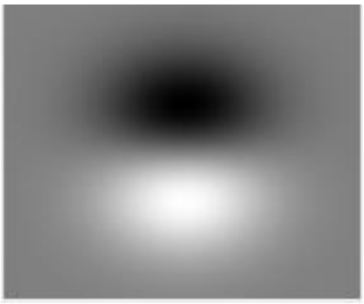


Figure 6: StWT - 1st order filter with μ =0 & σ = 4

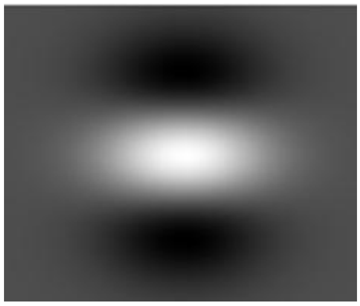
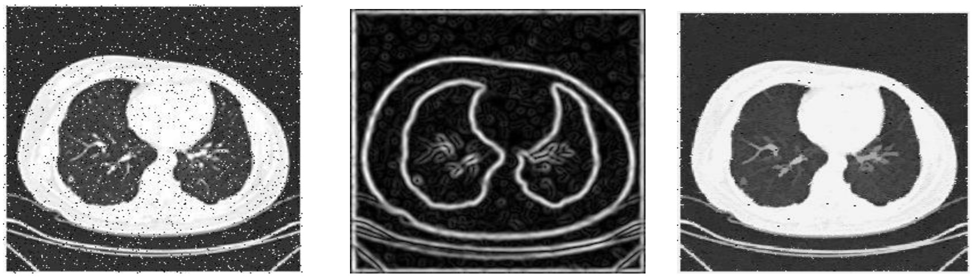
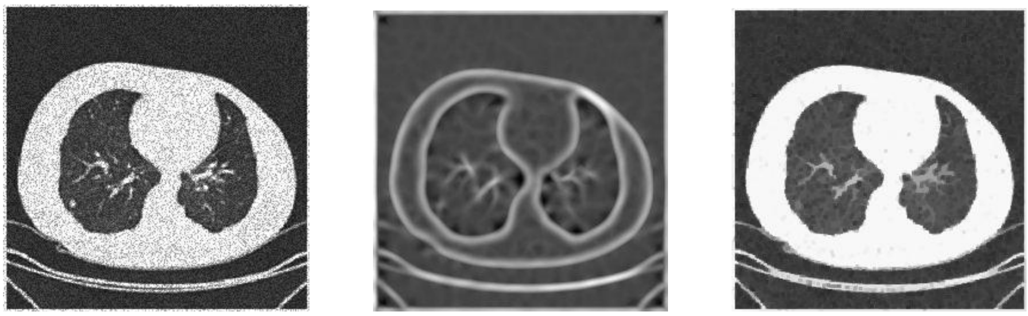


Figure 7: StWT- 2nd order filter with μ =2 & σ =4



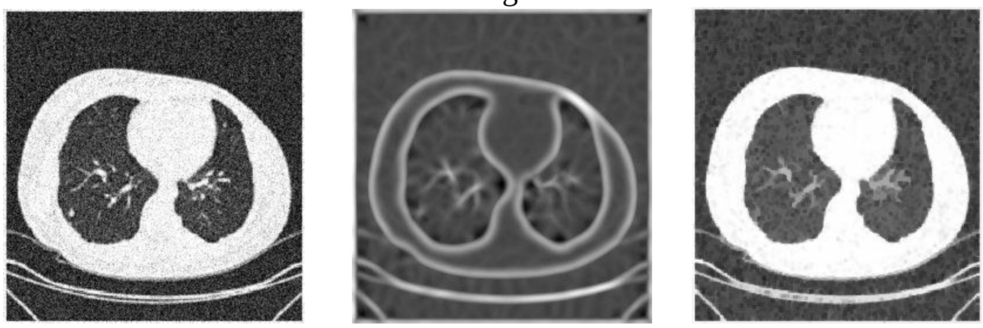
8.a 8.b 8.c

Figure 8: a: Lung Image impregnated with salt & pepper noise. Figure.8.b: Edge detected image using StWT filter of order 1, μ = 0 & σ =2. Figure.8.c: Reconstructed Lung Image



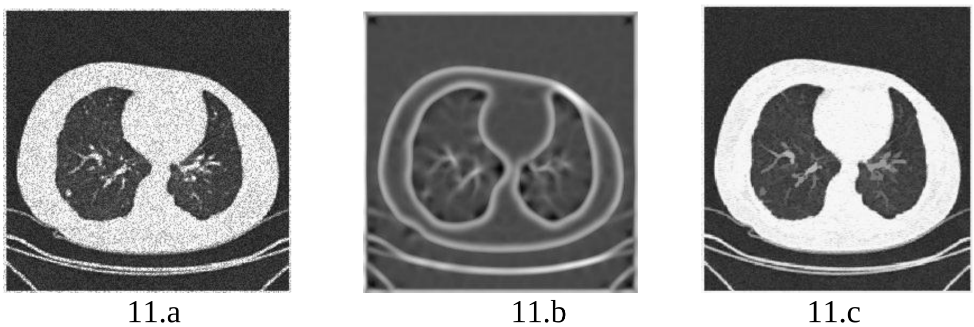
9.a 9.b 9.c

Figure 9: a: Lung Image impregnated with speckle noise. Figure.9.b: Edge detected image using StWT filter of order 2, μ=2 & σ =4. Figure.9.c: Reconstructed Lung Image



10.a 10.b 10.c

Figure 10: a: Lung Image impregnated with Gaussian noise. Figure.10.b: Edge detected image using StWT filter of order 2, μ=2 and σ=4. 10. Figure.10.c: Reconstructed Lung Image



11.a 11.b 11.c

Figure 11: a: Lung Image impregnated with Poisson noise. Figure.11.b: Edge detected image using StWT filter of order 2, μ=2 and σ=4. Figure.11.c: Reconstructed Lung Image

Table 5: Proposed Algorithm (Combining StWT with Morphology approach) – CT Lung Image

Noise Type	Order	μ	σ	CC	PSNR(dB)	MAE	SSIM	UIQI
Salt & Pepper	I	0	2	0.98	25.01	3.01	0.99	0.99
Speckle	II	2	4	0.98	23.84	9.07	0.98	0.98
Gaussian	II	2	4	0.98	21.46	15.27	0.94	0.94
Poisson	II	2	4	0.99	28.46	2.47	0.99	0.99

Table 6: Proposed Algorithm (Combining StWT with Morphology approach) – CT Brain Image

Noise Type	Order	μ	σ	CC	PSNR(dB)	MAE	SSIM	UIQI
Salt & Pepper	I	0	2	0.97	24.30	4.471	0.86	0.82
Speckle	II	2	4	0.96	22.19	11.77	0.94	0.90
Gaussian	II	2	4	0.97	20.45	19.11	0.68	0.72
Poisson	II	2	4	0.99	28.51	2.55	0.99	0.93

The simulation results clearly indicate the performance of the algorithm with respect to evaluation measures for image reconstruction. Towards this goal, it is briefly reviewed that, the proposed algorithm with the effective combination of Steerable Wavelets and modified morphological approach suits the best for Poisson noise. Second order steerable filter with $\mu = 2$ and $\sigma = 4$ provides better results. The proposed algorithm can also be used for the other types of noises. But Poisson noise gives better results when compared to the other three. For speckle noise and Gaussian noise also, second order steerable filter with $\mu = 2$ and $\sigma = 4$ can be used to get better results than spatial domain approaches. But for salt and pepper noise, 1^{st} order steerable filter with $\mu = 0$ and $\sigma = 2$ can be used. Table. 7. gives the comparison between all the three approaches.

Table 7: Comparison of all the four approaches

Type of Approach	Noise Type	Parameter				
		CC	PSNR (dB)	MAE	SSIM	UIQI
Purely Classical Operators Approach	Salt & Pepper	0.96	18.86	9.12	0.97	0.98
Purely Mathematical Morphology		0.96	15.42	4.98	0.95	0.96
Classical Operator with Modified Morphology		0.97	25.82	3.38	0.94	0.99
Steerable Wavelet Transform with Modified Morphology Approach (StWTMMA)		0.9914	28.77	3.0110	0.99	0.99

Conclusion

The increasingly important role of medical imaging in the diagnosis and treatment of disease has opened an array of challenging problems centered on the computation of accurate geometric models of anatomic structures from medical images. With medical imaging playing an increasingly prominent role in the diagnosis and treatment of disease, the medical image analysis community has become preoccupied with the challenging problem of extracting—with the assistance of computers—clinically useful information about anatomic structures imaged through CT, MR, PET, and other modalities and through this paper we provide insights on various image reconstruction approaches. Accurate, repeatable, quantitative data must be efficiently extracted in order to support the spectrum of biomedical investigations and clinical activities from diagnosis, the comparison of these image reconstruction techniques have been discussed with the appropriate combination of edge detection technique and morphological operation. It includes the reconstruction of images namely through Classical operators, modified Morphological based approach, a combined process of classical operators and modified morphology and finally StWT with morphological approach. Steerable wavelet filter with mathematical morphology approach outperforms other mentioned approaches with respect to evaluation parameters. Our proposed method ascertains the detailed shape and organization of anatomic structures which enables a physician preoperatively to plan an optimal approach to prominent role in the diagnosis and treatment of diseases.

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