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IMAGE DE-NOISING USING MULTI-SCALE TRANSFORM BASED TECHNIQUE

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ABSTRACT

This paper aims in presenting a comparative analysis of Multi-scale Transform (MST) based de-noising techniques. MST based image de-noising techniques overcome the limitation of Fourier transform and spatial based de-nosing techniques, as it provides the local information of non stationary image in a more comprehensive manner. The MST techniques, namely, Discrete Wavelet Transform (DWT), Stationary Wavelet Transform (SWT) and Contour-let Transform (CT) have been selected for the de-nosing of standard and medical images. Further, the comparison of performance of different image de-noising technique has been carried out in terms of different noise variances, subjective and quantitative measures. Analysis of result shows that CT technique outperforms SWT and DWT techniques in terms of both qualitatively and quantitatively.

KEYWORDS: Spatial-scale, SWT, CT.

I. INTRODUCTION

Over the years, digital images play an indispensable role both in daily life applications such as, satellite television, computer tomography, geographical information systems and astronomy. Images acquired by image sensors are generally contaminated by noise. There are various factors responsible for affecting the quality of images such as, imperfect instruments, problems with the data acquisition process, and interfering natural phenomena. Thus, de-noising is often an indispensable step to be taken before the images data is analyzed. This can be achieved by applying an efficient de-noising technique to compensate for such data corruption [1-2].

Analysis of non-stationary image corrupted with noise, is a challenging job, as their properties change with time. Such 2D-signals cannot be analyzed well by pure spatial and frequency domain representations. The joint spatial-scale domain has been proven to be a effective tool for analyzing and detection of spatial-frequency characteristics of non-stationary images in a more descriptive manner. Spatial-scale domain-based image analysis methods such as, Non Sub-sampled Contourlet Transform(SWT)overcome the shortcomings of the traditional Fourier-based methods and Contourlet Transform (CT). However, it is found that CT suffers with the problem of shift invariance due to aliasing between sub-bands. Thus, to resolve the limitation of CT, SWT has been introduced [10-13]. SWT is the multi-direction and shift-invariant technique which is desirable in image analysis applications, such as, edge detection, contour characterization and image de-nosing

Thus, in this study, the comparison of performance of SWT and CT in terms of different noise variances, subjective and objective performances, is the central theme of this article

II. IMAGE DE-NOISING TECHNIQUES

Before discussing the image de-noising techniques, first of all, it would be appropriate to discuss in general different types of noises, such as Poisson noise, Speckle noise, Gaussian noise, Salt and Pepper noise. Here, in this study, Salt & Pepper and Gaussian noises have been selected for analysis and implementation purpose. Salt & pepper Noise also known as intensity spikes, arises due to errors in data transmission and impairments of pixel elements in the camera sensors, timing errors in the digitization process, or faulty memory locations, while Gaussian noise arises due to amplifiers or detectors and is uniformly distributed over the signal.

Further, image de-nosing techniques are broadly classified into Spatial and Transform domain filtering techniques. Here, in this study, emphasis has been given to transform domain filtering, as it is more suitable for

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information representation, interpretation and analysis. Multi-scale Transform based de-nosing techniques, such as SWT and CT has been selected for the implementation purposes. The detailed description of CT and SWT based de-noising techniques are outlined below:

Image De-nosing by Contourlet Transform (CT)
To overcome the shortcomings of wavelets and curvelets, [10] recently pioneered a new system of image representations named contourlets. Contourlet is a "true" two dimensional transform that can capture the intrinsic geometrical structures information of images, as well as, provides flexible number of directions. In other words, CT is driven based on curvelet concepts [12].

The Contourlet Transform (CT) proposed by [10] is a real two-dimensional transform, which is based on non-separable filter banks and provides an efficient directional multi-resolution image representation. The Contourlet Transform is also known as Pyramidal Directional Filter Bank (PDFB). Implementation of the CT is achieved via two major steps: The Laplacian Pyramid (LP) is first used to capture the point discontinuities (Starck *et al.*, 1998), and then followed by a Directional Filter Bank (DFB) to link point discontinuities into linear structures. The procedure for the de-noising of images by DWT has been explained in the section 2.2.

Image De-nosing by Stationary Wavelet Transform (SWT)
In order to reduce the frequency aliasing of contourlets, enhance directional selectivity and shift-invariance, [11] proposed Non Sub-sampled Contourlet Transform. This is based on the Non Sub-sampled Pyramid Filter Banks (NSPFB) and the Non Sub-sampled Directional Filter Banks (NSDFB) structure. The former provides multi-scale decomposition using two channel non sub-sampled 2-D filter banks, while the later provides directional decomposition i.e. it is used to split band pass sub-bands in each scale into different directions [9-12]. As a result, SWT is shift-invariant and leads to have better frequency

selectivity and regularity than CT. The scheme of SWT structure is shown in Fig. 1(a). The SWT structure classify 2-Dimensional frequency domain into wedge-shaped directional sub-band as shown in Fig. 1(b) The general methodology adopted for the de-noising of images using CT and SWT techniques can be summarized as follows (Figure. 2): Decompose the noisy image into a contourlet domain.Apply a specific thresholding rule to the coefficients in contourlet domainthe de-noised coefficients are subject to an inverse Contourlet Transform to construct the de-noised image.

III. EVALUATION CRITERIA
It is obvious that there is slight variation among de-noised results. Therefore, in order to assess the quality of the de-noised image other than simple visual inspection of the images, some quantitative assessment criteria have been defined. The quantitative indicators which have been used for this purpose are Peak Signal-to-Noise Ratio (PSNR), Root Mean Square Error (RMSE) [14-15] are outlined below.
RMSE

The RMSE is the most valuable performance evaluation criterion when original image is present. RMSE is a good measure of accuracy [14].

$$RMSE = \sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{\left(F(i,j) - R_o(i,j)\right)^2}{M \times N}} \quad \dots (4)$$

where, M, N indicate the size of the image is $M \times N$. $F(i,j)$, $R_o(i,j)$ indicate the gray value of the pixel which is in the row i and in the column j of the image. With smaller RMSE, there is less difference between them.
PSNR

The PSNR indicator measure the distortion of the de-noised image compared with the reference image. For less amount of image distortion, the value of PSNR should be large [15].

$$PSNR = 10log\left(\frac{255}{RMSE}\right)^2 \qquad \dots (5)$$

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IV. EVALUATION OF RESULTS AND DISCUSSION

The analysis of results of various image de-noising techniques belonging to multi-scale transform based domain, has been carried out using standard images. In order to analyze the performance and capability of the de-noising techniques used in this study, it is, necessary to perform the assessment of accuracy and review the results. Further, a thorough analysis of the performance of the image de-noising techniques has been carried out for dataset, both visually and quantitatively.

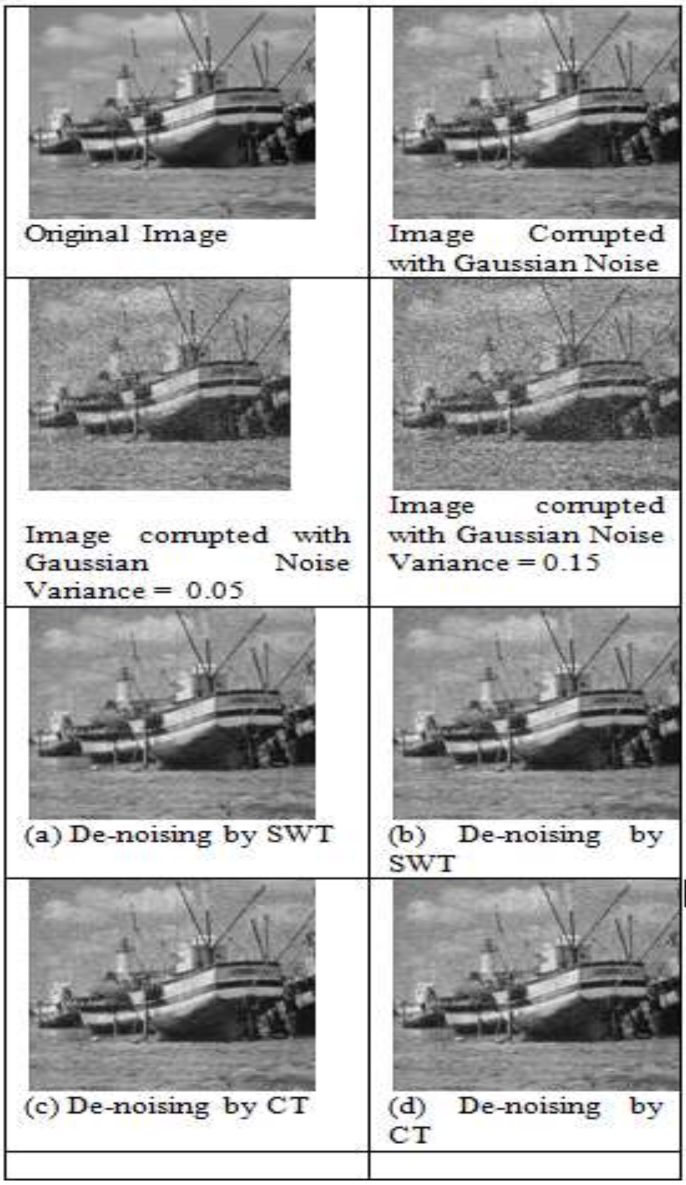
Visual (Qualitative) Analysis

The visual comparison of the de-noised images is carried out for the subjective (qualitative) assessment, since, it is a simple, yet one of the effective method for assessing advantages and disadvantages of any de-noising technique. Here, in this study for the simulation purpose, image of size 512×512 has been taken. The de-noised images are visually evaluated in terms of different parameters as listed below:

Shape of the object (SO)

Colour Radiometry (CR),

Edge Sharpening(ES)



Original Image | Image Corrupted with Gaussian Noise

Image corrupted with Gaussian Noise Variance = 0.05 | Image corrupted with Gaussian Noise Variance = 0.15

(a) De-noising by SWT | (b) De-noising by SWT

(c) De-noising by CT | (d) De-noising by CT

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a) Analysis of Boat Image Corrupted with Gaussian Noise for different noise variances

It is observed that the spatial information of all the de-noised images has improved when compared to the noisy image indicating that the small features that were not noticeable in the noisy image are now be distinguishable and identifiable. Fig. 3 shows the de-noised images generated by different de-nosing techniques for dataset DS corrupted with Gaussian noise, for different noise variances

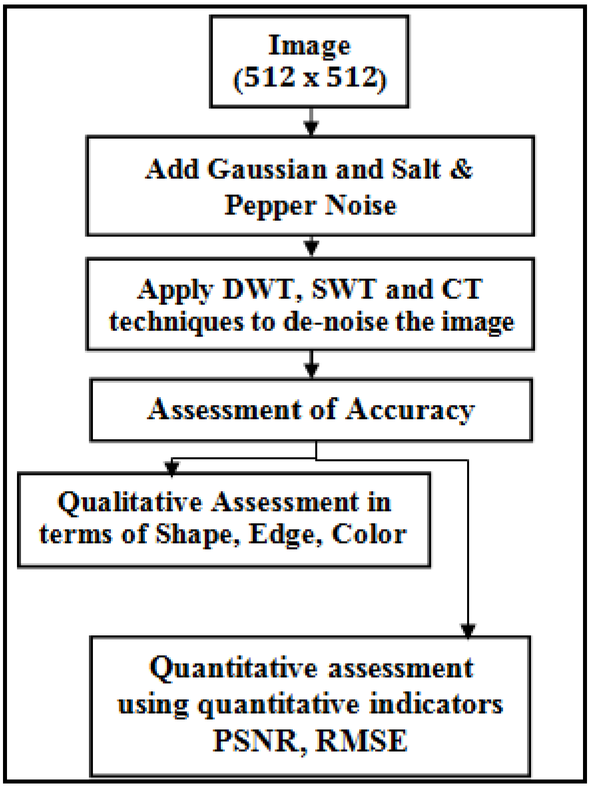

Figure 2 Methodology adopted for image de-noising by CT and SWT techniques

With reference to Fig. 3, it is observed that the de-noised images generated by SWT technique (Fig. 3 (d), (e) & (f)), for different noise variances exhibit good geometric details, when compared to the original image. This is followed by CT (Fig. 3(a), (b) & (c) technique. However, the intensity of colour in the de-noised images generated by SWT is slightly lighter, when compared to the original image, followed by CT based de-noising techniques. Further, the de-noised image generated by CT technique yields lower spatial quality, when compared to SWT based de-nosing technique. This is due to the sub-sampling process involved in CT technique, leading to the introduction of artifacts such as, existence of square blocks, making the linear features zigzag in the image, when images are zoomed in to see very small objects.

b) Analysis of Boat Image corrupted with Salt & Pepper Noise for different noise variances

With reference to Fig. 4, it is observed that the de-noised images generated by SWT (Fig. 4(d), (e) & (f)), and CT (Fig. 4(a), (b) & (c)), techniques exhibit good geometric details, when compared to the original image. However, the intensity of colour in the de-noised images generated by SWT technique are slightly lighter, when compared to the original image, followed by CT based de-noising technique. However, the de-noised image generated by CT technique yields lower spatial quality. This may be due to the limited directional selectivity i.e. horizontal, vertical and diagonal directions possess by the technique,

Which in turn deteriorate the geometry of the features in the de-noised images. The comparison results of different de-nosing techniques on the basis of visual object detection are listed in Table 2. Fig. 3 De-noised images generated by different de-nosing techniques for DS corrupted with Gaussian noise. Fig. 4 De-noised images generated by different de-nosing techniques for DS corrupted with Salt & Pepper noise. Table 2 Comparison of de-noising techniques on the basis of visual object detection

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Dataset	Type of Noise	Noise Variance	De-noising Technique					
			SWT			CT		
			Colour	Shape	Edge	Colour	Shape	Edge
DS	GAUSSIAN NOISE	0.05	G	A	A	G	G	G
		0.15	A	A	AA	A	AA	AA
	SALT & PEPPER NOISE	0.05	AA	A	A	AA	A	A
		0.15	A	A	AA	A	AA	AA

Table 2 shows that SWT based de-nosing technique yields the highest performance for different types of noises of different variances, when compared to CT based de-nosing technique. In other words, the background of the de-noised images with SWT appears smoother and removes the noise pretty well in the smooth regions, as well as, along the edges.

Thus, visually, it can be inferred that SWT de-nosing technique for different noise variances works well and yields the better performance in terms of preservation of spectral, spatial and structural similarity information, followed by CT based de-nosing technique.

Quantitative Analysis

The analysis and investigation of results obtained from different de-noising techniques have been carried out using quantitative indicators, as mentioned in the Table 3. It is observed that all types of noises causes degradation in the image quality which in turn results in loss of information. The de-noising of degraded image is performed using SWT and CT techniques. The de-noised image which will best preserve the spectral, spatial and structural similarity information of the original image is the one that has satisfied the following conditions (Table 3). Based on these parameters, the performance and accuracy of the de-noising techniques will be carried out. Table 3 The ideal and error value of different quantitative indicators

S. No.	Metric	Ideal Value	Error Value
1	Root Mean Square Error (RMSE)	0	> 0
2	Peak Signal-to-Noise Ratio (PSNR)	NA	> 1

Analysis based on RMSE

Generally, smaller RMSE value represents a greater accuracy measure in terms of image fidelity. The results of RMSE generated by different image de-nosing techniques for different datasets are tabulated in Table 4. Table 4 show the comparison of RMSE for Boat image for various noise variances.

Table 4 Comparison of RMSE for Boat Images corrupted with Gaussian and Salt & Pepper at different noise variances.

a) of DS-I dataset

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Dataset	Type of Noise	Noise Variance	RMSE	
			De-noising	
			CT	SWT
DS	GAUSSIAN NOISE	0.05	4.698	3.781
		0.15	5.739	4.932
	SALT & PEPPER NOISE	0.05	4.651	4.023
		0.10	6.472	5.374
		0.15	8.579	7.109

a) Analysis of DS-I dataset

Analysis of result shows that the Gaussian and Salt & Pepper noise affected images are effectively de-noised with SWT based de-nosing technique, as indicated by low RMSE value, when compared to CT based de-nosing technique. Amongst de-nosing techniques, CT based de-nosing technique exhibits low performance in terms of RMSE metric. This is due to the sub-sampling process involved in CT technique, leading to the introduction of artifacts such as, existence of square blocks, making the linear features zigzag in the image. Thus, it can be concluded that SWT based de-nosing technique yields the highest performance in terms of preservation of edge information, when compared to CT de-nosing technique. In other words, SWT technique is suitable for de-nosing of images corrupted with Gaussian and Salt & Pepper noise, when compared to CT based de-nosing technique. The RMSE values corresponding to different de-noising techniques has been plotted for DS, as shown in Fig. 5.

Analysis based on PSNR

Generally, higher values of PSNR reflect less amount of image distortion. The analysis of PSNR values for different de-nosing techniques are tabulated in Table 6.

Table 6 Comparison of PSNR for Boat Images corrupted with Gaussian, Salt & Pepper Noise for different noise variances

Dataset	Type of Noise	Noise Variance	PSNR Metric	
			De-noising	
			CT	SWT
DS	GAUSSIAN NOISE	0.05	27.358	28.122
		0.10	26.286	27.034
		0.15	24.710	25.798
	SALT & PEPPER NOISE	0.05	27.746	28.486
		0.10	26.980	27.019
		0.15	25.026	25.924

Analysis to Table 6, a high value for PSNR is observed for SWT based de-noising technique. In other words, SWT technique produces good quality de-noised image with high PSNR values in comparison to CT based de-nosing technique. Further, the de-noised image generated by CT technique yields low values of PSNR, amongst the techniques. This may be due to the sub-sampling process associated with the CT technique, leading to the introduction of artifacts in the resulting de-noised image. The different de-nosing techniques outputs corresponding to PSNR values are shown for Boat images in Fig 6.

A visual interpretation of PSNR values (Fig. 6) suggests that SWT based de-nosing technique using yields the highest performance in terms of preservation of spectral, spatial and structural similarity information, when compared to CT based de-nosing techniques.

Thus, it can be concluded that SWT technique is best in preserving the structural similarity, spatial and spectral information, when compared to CT based de-nosing technique. In other words, SWT based de-nosing technique emerged as one of the most effective de-nosing technique, followed by CT based de-nosing technique.

V. CONCLUSION

In this study, a comparative assessment of spatial-scale domain based de-noising techniques, has been carried out in terms of quantitative and qualitative measures. The image is corrupted with Gaussian and Salt & pepper noises for different noise variances. The result shows that de-noising of images by SWT technique provides the good result in terms of qualitatively and quantitatively parameters. Further, SWT technique exhibits good performance in terms of PSNR and RMSE. This may be due to the reason that SWT technique possess shift-invariant property, which avoids the introduction of artifacts in the resulting image.

Thus, it can be ascertained from this study that analysis and de-nosing of non-stationary image can be analyzed effectively by using shift-invariant SWT technique, when compared to shift-variance CT technique. The outcome of this study could therefore be utilized for further image processing tasks

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