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Comparison of Modern Denoising Algorithms

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Abstract— **Integrity of edge and detail information associated with the original images play an important role in applications. Images acquired from sensors, transmission errors and lossy compression contains noise and it is necessary to apply an efficient denoising technique to compensate for such data corruption. Image denoising still remains a challenge for researchers, since noise removal introduces artifacts and causes blurring in images. The median filter and specialized median filters are most popular for removing salt and pepper noise however when the noise level is high some details and edges of the original image are smeared by the filter. Decision based Tolerance based Selective Arithmetic Mean Filtering Technique (TSAMFT) algorithm works very well but if the noise density is high, then the image recovered using TSAMF is not good. Improved Tolerance based Selective Arithmetic Mean Filtering Technique (ITSAMFT) provides best results for removing salt and pepper noise even for higher noise density levels and it preserves the best edges and fine details. Comparison of these algorithms provides a suitable basis for separating noisy signal from the image signal. This paper presents a performance evaluation of Level-1 and Level-2 ITSAMFT, TSAMFT and Median Filtering algorithms in the detection and removal of Salt and Pepper Noise. The simulation results shows that the Level-2 ITSAMFT is superior over the Median Filter and TSAMFT in maintaining high peak signal to noise ratio (PSNR), correlation (COR) , image enhancement factor (IEF) and is more powerful algorithm in removing the heavy salt and pepper noise.**

Index Terms—**Improved Tolerance based Selective Arithmetic Mean Filtering Technique (ITSAMFT), Median Filter, Correlation, Image Enhancement Factor (IEF), Peak Signal to Noise Ratio.**

I. Introduction

Image processing is the system of mathematically transforming an image, generally to change some characteristics [1]. This includes many applications such as image enhancement, edge detection, object recognition and noise reduction. Providing digital images with good contrast and detail is required for many important areas such as vision, remote sensing, dynamic scene analysis, autonomous navigation, and biomedical image analysis [2].

Noise is considered to be undesired information that contaminates the image. Among various types of noises, salt and pepper noise typically causes error in pixel elements in the camera sensors, faulty memory locations, or timing errors in the digitization process. For the images corrupted by salt and pepper noise, the noisy pixels can take only the maximum and the minimum values in the dynamic range (0, 255) [3]**.** Thus, denoising is often necessary step to be carried out before the image data is analyzed. Several nonlinear filters have been proposed for restoration of images contaminated by salt and pepper noise. Among these standard median filter has been established as reliable method to remove the salt and pepper noise without damaging the edge details. However, the major drawback of standard Median Filter (MF) is that the filter is effective only at low noise densities [4]. The median filter was once the most popular nonlinear filter for removing impulse noise, because of its good denoising power [5] and computational efficiency [6]. But this removes some desirable details in the image [4], [7].

Different remedies of the median filter have been proposed, e.g. the Weighted Median Filter [8], Centre Weighted Median Filter [9], and Recursive Weighted Median Filter [10], Adaptive Recursive Weighted Median Filter [11] these filters first identify possible noisy pixels and then replace them by using the median filter or its variants, while leaving all other pixels unchanged. In these filters more weight is given to some pixels in the processing window. The main drawback of these filters is that the noisy pixels are replaced by some median value in their vicinity without taking into account local features such as the possible presence of edges. Hence details and edges are not recovered satisfactorily, especially when the noise level is high. Decision Based Median Filtering Algorithm [12], Robust Estimation Algorithm [13] was proposed to remove high density impulse noise. The corrupted pixels are replaced by median or the immediate neighbourhood pixel. At higher noise densities the median may also be a noisy pixel. However, when the noise level is over 50% some details and edges of the original image are smeared by the filter [14].

For the mean filtering techniques each pixel is considered to calculate the mean and also every pixel is replaced by that calculated mean. So affected pixels are considered to calculate the mean and unaffected pixels are also replaced by this calculated mean. This undesirable feature prevents the mean filtering techniques from providing higher PSNR or better quality image. Arithmetic Mean Filtering Technique can successfully remove Salt and Pepper noise from the distorted image but in this filter the filtered image suffers the blurring effect. To overcome this problem, some preventive measures must be ensured so that the affected pixels are not considered while calculating the mean and the unaffected pixels are not replaced at all.

In this paper, Improved Tolerance based Selective Arithmetic Mean filtering Technique (ITSAMFT) for both Level-1 and Level-2, Tolerance based Selective Arithmetic

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Mean filtering Technique (TSAMF) and Median Filtering algorithms comparative study is carried out at first.

This paper is organized in the following way. In section II Image Processing Terminologies; section III Median Filtering Algorithm; section IV Algorithm of TSAMFT; section V Level-1 and Level-2 ITSAMFT Algorithm; section VI presents the experimental results and discussions; finally in section VII Conclusions are made.

II. Image Processing Terminologyies

Some important features and terminologies that are related with these paper and image processing [15] are given below-

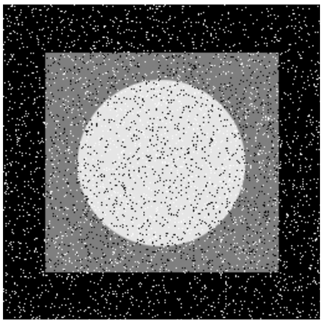
A. Probability Density Function (PDF):

The PDF of (Bipolar) Impulse noise is given by

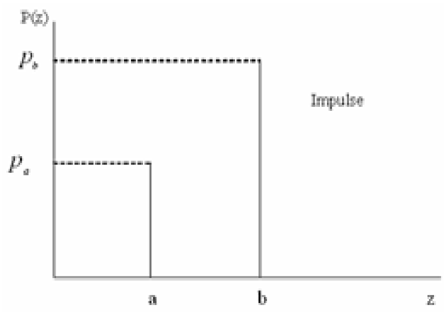
$$p(z) = \begin{cases} p_a & for\ z = a \\ p_b & for\ z = b \\ 0 & otherwise \end{cases}$$

If b>a, gray-level **b** appears as a light dot in the image. Conversely, level **a** appears like a dark dot.

If either $p_a\ or\ p_b$ is zero, the impulse noise is called unipolar.



a) Image affected by Salt and Pepper Noise



b) PDF of the Impulse noise

Fig.1 Image with Salt and Pepper Noise and PDF

If in any case, the probability is zero and especially if they are approximately equal, impulse noise values resemble Salt and Pepper granules randomly distributed over the image. For this reason, bipolar noise or impulse noise is also called Salt and Pepper (Shot and Spike) noise.

Noise impulses can be either negative or positive. Impulse noise generally is digitized as extreme (pure black and white) values in an image. Hence the assumption usually is that **a** and **b** are "Saturated values", in the sense that they are equal to the minimum and maximum allowed values in the digitized image. As a result, negative impulses appear as black (Pepper) points in an image. For the same reason positive impulses appear as white (Salt) noises. For an 8 bit image this means that a=0 (black) and b=255 (white).

B. Mean Square Error (MSE):

$$MSE = \frac{1}{MN} \sum_{ij} (y_{ij} - x_{ij})^2$$

C. Mean Absolute Error (MAE):

$$MAE = \frac{1}{MN} \sum_{ij} | y_{ij} - x_{ij} |$$

D. Peak Signal to Noise Ratio (PSNR):

$$PSNR = 10\, log_{10} [\frac{255^2}{MSE}]$$

E. Correlation (COR):

$$COR = \frac{\sum_{ij}^{MN} (y_{ij} - \mu_y)(x_{ij} - \mu_x)}{\sqrt{\sum_{ij}^{MN} (y_{ij} - \mu_y)^2 \sum_{ij}^{MN} (x_{ij} - \mu_x)^2}}$$

F. Image Enhancement Factor (IEF):

$$IEF = \frac{\sum_i \sum_j (\eta_{ij} - x_{ij})^2}{\sqrt{\sum_i \sum_j (y_{ij} - x_{ij})^2}}$$

Where y_{ij}, x_{ij} and η_{ij} represents the pixel values of the restored image, original image and the noisy image respectively. $M \times N$ *is* the size of the image. μ_x and μ_y represent the mean of the original and restored images [16-17].

III. Median Filtering Algorithm:

The basic principle of median filtering algorithm is to use the median value of all the pixel values in the filtering neighbourhood of a certain point in part of an image, which is the value of the midpoint position item of all the pixel values sorted ascending or descending, to replace the value of the particular point. The method to calculate the median value can be described as following:

Assume that $x_1, x_2, x_3, \ldots, x_n$ is a set of one dimensional point value, after sorted in ascending it becomes:

$$x_{i1} \le x_{i2} \le x_{i3} \ldots \le x_{in} \quad (1)$$

Or after sorted in descending it becomes:

$$X_{i1} \ge X_{i2} \ge X_{i3} \ldots \ge X_{in} \quad (2)$$

Then its median value is:

$$x_{median} = Med\{x_i\} = \begin{cases} x_{i(n+1)/2}, & n\%2 = 1 \\ \frac{1}{2}[x_{i(n/2)} + x_{i(n/2+1)}], & n\%2 = 0 \end{cases} \quad (3)$$

In application, n is often chosen to be an odd number and thus we have

$$x_{median} = Med\{x_i\} = x_{i(n+1)/2} \quad (4)$$

In the case of two dimensions, assume that the set In,n is a two-dimension matrix with the items of a neighborhood of the midpoint position *n*/2,*n*/2 *I* of the image, with the radius as *n* / 2 , after sorting 'In,n is obtained, and its median value is:

$$I_{median} = Med(I_{n,n}) = I'_{n/2,n/2} \quad (5)$$

In median filtering algorithm, all pixels in the neighbourhood of the destination pixel must be sorted as a ascending or descending sequence, and then the midpoint position value is just its median value. When the radius of the window becomes comparatively larger, the image processing speed will be greatly slowed down. Therefore, median filtering algorithm can only be used in the processing of small size filtering window or in the cases where high real-time performance is not required [11] [18-20].

IV. ALGORITHM OF TSAMFT:

The Tolerance based Selective Arithmetic Mean Filtering Algorithm has been proposed by Shahriar Kaisar, Md.Sakib Rijwan et al. [15] and the steps of the algorithm is given below.

For each pixel *p* in the image;

1. Take a sub window of size $m \times n$ *around* that pixel.
2. Find out the number of pixels in the sub window by ignoring the pixels with the maximum (255) and minimum value (0).
3. If the number of pixels obtained after ignoring pixels of minimum and maximum value is greater than or equal to 1/3 rd of $m \times n$ then calculate the Arithmetic Mean Value (AM) with the selected pixels. Otherwise, calculate Arithmetic Mean Value for all the pixels in the $m \times n$ sub window.
4. Calculate the Difference between Arithmetic Mean and the intensity of *p*.
   a. If Difference ≥ Tolerance then replace Intensity of *p* by AM
   b. Otherwise leave the pixel value unchanged.

When noise density is high, then the image recovered by using TSAMF algorithm is not good.

V. LEVEL-1 AND LEVEL-2 ITSAMFT ALGORITHM:

The TSAMFT algorithm works very well for noise densities up to 50-60 [15]. But if the noise density is very high, then the image recovered using TSAMF is not good. The main reason is that in TSAMF, we find whether the number of information pixels within a mask is greater than three or not. However, when noise density is high, say more than 80, then it is highly unlikely that there might be more than 3 number of information pixels in every 3x3 mask. Thus, for better performance some changes to the basic algorithm is suggested and the same is given below.

1. Store all pixels of noisy image in a temporary matrix.
2. For every mask of size 3x3, find if the number of information pixel is greater than or equal to n_1 (say 1 and assume tolerance to be 0 as noise density is very high). If so, do the following steps.
   i). Calculate the Arithmetic Mean Value (AM) for the information pixels.
   ii). Calculate the Difference between Arithmetic Mean and pixel *p* in the mask.
   a) If Difference ≥ Tolerance then replace Intensity of *p* by AM
   b) Otherwise leave the pixel value unchanged.
3. If not, then extend the mask around the pixel of interest to size 5·5. If all the pixels in that mask are non informative then calculate the arithmetic mean of all pixels in that mask then go to step v. Otherwise follow the steps given below.
   i). Choose the very first information pixel in that mask and set the appropriate range.
   ii). Find the number of pixels within that range and calculate the sum of those pixels.
   iii). Find the number of pixels out of range and calculate the sum of those pixels.
   iv). If the numbers of pixels within that range greater than or equal to number of pixels out of range, then find the AM of pixels within the range. Otherwise, find the arithmetic mean of pixels out of range.
   v). Then, calculate the difference between the pixel of interest and Arithmetic mean.
4. If the difference is greater than tolerance then replace that pixel by arithmetic mean, otherwise that pixel information remains unchanged.
5. Once the mask operation is carried out for the entire image. For Level-2 ITSAMFT repeat steps 2 through 4 for the temporary image [16].

Finally compute the MSE, MAE, PSNR, Correlation and IEF to analyze the performance of Level-1 and Level-2 ITSAMFT, TSAMFT and median filtering denoising algorithms.

VI. EXPERIMENTAL RESULTS AND DISCUSSION

The simulation has been carried for Level-1 and Level-2 ITSAMFT, TSAMFT and Median Filtering algorithms in MATLAB R2011b using 512X512, 8-bits/pixel standard Lena image. The performance analysis of algorithms is tested for various levels of noise corruption and compared.

Fig.2 Lena Image

Each time the test image is corrupted by different salt and pepper noise ranging from 10 to 90 with an increment of 10 will be applied to the various filters. However Median Filter works better for up to noise density level 30 and TSAMFT works better for up to noise density level 50, performance analysis for noise density level above 50 is concentrated more with tolerance value as Zero, since this value result in better denoising performance[15].

The results are shown in Table I-X for different high noise density levels varied from 50 to 95 with increments of 10 up to noise density level 90 and above 90 with increments of 1.

TABLE I: FOR LENA IMAGE AT NOISE DENSITY LEVEL 50

	MSE	MAE	PSNR	COR	IEF
MEDIAN FILTER	2047.05	-4.613	15.019	0.592	4.92
TSAMFT	377.047	-3.54	22.367	0.874	26.715
ITSAMFT LEVEL-1	137.96	0.544	26.734	0.950	73.015
ITSAMFT LEVEL-2	127.792	0.544	27.077	0.954	78.822

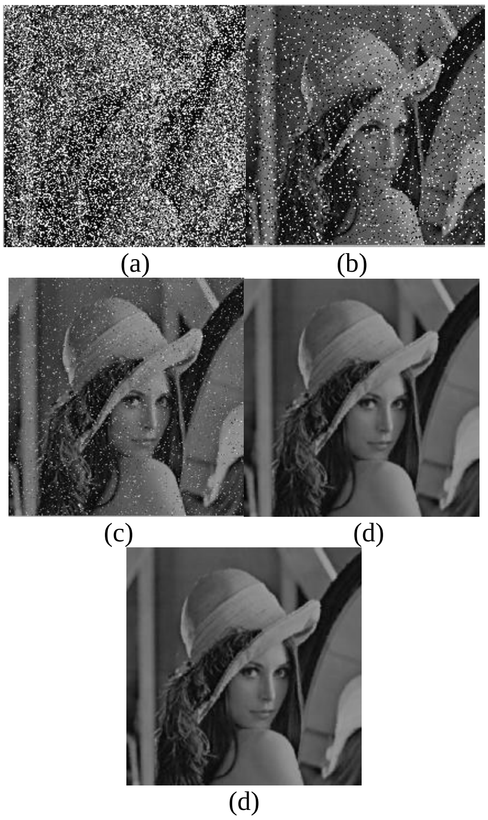


Fig.3 (a) Noisy image (σ =50) (b) Median filter (c) TSAMFT (d) Level-1 ITSAMFT (e) Level-2 ITSAMFT

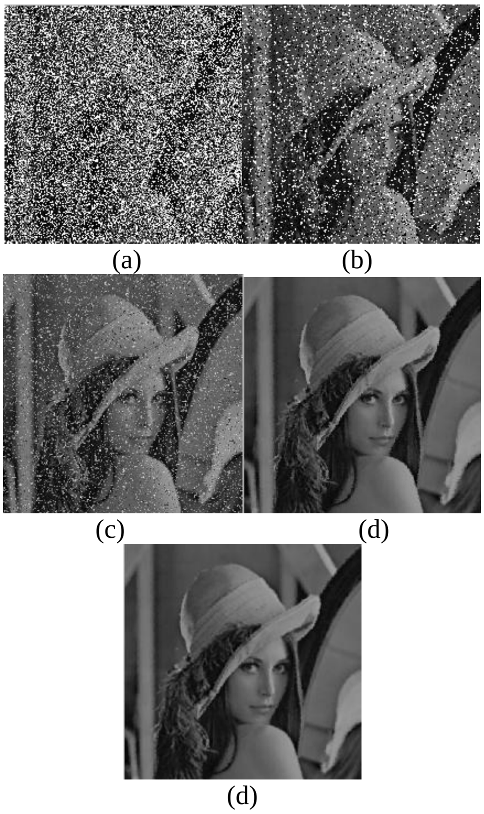


Fig.4 (a) Noisy image (σ =60) (b) Median filter (c) TSAMFT (d) Level-1 ITSAMFT (e) Level-2 ITSAMFT

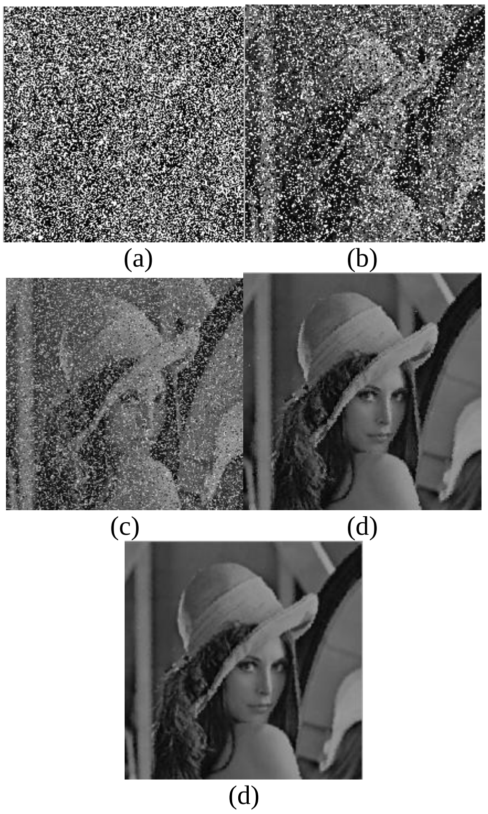


Fig.5 (a) Noisy image (σ =70) (b) Median filter (c) TSAMFT (d) Level-1 ITSAMFT (e) Level-2 ITSAMFT

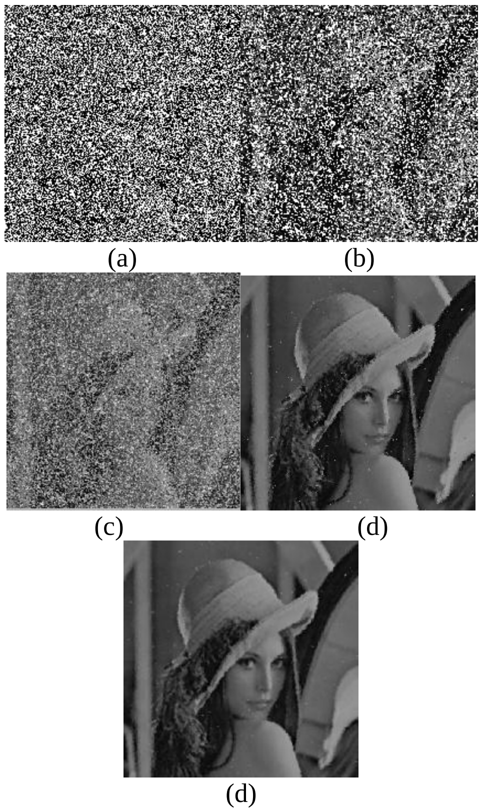


Fig.6 (a) Noisy image (σ =80) (b) Median filter (c) TSAMFT (d) Level-1 ITSAMFT (e) Level-2 ITSAMFT

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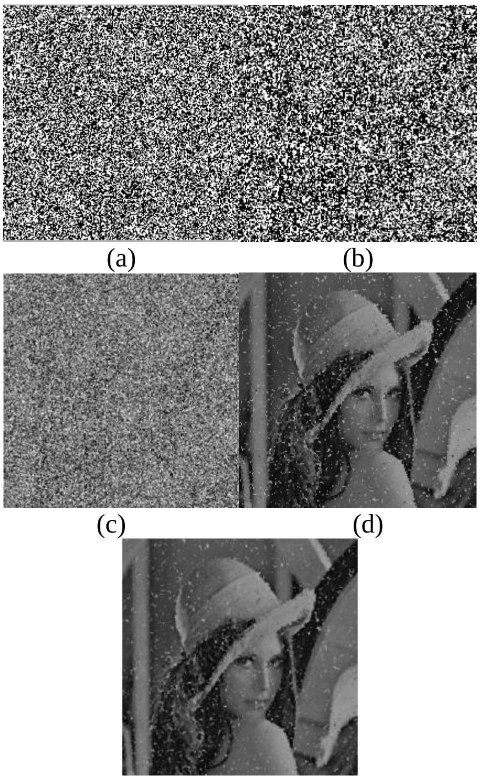

Fig.7 (a) Noisy image (σ =90) (b) Median filter (c) TSAMFT (d) Level-1 ITSAMFT (e) Level-2 ITSAMFT

TABLE II: For Lena Image at Noise Density Level 60

	MSE	MAE	PSNR	COR	IEF
MEDIAN FILTER	4015.84	-9.245	12.093	0.428	2.996
TSAMFT	965.01	-9.343	18.285	0.718	12.46
ITSAMFT LEVEL-1	135.68	0.520	26.806	0.951	88.66
ITSAMFT LEVEL-2	122.33	0.520	27.255	0.956	98.335

TABLE III: For Lena Image at Noise Density Level 70

	MSE	MAE	PSNR	COR	IEF
MEDIAN FILTER	7027.06	-17.26	9.663	0.280	2.008
TSAMFT	1971.2	-19.13	15.183	0.516	7.16
ITSAMFT LEVEL-1	135.113	0.533	26.824	0.951	104.47
ITSAMFT LEVEL-2	117.79	0.533	27.42	0.957	119.83

TABLE IV: For Lena Image at Noise Density Level 80

	MSE	MAE	PSNR	COR	IEF
MEDIAN FILTER	10808.3	-26.39	7.793	0.168	1.493
TSAMFT	3318.98	-31.69	12.921	0.301	4.862
ITSAMFT LEVEL-1	157.876	0.293	26.148	0.943	102.21
ITSAMFT LEVEL-2	122.36	0.293	27.25	0.955	131.89

TABLE V: For Lena Image at Noise Density Level 90

	MSE	MAE	PSNR	COR	IEF
MEDIAN FILTER	15276	-37.48	6.290	0.074	1.186
TSAMFT	4657.74	-42.9	11.449	0.114	3.891
ITSAMFT LEVEL-1	477.48	-2.93	21.34	0.840	37.96
ITSAMFT LEVEL-2	274.14	-2.93	23.75	0.902	66.11

TABLE VI: For Lena Image at Noise Density Level 91

	MSE	MAE	PSNR	COR	IEF
MEDIAN FILTER	15673.6	-37.71	6.18	0.062	1.16
TSAMFT	4754.75	-43.57	11.359	0.092	3.856
ITSAMFT LEVEL-1	581.21	-4.069	20.49	0.809	31.547
ITSAMFT LEVEL-2	340.52	-4.070	22.81	0.879	53.85

TABLE VII: For Lena Image at Noise Density Level 92

	MSE	MAE	PSNR	COR	IEF
MEDIAN FILTER	16188.4	-39.34	6.038	0.058	1.144
TSAMFT	4867.58	-44.46	11.258	0.082	3.805
ITSAMFT LEVEL-1	735.20	-5.76	19.467	0.768	25.198
ITSAMFT LEVEL-2	441.0	-5.764	21.686	0.849	42.008

TABLE VIII: For Lena Image at Noise Density Level 93

	MSE	MAE	PSNR	COR	IEF
MEDIAN FILTER	16581.8	-39.92	5.934	0.054	1.128
TSAMFT	4962.22	-45.04	11.174	0.072	3.769
ITSAMFT LEVEL-1	902.10	-7.44	18.578	0.723	20.74
ITSAMFT LEVEL-2	555.153	-7.44	20.687	0.814	33.7

TABLE IX: For Lena Image at Noise Density Level 94

	MSE	MAE	PSNR	COR	IEF
MEDIAN FILTER	17073	-40.99	5.81	0.044	1.11
TSAMFT	5052.33	-45.64	11.096	0.058	3.74
ITSAMFT LEVEL-1	1094.5	-9.62	17.74	0.677	17.27
ITSAMFT LEVEL-2	700.757	-9.619	19.68	0.772	26.97

TABLE X: For Lena Image at Noise Density Level 95

	MSE	MAE	PSNR	COR	IEF
MEDIAN FILTER	17501.7	-43.15	5.700	0.048	1.091
TSAMFT	5137.42	-46.89	11.023	0.063	3.718
ITSAMFT LEVEL-1	1490.02	-12.04	16.399	0.577	12.818
ITSAMFT LEVEL-2	1028.13	-12.05	18.010	0.668	18.57

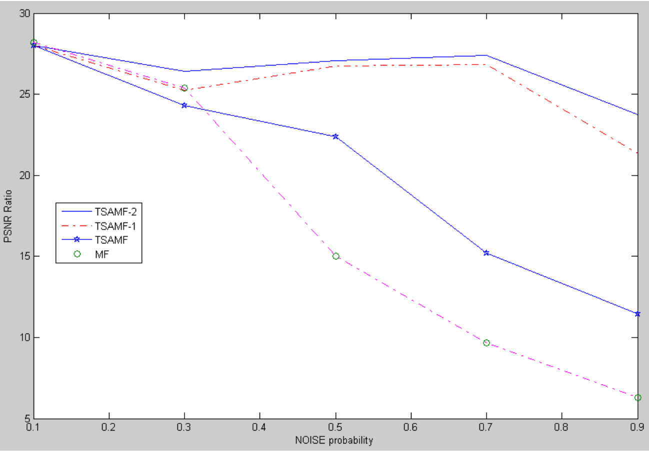

Fig.8 Comparison graph of PSNR at different Noise Densities.

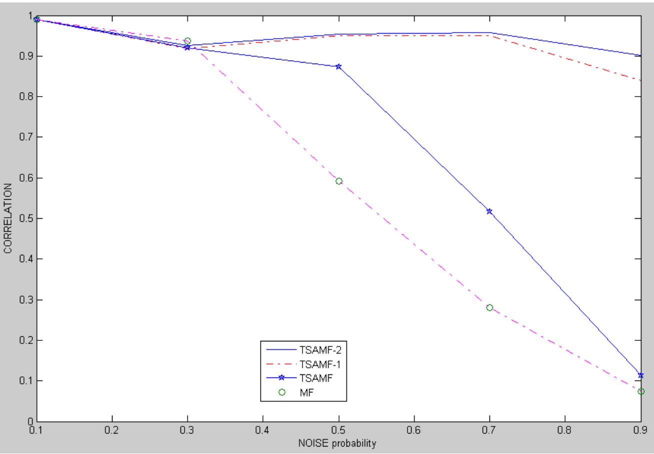

Fig.9 Comparison graph of Correlation at different Noise Densities.

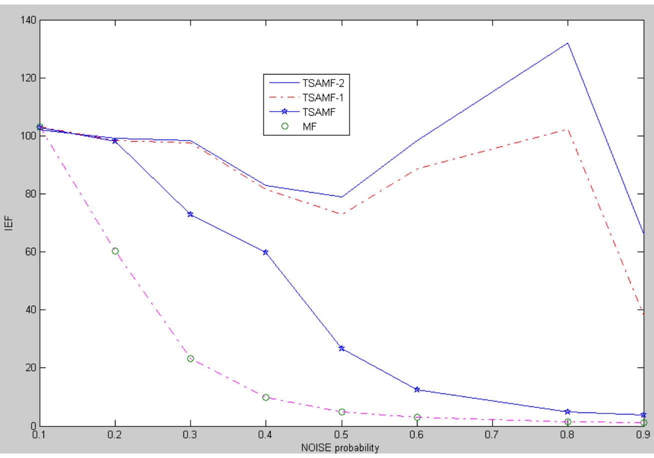

Fig.10 Comparison graph of Image Enhancement Factor at different Noise Densities.

It is interested to note that the Simulation Results obtained for Level-2 ITSAMFT for higher Noise density (especially for greater than 90) is higher than that of Level-1 ITSAMFT, Median Filter and TSAMFT.

VII. Conclusion

Exhaustive experimental analysis in MATLAB R2011B for Level-1 and Level-2 ITSAMFT, TSAMFT and median filter at different noise densities shown that if the noise density is high (> 50) then details and edges of the original image are smeared by the TSAMFT and Median Filtering algorithms. Comparing quantitative measures for higher density salt and pepper noise added Lena image, the highest quality image, highest PSNR (dB) and higher IEF is obtained for Level-2 ITSAMFT. Moreover, it is interested to note that the PSNR, COR, IEF obtained for Level-2 ITSAMFT for higher Noise density (especially for > 90) is higher than for Level-1 ITSAMFT, TSAMFT and median filter. At a very high noise density Level-2 ITSAMFT gives better performance than the other existing filters, being consistently effective in noise suppression and detail preservation for various images Finally it is recommended that for images corrupted with higher noise densities Second Level of ITSAMFT is used to filer the images to improve the future experiments over image processing and performance analysis.

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