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AN UNSYMMETRICAL TRIMMED MEDIAN USING DISTANCE MEASURE AND MIDPOINT FILTER FOR THE REMOVAL OF SALT AND PEPPER NOISE

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Abstract

Image denoising was a preprocessing step in image processing used to remove the noise while retaining as much as possible the important features. The fluctuations in the pixel value caused by the unwanted disturbance were known as noise. Hence, noise reduction techniques have to be used to improve the quality of the image. This article reports on the results of a research algorithm that uses median, midpoint and mean for the reduction of salt and pepper noise from the grayscale images. The median value was calculated for the uncorrupted pixels which are having the minimum distance. The proposed algorithm was tested using Euclidean distance, D4 distance and D8 distance as the distance measures. In this approach, the 3x3 window was selected as initial window size and the window size was made adaptive based on the noise density. The proposed filter was experimented using standard Lena image, 200 iris images, sample Plant images, sample MRI images and sample CT images in JPG/JPEG (Joint Photographic Experts Group) format. These grayscale images used as a test image were induced with salt and pepper noise density ranging from 10% to 90%. The simulated results proved that the proposed approach performs better than the MDBUTMF, AMMF, MNF, IUTMMF, and HYBRID filtering algorithms reported in the literature in terms of PSNR, IEF and MSE.

Keywords:

Unsymmetrical, Trimmed, Median, Distance Measure, Midpoint, Salt and Pepper Noise

1. INTRODUCTION

Image De-noising was the key research fields in Image Processing. Feature Detection, Medical Image Processing, Remote Sensing and Machine vision was the applications in which noise reduction was used to improve clarity of the image and visual perception of human beings. They modify images to improve them (enhancement, restoration) [1]. Transmission errors, malfunctioning pixel elements in the camera sensors and faulty memory locations are the general cause of impulse noise in the images. Noises have been introduced during acquisition of medical images like MRI, CT scan, X-ray etc. Random values impulse noise and Salt and pepper impulse noise are the two types of impulse noise.

The Salt and Pepper pixels (SP) noise was also called as fixed valued impulse noise. In this type of noise, the image was randomly corrupted by either 0 or 255. Random Valued Impulse noise (RVIN) was also known as variable type impulse noise. RVIN replaces some pixels with random values in the range lies between 0 and 255 in the grayscale image. The noise degrades the image quality and causes great loss of information details. Hence, these noises have to be suppressed in the images before some subsequent processing, such as edge detection/extraction, images segmentation and object recognition [2]. To enhance the image qualities the noises from the images should be removed without loss of any image information.

2. EXISTING NOISE REMOVAL TECHNIQUES

Standard Median filter was the most common filter used to remove the fixed valued impulse noise by preserving the edges. It works well only for very low noise densities. When the window size was increased, then the denoised image loses lines and some sharp corners [3]. This filter operates on all pixels whether it is corrupted or uncorrupted.

Adaptive median filter (AMF) works well at low and medium noise density but blur the image for high noise density due to increasing window size [4]. The performance of the Decision Based Algorithm (DBA) was better than median filters and its enhancements [5], [6]. The noisy pixels was first detected and then replaced by the median of neighborhood pixels in the window. DBA takes both the corrupted and uncorrupted pixels while calculating the median which was the drawback of using this technique.

Modified decision based Unsymmetrical Trimmed Median Filter (MDBUTMF) was proposed [7]. In this algorithm, a centre noisy pixel value was replaced by the median value of uncorrupted pixels in the selected window. If all the pixels where 0's and 255's then it have been replaced by the mean value of all the pixels in the selected window.

Adaptive Median based modified mean filter (AMMF) [8] uses two stages for the removal of salt and pepper noise. In the first stage, the noisy image is processed by the adaptive median filter. In this stage minimum, maximum and median valued was calculated. If the median value lies between the minimum and maximum value then median was considered as the noise free. This median value replaces the centre processing pixel. If the above condition was false then the window size was increased and the process was repeated. In the second stage, a 2×2 window was considered. The corrupted centre pixel was replaced by the mean value of the uncorrupted pixels in that window.

The Modified nonlinear (MNF) [9] filter was proposed for removal of salt and pepper noise from the grayscale image. The central processing noisy pixel was replaced by trimmed median value in the selected window. When all the pixel values are 0's and 255's then the window size was increased and the trimmed mean value of uncorrupted pixels replaced the noisy pixel. This algorithm tested using the standard Lena image.

An Iterative unsymmetrical trimmed midpoint-median filter (IUTMMF) was proposed for the removal of high density salt and pepper noise. This algorithm works using two phases. In the first phase, if the centre processing pixel was noisy pixel then neighboring pixels which are uncorrupted are stored in the 1-D array. If the count of noise free pixel in the 1-D array was greater than 4 then the median of 1-D array replaces the processing pixel. If the count was less than 5 then processing pixel was replaced by midpoint mean value which was calculated by dividing the sum of maximum value and the minimum value of the array by 2. In the second phase, if the processing pixel is noisy and if all the neighboring pixels are not corrupted then the median of uncorrupted pixels replaces the processing pixel. If all the neighboring pixels are corrupted then mean of the selected window replaces the centre pixel [10].

A hybrid filter (HYBRID) was proposed in which noise density was calculated. If the noise density is 60% then High density Bilateral filter (HDBF) with the window size 3×3 was applied. If the noise density lies between 60% and 80% the window size increased to 5×5 and MDBUTF filter was used. If the noise density greater than 90% then window size was increased to 7×7 and MDBUTF filter was applied [11]. Of the above techniques, certain estimates fail to detect edges, lines, even noises at high noise densities. Hence researcher's concentrates on finding a suitable algorithm that eliminates impulse noise and preserves edges for high noise density. When the noise density increases to high density the existing algorithms lead to loss of the image details and blurring of the image. To overcome these drawbacks, a new algorithm has been proposed in this article.

3. PROPOSED ALGORITHM

The proposed algorithm processes the corrupted images by first detecting the impulse noise and the correcting the noisy pixel. This algorithm was tested using three commonly used distance measure such as Euclidean distance, D4 distance and D8 distance measures [12].

3.1 DISTANCE MEASURES

3.1.1 Euclidean Distance:

Euclidean distance defined as the straight line connecting two point's distance [13]. The Euclidean distance between the pixels $q(s,t)$and $p(x,y)$ can be defined in the Eq.(1),

$$De(p,q)=\sqrt{\left((x-s)^2+(y-t)^2\right)} \tag{1}$$

3.1.2 D4 Distance:

The $D4$ distance (also called the city block distance/Manhattan distance) between p and q is given by,

$$D4(p,q)=|x-s|+|y-t| \tag{2}$$

3.1.3 D8 Distance:

The $D8$ distance (also called the chessboard distance/Chebyshev distance) between p and q is given by,

$$D8(p,q)=\max\left(|x-s|,|y-t|\right) \tag{3}$$

By trial and error a window size of 13×13 has been chosen, beyond which there was no improvement in PSNR. The proposed algorithm first checks whether the processing pixel was noisy or noise free. If the processing pixel lies between 0 and 255 gray level values then it was the noise free pixel and left unchanged. If the processing pixel was having intensity value either 0 or 255 then it was a noisy pixel. This noisy pixel was processed by the proposed algorithm. The steps of the algorithm are as follows.

3.2 ALGORITHM

Step 1: Read noisy image.

Step 2: Initialize the window size W = 3(maximum window size W_{max} = 13). Assume that the centre element as processing Pixel P_{ij}.

Step 3: If $0 < P_{ij} < 255$ then P_{ij} as an uncorrupted pixel and its value is left unchanged.

Step 4: If $P_{ij} = 0$ or $P_{ij} = 255$ then P_{ij} is corrupted pixel then two cases are possible as given in case 1 and case 2.

Case 1: If the selected window contains not all elements as 0's and 255 then count the uncorrupted pixels in the window.

Case 1.1: If ($count$>3/4(W×W)) or ($count$>(1/2(W×W))) and W=3) then find the median of uncorrupted pixels which are having minimum distance in that window. Replace P_{ij} with this median value.

Case 1.2: If ($count$< 3/4(W×W)) then find the average of minimum and maximum intensity of uncorrupted pixels in the window. Replace P_{ij} with this average value.

Case 2: If the selected window contains all elements as 0's and 255's then two cases are possible.

Case 2.1: If $W<W_{max}$ then increase the window size W by 2 and go to step 4.

Case 2.2: If $W=W_{max}$ then replace P_{ij} with the mean of the elements in that window.

Step 5: Repeat steps 2 to 4 until all the pixels in the entire image are processed.

4. IMPLEMENTATION OF PROPOSED ALGORITHM

Implementation of the suggested algorithm was carried out in Matlab. The other existing algorithms considered in this study are also implemented in Matlab. The algorithm was tested with the standard Lena image of size 512×512, 200 iris images of size 640×480 from CASIA-Irisv3 database, sample Plant images of size 320×212, sample medical images like MRI standard knee image of 256×256 size and CT Dental scan image with 512×512 size taken from DICOM sample dataset are used as test images. The proposed technique was analyzed based on different noise density of Salt and Pepper noise in gray-scale JPEG images. The original image was induced with salt and pepper noise to produce a noisy image. The noisy image was taken as an input to the proposed noise removal filter. The output of the filter gives a denoised image. The Fig.1 shows the De-noising method using Lena image. The flow chart for the proposed filter is shown in the Fig.2.

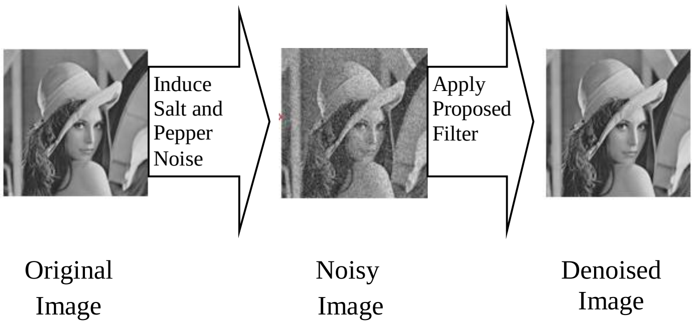


Fig.1. Shows the De-noising method using Lena image

5. SIMULATION RESULTS

The performance of the proposed algorithm was tested with the noise density varying from 10% to 90% in images and compared with MDBUTMF, AMMF, MNF, IUTMMF and HYBRID filters. The performance of the noise reduction techniques are commonly measured in terms of Peak Signal to Noise Ratio (*PSNR*) [14]-[18], Mean Square Error (*MSE*) [19] and Image Enhancement Factor (*IEF*) [20],[21].

5.1 PEAK SIGNAL TO NOISE RATIO (PSNR)

A standard mathematical model was used by the *PSNR* analysis to measure an objective difference between two images. This estimates the quality of a reconstructed image with respect to an original image. If the reconstructed image has higher *PSNR* value then it was judged better. Given that original image and the reconstructed image should be of the same size. The *PSNR* was defined in dB. The *PSNR* was defined in the Eq.(4).

$$PSNR = 10\log_{10}\frac{255^2}{MSE} \tag{4}$$

5.2 MEAN SQUARE ERROR (MSE)

Mean Square Error (*MSE*) was the simplest of image quality measurement. Let the noisy image be $g(x,y)$, filtered image be $\hat{f}(x,y)$ and original noise-free image be $f(x,y)$. The discrete spatial coordinates of the digital images are represented by x and y. Let $M \times N$ pixels be the size of the image. The *MSE* was defined in the Eq.(5).

$$MSE = \frac{1}{M \times N}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left[f(x,y) - \hat{f}(x,y)\right]^2 \tag{5}$$

5.3 IMAGE ENHANCEMENT FACTOR (IEF)

The performance of the filter has been studied by computing Image enhancement factor (*IEF*). It was the ratio of mean square error before filtering to the mean square error after filtering. IEF was defined in the Eq.(6). In this Y represents the original image, $\hat{Y}$ denotes the denoised image and η represents the noisy image.

$$IEF = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\eta(i,j) - Y(i,j)\right)^2}{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\hat{Y}(i,j) - Y(i,j)\right)^2} \tag{6}$$

The original Lena image and noisy image are shown in the Fig.3. The original iris image and noisy image are shown in the Fig.4. The Fig.5 displays the MRI image, and its noisy image. The CT image and its noisy image are shown in Fig.6. The plant image taken using camera is displayed with its noisy image in Fig.7. The results of the experiment with 90% noise density in Lena image, Iris image, MRI image, CT image and plant image are shown in the Fig.8, Fig.9, Fig.10, Fig.11 and Fig.12, respectively. The *PSNR*, *MSE* and *IEF* values of the proposed algorithm are compared against the existing filters for standard Lena image and average *PSNR*, average *MSE* and average *IEF* values for 200 iris images with various noise densities from 10% to 90% are shown in the Table.1 and Table.3. The Table.4, Table.5 and Table.6 shows the comparison of the filter for MRI images, CT images and Plant images.

A plot of *PSNR* against noise densities for Lena image and iris images are shown in the Fig.13 and Fig.14 respectively. The graphs in the Fig.13 and Fig.14 shows that the PSNR for the proposed algorithm using Euclidean distance and *D*4 distance was relatively better for low and high noise density levels. The computational time of the proposed and existing algorithms is shown in the Table.2.

The proposed algorithm gives a better PSNR and IEF value for both low and high salt and pepper noise levels than the other existing filters [7-11]. The result shows that the performance of the proposed algorithm is relatively better than the existing filters proposed in the literature on Lena image, 200 Iris images, sample MRI images, sample CT images and sample Plant images tested noise density from 10% to 90%.

6. CONCLUSION

In this article an attempt has been made to propose novelty in developing a filter to reduce Salt and Pepper noise levels. The filter has been tested with images from standard database and its performance has been measured using PSNR, MSE and IEF and compared with the article reported in the literature. Also, the various distance measure such as Euclidean distance, D4 distance and D8 distance measures has been considered. Their performance has been indicated in the above mentioned table. This provides evidence that Euclidean distance and D4 distance has given relatively better performance than D8 distance measure. The above result reveals that the proposed filter performs relatively better with respect to the modality of images like Iris images, Lena image, medical images like MRI and CT scan grayscale images. The proposed filter will be helpful in removing the noises and enhancing the images of above specified modality. Future work will concentrate on suggesting noise reduction methods for noises like speckle and Gaussian noise to improve the quality of the images. The algorithm suggested will also be fine-tuned to minimize the execution time.

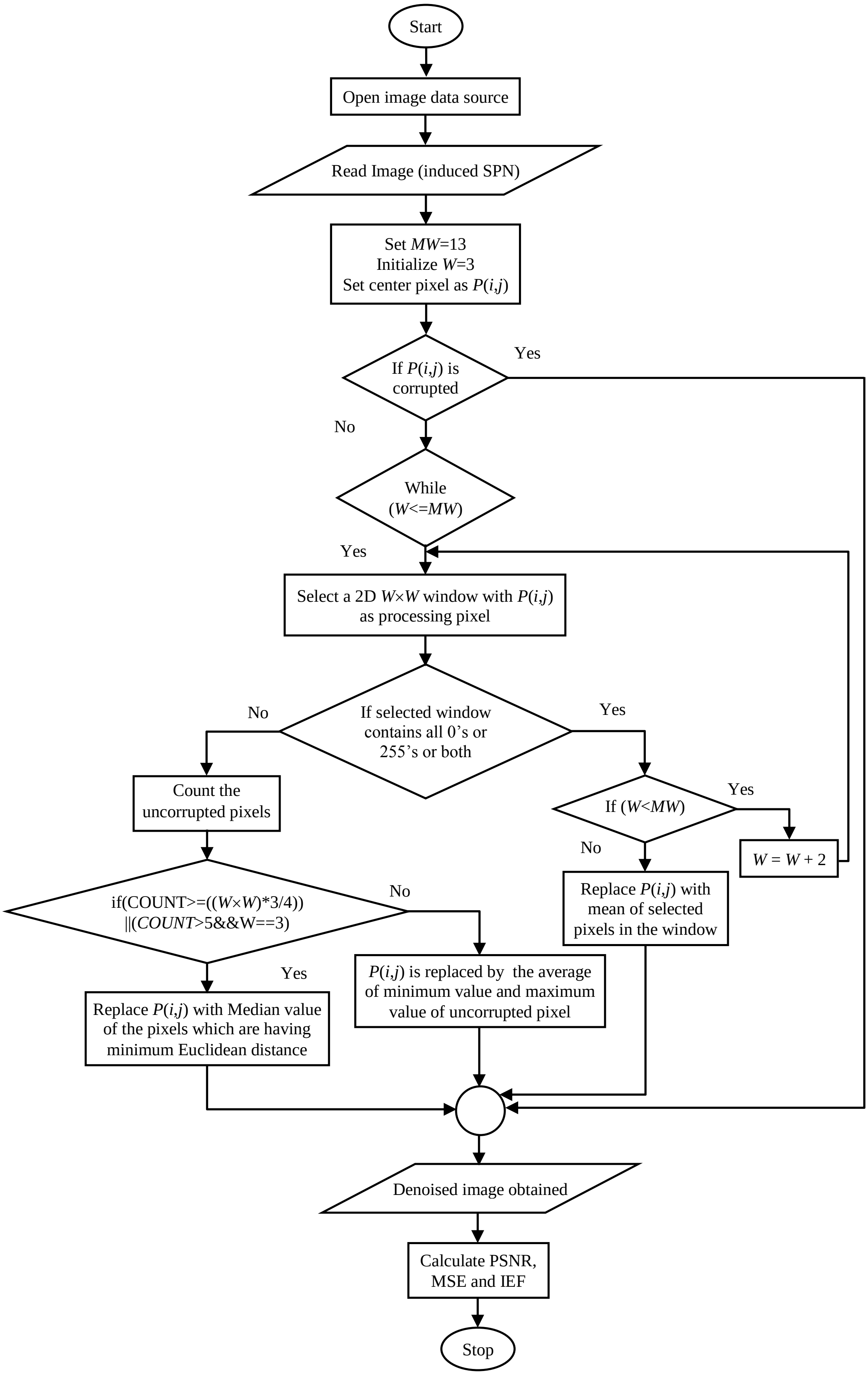
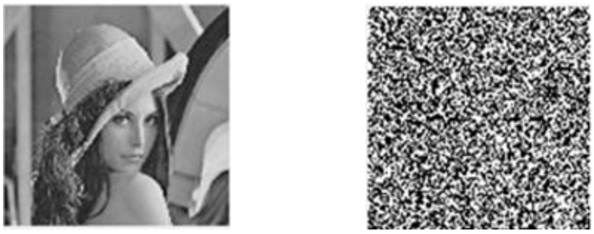
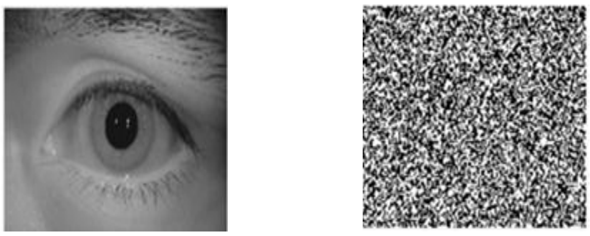


Fig.2. Flow chart of proposed filter



LENA IMAGE NOISY IMAGE

Fig.3. Shows the original Lena image and 90% noisy image



IRIS IMAGE NOISY IMAGE

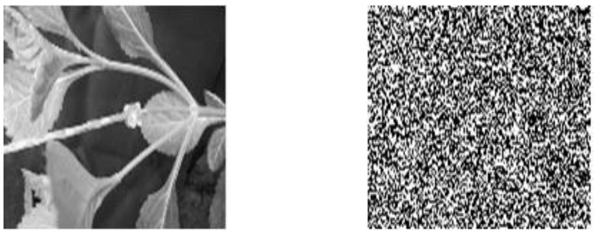
Fig.4. Shows the original Iris image and 90% noisy image

MRI IMAGE NOISY IMAGE

Fig.5. Shows the original MRI image and 90% noisy image

CT IMAGE NOISY IMAGE

Fig.6. Shows the original CT image and 90% noisy image



PLANT IMAGE NOISY IMAGE

Fig.7. Shows the original Plant image and 90% noisy image

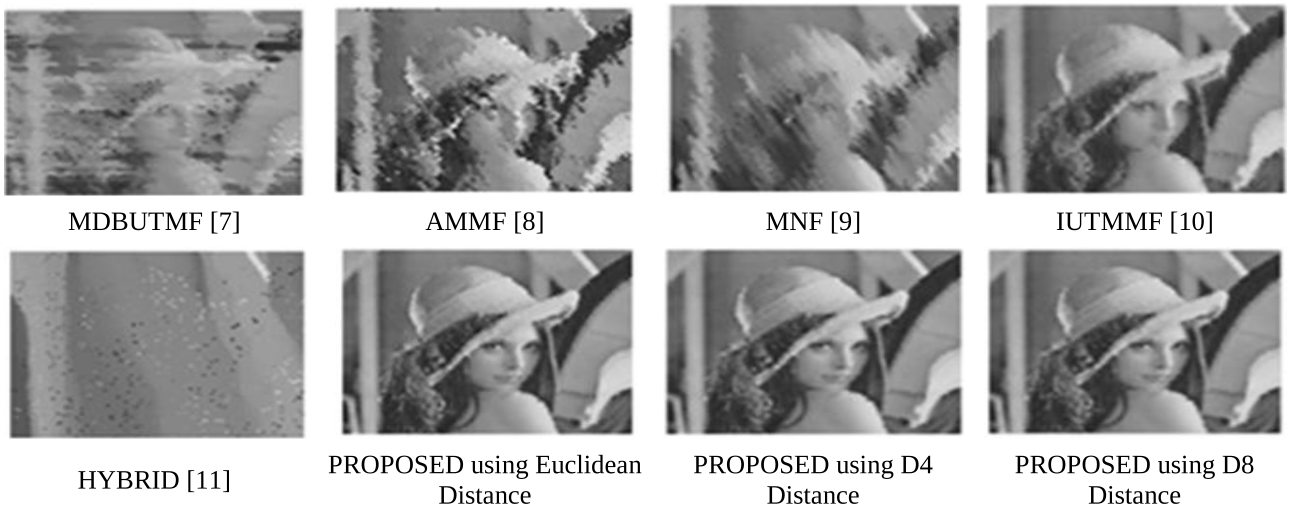


Fig.8. Result of Lena image with 90% noise density

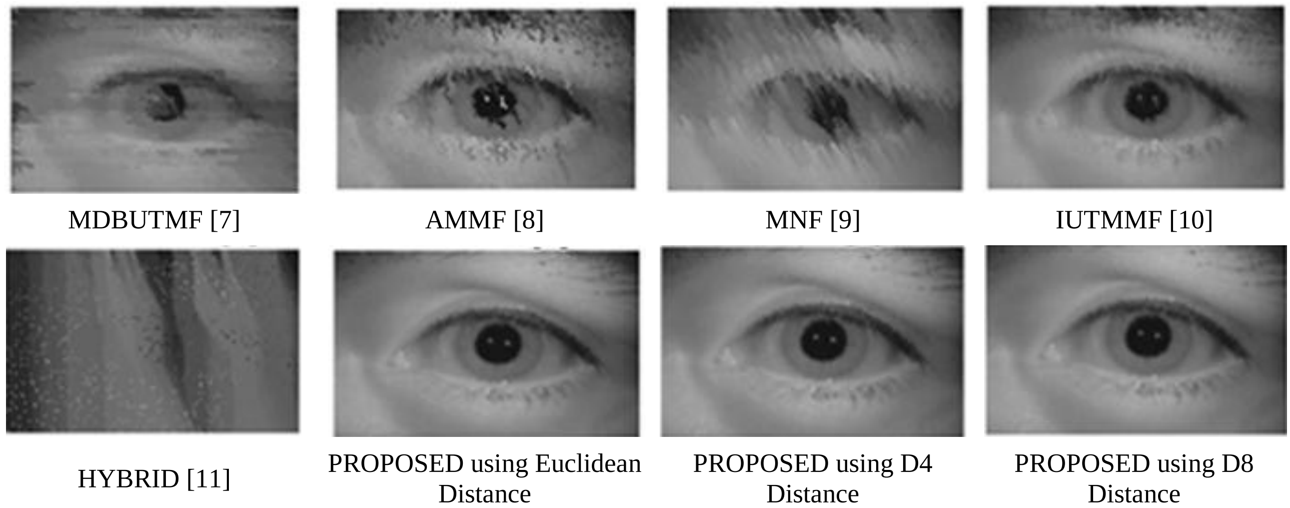


Fig.9. Result of Iris image with 90% noise density

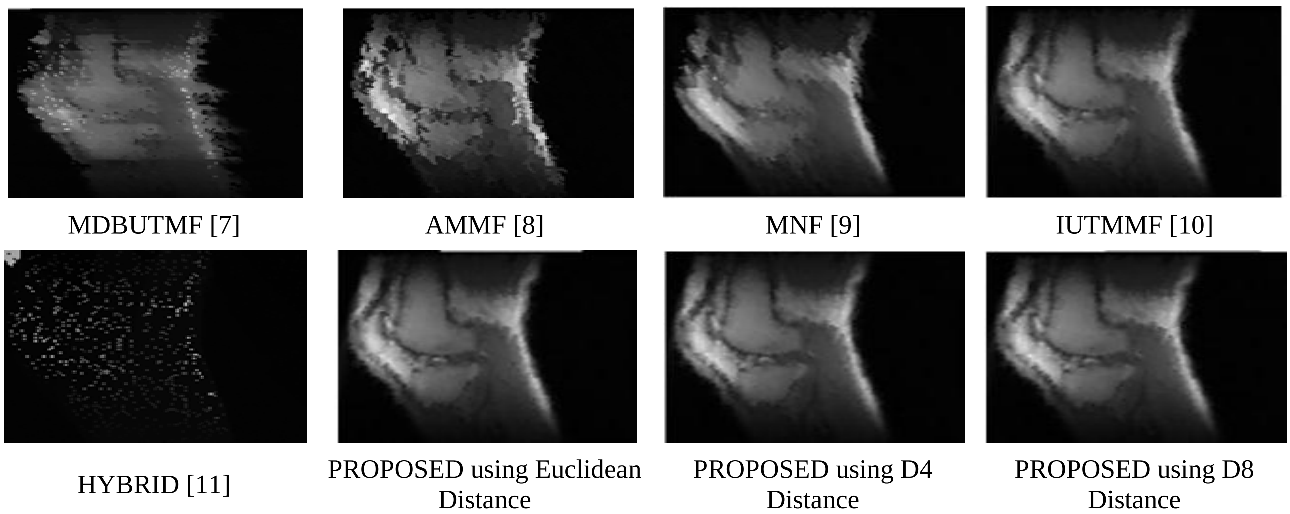
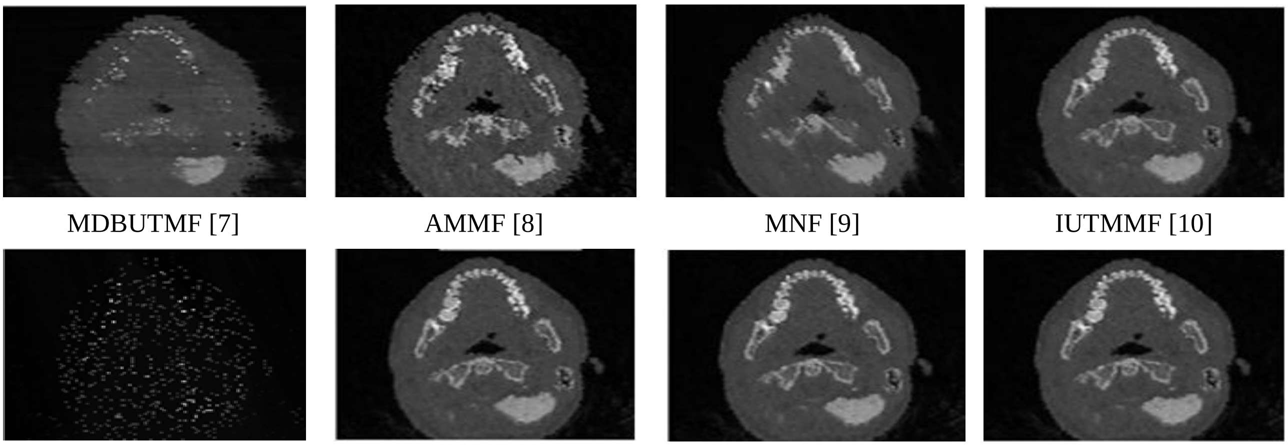


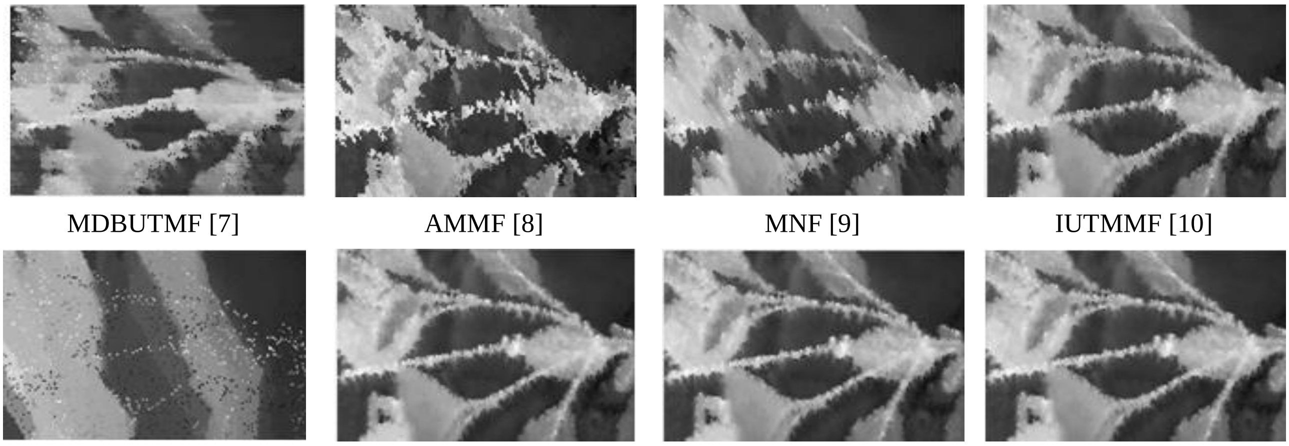
Fig.10. Result of MRI image with 90% noise density



MDBUTMF [7] AMMF [8] MNF [9] IUTMMF [10]

HYBRID [11] PROPOSED using Euclidean Distance PROPOSED using D4 Distance PROPOSED using D8 Distance

Fig.11. Result of CT image with 90% noise density



MDBUTMF [7] AMMF [8] MNF [9] IUTMMF [10]

HYBRID [11] PROPOSED using Euclidean Distance PROPOSED using D4 Distance PROPOSED using D8 Distance

Fig.12. Result of Plant image with 90% noise density

Table.1. Comparison of PSNR, MSE and IEF values of Lena Image with Different Noise Levels

SALT AND PEPPER NOISE DENSITY IN %		**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
MDBUTMF [7]	**PSNR**	43.26	38.33	35.00	32.33	29.99	27.63	25.12	22.48	19.40
	MSE	3.00	9.54	20.54	37.94	65.17	112.00	199.50	366.70	745.70
	IEF	602.20	389.30	271.60	195.57	141.88	99.49	65.02	40.46	22.40
AMMF [8]	**PSNR**	40.93	36.88	34.32	31.89	30.09	28.00	26.02	23.78	20.05
	MSE	5.24	13.31	24.04	41.99	63.62	103.33	162.50	272.09	642.40
	IEF	352.2	279.1	232.1	176.74	145.32	108.20	79.85	54.53	26.00
MNF [9]	**PSNR**	43.9	39.75	37.19	34.60	32.68	30.19	27.70	24.64	20.45
	MSE	2.63	6.88	12.39	22.46	35.07	62.12	106.98	222.90	586.00
	IEF	700.10	540.00	450.30	330.30	263.6	179.40	118.00	66.57	28.50
IUTMMF [10]	**PSNR**	43.90	39.76	37.22	34.70	32.88	30.88	28.58	26.38	23.69
	MSE	2.64	6.86	12.33	22.01	33.45	55.43	90.00	149.60	277.95

	IEF	699.05	541.69	452.49	337.15	276.4	201.04	144.19	99.17	60.10
HYBRID [11]	**PSNR**	43.37	39.79	37.55	**35.54**	**33.94**	27.33	24.84	21.59	15.85
	MSE	2.99	6.81	11.37	**18.13**	**26.23**	123.12	213.09	450.89	1689.06
	IEF	617.25	545.63	490.76	**409.25**	**352.39**	92.78	60.90	32.91	9.89
PROPOSED using Euclidean Distance	**PSNR**	**44.73**	**40.21**	**37.56**	35.13	33.53	31.84	**30.27**	**28.36**	**25.61**
	MSE	**2.18**	**6.18**	**11.30**	19.90	28.80	42.50	**61.08**	**94.83**	**178.37**
	IEF	**844.05**	**601.30**	**497.22**	372.01	320.60	262.19	**212.93**	**156.48**	**93.66**
PROPOSED using D4 Distance	**PSNR**	**44.73**	**40.21**	**37.56**	35.13	33.53	31.84	**30.27**	**28.36**	**25.61**
	MSE	**2.18**	**6.18**	**11.30**	19.90	28.80	42.50	**61.08**	**94.83**	**178.37**
	IEF	**844.05**	**601.30**	**497.22**	372.01	320.60	262.19	**212.93**	**156.48**	**93.66**
PROPOSED using D8 Distance	**PSNR**	43.92	39.78	37.22	35.36	33.53	**32.04**	30.25	28.32	25.34
	MSE	2.63	6.85	12.33	18.94	28.80	**40.63**	61.33	95.83	190.25
	IEF	699.42	544.46	452.56	393.62	322.04	**273.51**	211.60	154.80	87.73

Table.2. Computational Time for Denoising Algorithms

METHOD	**COMPUTATIONAL TIME IN SECONDS**						
	JPEG			**GIFF**		**TIFF**	
	Lena Image (512×512)	**Iris Image (640×480)**	**Iris Image (512×512)**	**Iris Image (640×480)**	**Iris Image (512×512)**	**Iris Image (640×480)**	**Iris Image (512×512)**
MDBUTMF[7]	6.1	7.155	5.70	6.58	5.64	6.58	5.60
AMMF [8]	79.09	94.57	89.43	105.50	89.70	105.12	90.38
MNF [9]	24.93	29.20	26.12	30.38	26.35	30.47	26.04
IUTMMF [10]	21.85	26.12	20.10	22.94	19.68	23.07	19.84
HYBRID [11]	13.19	15.50	12.34	14.48	12.91	14.65	12.54
PROPOSED using Euclidean Distance	35.39	44.53	36.02	42.68	36.52	42.95	36.84
PROPOSED using D4 Distance	35.38	44.24	36.13	43.62	36.62	42.99	36.55
PROPOSED using D8 Distance	36.28	45.07	36.93	43.75	37.36	43.48	37.24

Table.3. Comparison of average PSNR, MSE, IEF values of 200 Iris images with different noise levels

SALT AND PEPPER NOISE DENSITY IN %		**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
MDBUTMF [7]	**PSNR**	47.85	43.93	41.10	38.69	36.54	34.43	32.44	30.69	26.28
	MSE	1.18	2.88	5.49	9.47	15.41	24.65	39.07	65.86	159.04
	IEF	1843.85	1485.99	1152.28	874.73	659.44	489.29	355.45	238.07	109.06
AMMF [8]	**PSNR**	46.77	42.86	40.14	37.94	35.97	34.01	32.11	30.41	26.65
	MSE	1.52	3.73	6.96	11.51	17.99	27.78	43.07	71.43	147.41
	IEF	1448.70	1175.91	939.25	752.66	592.23	454.84	335.35	226.09	119.31
MNF [9]	**PSNR**	48.34	44.72	42.18	39.96	37.90	35.76	33.59	31.57	26.57

	MSE	1.06	2.43	4.38	7.25	11.61	18.69	30.72	55.37	149.47
	IEF	2077.57	1818.54	1514.72	1207.75	933.31	680.84	472.43	290.69	116.69
IUTMMF [10]	**PSNR**	48.30	44.70	42.18	40.01	38.05	36.11	34.23	32.67	29.46
	MSE	1.07	2.44	4.37	7.17	11.22	17.34	26.60	42.29	77.67
	IEF	2058.5	1808.23	1513.56	1220.06	964.95	737.70	550.31	386.63	229.94
HYBRID [11]	**PSNR**	48.20	44.98	42.81	40.98	39.23	35.55	31.21	27.13	17.20
	MSE	1.10	2.30	3.80	5.76	8.57	21.72	51.72	186.64	1282.12
	IEF	2019.94	1939.63	1756.28	1530.93	1271.39	723.46	266.41	98.12	13.46
PROPOSED using Euclidean Distance	**PSNR**	**49.68**	**45.85**	**43.23**	**41.19**	**39.44**	**37.80**	**36.14**	**34.18**	**31.31**
	MSE	**0.76**	**1.85**	**3.39**	**5.42**	**8.12**	**11.76**	**17.18**	**26.81**	**51.14**
	IEF	**2789.15**	**2314.85**	**1897.25**	**1588.04**	**1324.03**	**1084.59**	**857.72**	**619.14**	**354.09**
PROPOSED using D4 Distance	**PSNR**	**49.68**	**45.85**	**43.23**	**41.19**	**39.44**	**37.80**	**36.14**	**34.18**	**31.31**
	MSE	**0.76**	**1.85**	**3.39**	**5.42**	**8.12**	**11.76**	**17.18**	**26.81**	**51.14**
	IEF	**2789.15**	**2314.85**	**1897.25**	**1588.04**	**1324.03**	**1084.59**	**857.72**	**619.14**	**354.09**
PROPOSED using D8 Distance	**PSNR**	48.39	44.87	42.51	40.67	39.07	37.57	36.00	34.10	31.29
	MSE	1.05	2.34	4.03	6.13	8.85	12.44	17.77	27.29	51.44
	IEF	2101.11	1862.38	1620.18	1413.92	1220.72	1028.31	829.80	607.93	351.93

Table.4. Comparison of average PSNR, MSE, IEF values of MRI image with different noise levels

SALT AND PEPPER NOISE DENSITY IN %			**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
MDBUTMF [7]	**MRI image1**	**PSNR**	45.63	40.56	37.54	34.94	32.47	29.53	26.36	23.19	20.00
		MSE	1.77	5.70	11.44	20.81	36.75	72.42	150.30	311.83	649.03
		IEF	1472	922.86	694.28	509.55	357.48	217.41	123.25	67.27	36.477
	MRI image2	**PSNR**	45.14	40.83	37.71	34.55	32.03	29.41	27.73	24.04	19.91
		MSE	1.99	5.36	11.01	22.72	40.86	74.44	109.63	255.93	662.53
		IEF	1353.06	984.91	73.54	459.78	322.89	213.07	168.32	82.33	35.70
AMMF [8]	**MRI image1**	**PSNR**	43.17	39.78	37.33	34.99	32.36	30.47	28.57	25.88	22.33
		MSE	3.13	6.82	12.01	20.59	37.74	58.32	90.33	167.74	379.58
		IEF	834.94	771.88	661.64	515.12	348.13	269.98	205.07	124.98	62.37
	MRI image2	**PSNR**	43.67	39.69	37.04	34.79	32.10	30.61	28.70	26.65	23.34
		MSE	2.788	6.98	12.85	21.54	40.02	56.43	87.57	140.51	300.76
		IEF	965.99	756.75	626.86	484.86	327.842	281.06	210.71	149.97	76.65
MNF [9]	**MRI image1**	**PSNR**	46.87	42.76	40.47	38.14	35.98	33.87	31.60	27.72	22.30
		MSE	1.33	3.43	5.83	9.96	16.37	26.61	44.97	109.76	382.47
		IEF	1960	1532.64	1362.82	1064.21	802.55	591.58	411.88	191.01	81.89
	MRI image2	**PSNR**	47.20	43.09	40.33	37.81	35.87	33.99	31.92	29.08	23.34
		MSE	1.23	3.18	6.01	10.76	16.80	25.90	41.75	80.21	301.09
		IEF	2175.91	1658.42	1339.16	970.70	780.88	612.41	441.97	262.69	78.57
IUTMMF [10]	**MRI image1**	**PSNR**	46.11	42.41	40.23	38.03	36.07	34.03	32.16	29.40	25.95

		MSE	1.59	3.72	6.15	10.23	16.07	25.68	39.40	74.83	165.10
		IEF	1644.88	1413	1291.2	1036.63	817.611	613.05	469.38	280.90	143.39
	MRI image2	**PSNR**	47.07	43.06	40.30	37.91	35.83	34.04	32.82	30.32	26.92
		MSE	1.27	3.21	6.05	10.50	16.98	25.62	33.95	60.34	132.07
		IEF	2113.01	1644.67	1329.92	994.38	773.35	618.85	543.39	349.18	179.128
HYBRID [11]	**MRI image1**	**PSNR**	44.33	41.53	38.98	30.18	32.61	28.85	25.93	21.27	13.08
		MSE	2.39	4.56	8.21	62.36	35.60	84.59	165.62	484.38	3194.7
		IEF	1092	1154.54	968.09	170.09	369.03	186.14	111.85	43.28	7.41
	MRI image2	**PSNR**	44.29	41.82	39.93	38.22	36.19	28.02	27.20	22.64	14.48
		MSE	2.41	4.27	6.59	9.77	15.63	102.56	123.69	353.47	2313.41
		IEF	1114.64	1237.01	1222.07	1068.77	839.44	154.67	149.18	59.61	10.22
PROPOSED using Euclidean Distance	**MRI image1**	**PSNR**	**47.20**	**43.33**	**40.51**	**38.50**	**36.76**	**34.94**	**33.20**	**30.92**	**27.57**
		MSE	**1.23**	**3.01**	**5.77**	**9.17**	**13.69**	**20.83**	**31.05**	**52.60**	**113.64**
		IEF	**2113.19**	**1747.83**	**1377.31**	**1155.80**	**959.71**	**755.95**	**596.58**	**398.56**	**208.33**
	MRI image2	**PSNR**	**48.08**	**44.10**	**41.05**	**38.76**	**36.64**	**34.96**	**33.73**	**31.64**	**28.34**
		MSE	**1.01**	**2.52**	**5.09**	**8.65**	**14.08**	**20.71**	**27.51**	**44.56**	**95.18**
		IEF	**2663.43**	**2092.9**	**1580.91**	**11207.76**	**931.70**	**765.77**	**670.73**	**472.85**	**246.53**
PROPOSED using D4 Distance	**MRI image1**	**PSNR**	**47.20**	**43.33**	**40.51**	**38.50**	**36.76**	**34.94**	**33.20**	**30.92**	**27.57**
		MSE	**1.23**	**3.01**	**5.77**	**9.17**	**13.69**	**20.83**	**31.05**	**52.60**	**113.64**
		IEF	**2113**	**1747**	**1377.31**	**1155.80**	**959.71**	**755.95**	**596.58**	**398.56**	**208.33**
	MRI image2	**PSNR**	**48.08**	**44.10**	**41.05**	**38.76**	**36.64**	**34.96**	**33.72**	**31.64**	**28.34**
		MSE	**1.01**	**2.52**	**5.09**	**8.65**	**14.08**	**28.71**	**27.51**	**44.56**	**95.18**
		IEF	**2663.43**	**2092.9**	**1580.91**	**1207.76**	**931.70**	**765.77**	**670.73**	**472.85**	**248.53**
PROPOSED using D8 Distance	**MRI image1**	**PSNR**	46.10	42.60	40.33	38.30	36.59	34.85	33.16	30.844	27.52
		MSE	1.59	3.57	6.01	9.81	14.22	21.24	31.37	53.53	114.89
		IEF	1641	1475.69	1320.75	1103.16	923.47	741.32	590.54	391.82	206.06
	MRI image2	**PSNR**	47.17	43.11	40.67	38.40	36.27	34.77	33.61	31.58	28.34
		MSE	1.24	3.17	5.57	9.39	15.32	21.61	28.26	45.14	95.27
		IEF	2160.47	1664.77	1446.76	1112.22	856.41	733.74	652.77	466.80	248.31

Table.5. Comparison of average PSNR, MSE, IEF values of sample CT images with different noise levels

SALT AND PEPPER NOISE DENSITY IN %			**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
MDBUTMF [7]	**CT image1**	**PSNR**	38.58	35.70	33.02	31.17	29.16	27.14	25.00	22.73	20.08
		MSE	9.01	17.46	32.41	49.58	78.81	125.38	205.47	346.70	638.34
		IEF	288.3	292.05	238.77	209.26	164.46	123.91	87.71	69.33	36.32
	CT image2	**PSNR**	39.33	36.23	33.68	31.60	29.15	27.13	25.22	23.28	20.37
		MSE	7.58	15.46	27.85	44.93	78.94	125.87	195.34	304.98	596.91
		IEF	340.33	333.68	277.25	229.43	162.40	122.46	92.07	67.48	38.85
AMMF [8]	**CT image1**	**PSNR**	40.18	36.49	33.78	31.31	29.23	27.47	25.52	23.38	21.34

		MSE	6..23	14.56	27.23	47.99	77.49	116.21	182.38	297.98	476.74
		IEF	417.48	350.24	284.19	216.23	167.26	133.69	98.82	69.03	48.63
	CT image2	**PSNR**	40.36	36.85	33.96	31.63	29.61	27.86	25.78	23.75	21.26
		MSE	5.97	13.39	26.12	44.63	70.99	106.33	171.58	274.03	486.45
		IEF	432.00	385.03	295.59	230.97	180.60	144.99	104.82	75.10	47.67
MNF [9]	**CT image1**	**PSNR**	40.53	37.67	35.05	33.14	31.02	29.03	27.00	24.64	21.84
		MSE	5.74	11.11	20.32	31.49	51.33	81.12	129.58	223.07	425.14
		IEF	452.27	458.95	380.76	329.46	252.50	191.52	139.09	92..22	54.54
	CT image2	**PSNR**	40.63	37.85	35.44	33.48	31.20	29.20	27.26	24.94	22.08
		MSE	5.62	10.65	18.55	29.14	49.21	78.00	122.17	208.41	402.78
		IEF	458.84	483.99	416.30	353.74	260.52	197.81	147.23	98.75	57.58
IUTMMF [10]	**CT image1**	**PSNR**	40.47	37.63	35.07	33.19	31.19	29.44	27.75	25.77	23.82
		MSE	5.82	11.21	20.19	31.16	49.32	73.89	109.07	172.12	269.64
		IEF	446.32	454.75	383.20	332.96	262.78	210.24	165.24	119.52	85.99
	CT image2	**PSNR**	40.50	37.80	35.41	33.50	31.45	29.69	27.95	26.11	24.07
		MSE	5.65	10.77	18.70	28.99	48.50	69.70	104.06	159.07	254.34
		IEF	455.97	479.03	412.80	355.48	275.7	221.13	172.85	129.38	91.18
HYBRID [11]	**CT image1**	**PSNR**	39.81	37.27	35.15	33.33	31.54	25.55	23.70	21.03	13.55
		MSE	6.78	12.16	19.84	30.18	45.61	101.00	277.01	512.05	2865.48
		IEF	383.21	419.31	389.91	338.87	284.19	85.83	65.06	40.17	8.09
	CT image2	**PSNR**	40.16	37.25	35.38	33.74	31.86	25.44	24.04	21.34	13.59
		MSE	6.26	12.24	18.81	27.45	42.27	185.53	256.25	477.60	2843.28
		IEF	411.92	421.23	410.39	375.50	303.28	83.08	70.18	43.09	8.15
PROPOSED using Euclidean Distance	**CT image1**	**PSNR**	**41.16**	**38.25**	**35.89**	**33.90**	**32.16**	**30.66**	**29.13**	**27.26**	**25.04**
		MSE	**4.97**	**9.72**	**16.73**	**26.43**	**39.54**	**55.84**	**79.44**	**122.18**	**203.74**
		IEF	**522.19**	**524.46**	**462.43**	**392.61**	**327.80**	**278.24**	**226.87**	**168.37**	**112.81**
	CT image2	**PSNR**	**41.54**	**38.52**	**36.07**	**34.32**	**32.39**	**30.98**	**29.48**	**27.68**	**25.37**
		MSE	**4.55**	**9.13**	**16.05**	**24.01**	**37.43**	**51.88**	**73.18**	**110.78**	**188.55**
		IEF	**566.81**	**564.64**	**480.94**	**429.31**	**342.48**	**297.09**	**245.78**	**185.75**	**123.00**
PROPOSED using D4 Distance	**CT image1**	**PSNR**	**41.16**	**38.25**	**35.89**	**33.90**	**32.16**	**30.66**	**29.13**	**27.26**	**25.04**
		MSE	**4.97**	**9.72**	**16.73**	**26.43**	**39.54**	**55.54**	**79.44**	**122.183**	**203.74**
		IEF	**522.19**	**524.46**	**462.43**	**392.61**	**327.80**	**278.24**	**226.87**	**168.37**	**113.81**
	CT image2	**PSNR**	**41.54**	**38.52**	**36.07**	**34.32**	**32.39**	**30.98**	**29.48**	**27.68**	**25.37**
		MSE	**4.55**	**9.13**	**16.05**	**24.01**	**37.43**	**51.88**	**73.18**	**110.79**	**188.55**
		IEF	**566.81**	**564.64**	**480.94**	**429.31**	**342.48**	**297.09**	**245.78**	**185.75**	**123.00**
PROPOSED using D8 Distance	**CT image1**	**PSNR**	40.28	37.49	35.30	33.51	31.89	30.52	29.03	27.20	25.02
		MSE	6.09	11.58	19.15	28.94	42.03	57.60	81.25	123.89	204.54
		IEF	426.46	440.50	403.94	358.52	308.35	269.71	221.81	166.04	113.36
	CT image2	**PSNR**	40.52	37.73	35.55	33.92	32.16	30.81	29.41	27.63	25.35

		MSE	5.76	10.96	18.11	26.32	39.47	53.89	74.32	112.21	189.40
		IEF	447.56	470.56	426.40	391.61	324.80	286.03	242.01	183.40	122.45

Table.6. Comparison of average PSNR, MSE, IEF values of sample Plant image with different noise levels

SALT AND PEPPER NOISE DENSITY IN %			**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
MDBUTMF [7]	**Plant image1**	**PSNR**	40.88	36.96	33.93	31.50	29.28	27.22	24.92	22.33	19.88
		MSE	5.30	13.06	26.27	46.01	76.58	123.23	209.19	379.50	668.35
		IEF	342.52	276.79	205.50	158.01	117.94	87.67	60.55	38.17	24.39
	Plant image2	**PSNR**	39.81	35.77	32.71	29.62	27.62	25.02	22.52	19.81	16.15
		MSE	6.78	17.21	34.83	70.95	112.35	204.37	363.62	678.56	1574.76
		IEF	292.86	235.8	173.50	115.86	90.17	59.14	39.15	23.93	11.71
AMMF [8]	**Plant image1**	**PSNR**	38.93	35.21	32.45	29.93	28.31	26.21	24.01	21.80	18.68
		MSE	8.31	19.58	36.91	66.01	95.88	155.32	258.27	429.03	880.01
		IEF	218.59	184.70	146.23	110.14	94.20	69.56	49.04	33.76	18.52
	Plant image2	**PSNR**	37.27	33.36	30.74	27.49	25.85	24.16	21.18	19.16	15.45
		MSE	12.17	29.96	54.82	115.72	168.79	249.34	495.51	788.48	1852.7
		IEF	163.26	135.51	110.25	71.04	60.02	48.47	28.73	20.59	9.96
MNF [9]	**Plant image1**	**PSNR**	41.33	37.73	35.06	32.54	30.61	28.40	25.74	22.90	19.30
		MSE	4.78	10.96	20.27	36.16	56.42	93.79	173.12	333.35	761.55
		IEF	379.97	329.98	266.31	201.06	160.09	115.20	73.17	43.46	21.35
	Plant image2	**PSNR**	40.32	36.34	33.46	30.30	27.92	25.64	22.14	19.40	16.03
		MSE	6.03	15.08	29.33	60.63	104.76	177.16	396.88	745.75	1618.98
		IEF	329.22	269.19	206.07	135.58	96.71	68.22	35.87	21.77	11.39
IUTMMF [10]	**Plant image1**	**PSNR**	41.31	37.72	35.07	32.63	30.77	28.76	26.52	24.20	21.50
		MSE	4.80	10.97	20.21	35.42	54.44	86.44	144.75	246.98	460.00
		IEF	378.66	329.46	267.10	205.24	165.91	124.99	87.51	58.65	35.44
	Plant image2	**PSNR**	40.32	36.33	33.49	30.42	28.14	25.97	23.20	21.05	18.30
		MSE	6.03	15.10	29.09	58.99	99.70	164.22	311.11	510.00	959.82
		IEF	329.26	268.84	207.74	139.34	101.61	73.60	45.76	31.84	19.22
HYBRID [11]	**Plant image1**	**PSNR**	41.15	37.82	35.61	33.55	31.97	30.06	23.46	20.90	14.36
		MSE	4.98	10.72	17.86	28.69	41.23	64.01	292.64	527.67	2381.2
		IEF	364.72	337.15	302.18	253.41	219.07	158.79	43.28	27.45	6.84
	Plant image2	**PSNR**	39.15	35.64	33.51	31.28	**29.60**	27.83	21.14	15.60	13.87
		MSE	7.88	17.72	28.97	48.32	**71.15**	106.97	499.41	1786.95	2661.6
		IEF	251.74	229.19	208.64	170.11	**142.38**	112.99	28.51	9.08	6.93
PROPOSED using Euclidean Distance	**Plant image1**	**PSNR**	**42.32**	**38.57**	**35.88**	**33.62**	**32.01**	**30.30**	**28.50**	**26.27**	**23.18**
		MSE	**3.81**	**9.02**	**16.77**	**28.21**	**40.86**	**60.72**	**91.76**	**153.21**	**312.47**
		IEF	**477.09**	**400.97**	**321.85**	**257.74**	**221.03**	**177.93**	**138.04**	**94.55**	**52.17**
	Plant image2	**PSNR**	**40.89**	**36.66**	**33.97**	**31.42**	29.59	**28.07**	**25.78**	**23.81**	**20.36**

		MSE	5.29	14.00	26.01	46.87	71.31	101.19	171.78	270.03	597.4
		IEF	375.45	289.99	232.36	175.36	142.07	119.44	82.89	60.14	30.89
PROPOSED using D4 Distance	Plant image1	PSNR	42.32	38.57	35.88	33.62	32.01	30.30	28.50	26.27	23.18
		MSE	3.81	9.02	16.77	28.21	40.85	60.72	91.76	153.21	312.47
		IEF	477.09	400.97	321.85	257.74	221.03	177.93	138.04	94.55	52.17
	Plant image2	PSNR	40.89	36.66	33.97	31.42	29.59	28.07	25.78	23.81	20.36
		MSE	5.29	14.00	26.01	46.87	71.31	101.19	171.78	270.03	597.4
		IEF	375.45	289.99	232.36	175.36	142.07	119.44	82.89	60.14	30.89
PROPOSED using D8 Distance	Plant image1	PSNR	41.35	37.88	35.36	33.30	31.79	30.12	28.36	26.21	23.15
		MSE	4.76	10.57	18.90	30.35	42.97	63.10	94.85	155.30	314.72
		IEF	381.57	342.04	285.61	239.54	210.19	171.21	133.55	93.28	51.80
	Plant image2	PSNR	40.38	36.69	33.78	31.23	29.44	27.97	25.66	23.74	20.33
		MSE	5.94	13.92	27.21	48.94	73.86	104.77	176.24	274.64	601.75
		IEF	334.47	291.59	222.08	167.97	137.18	115.41	80.79	59.13	30.66

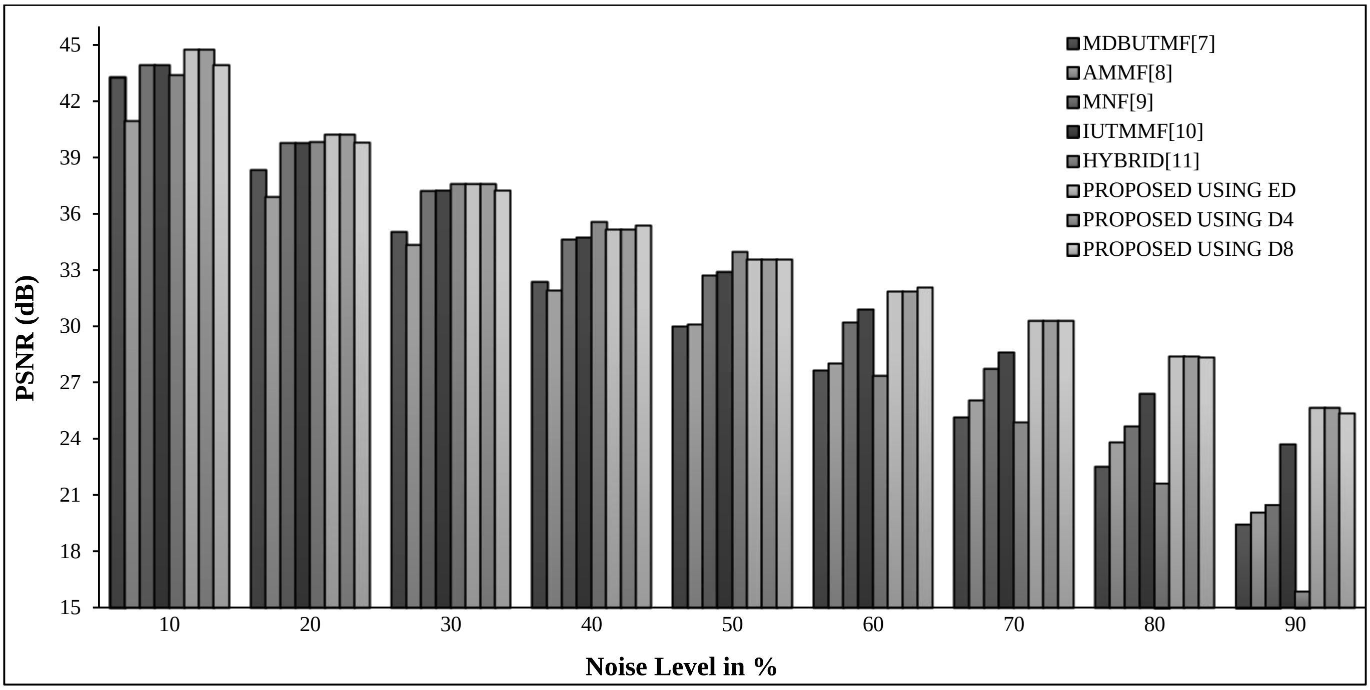


Fig.13. Comparison graph of PSNR at different noise density for Lena image

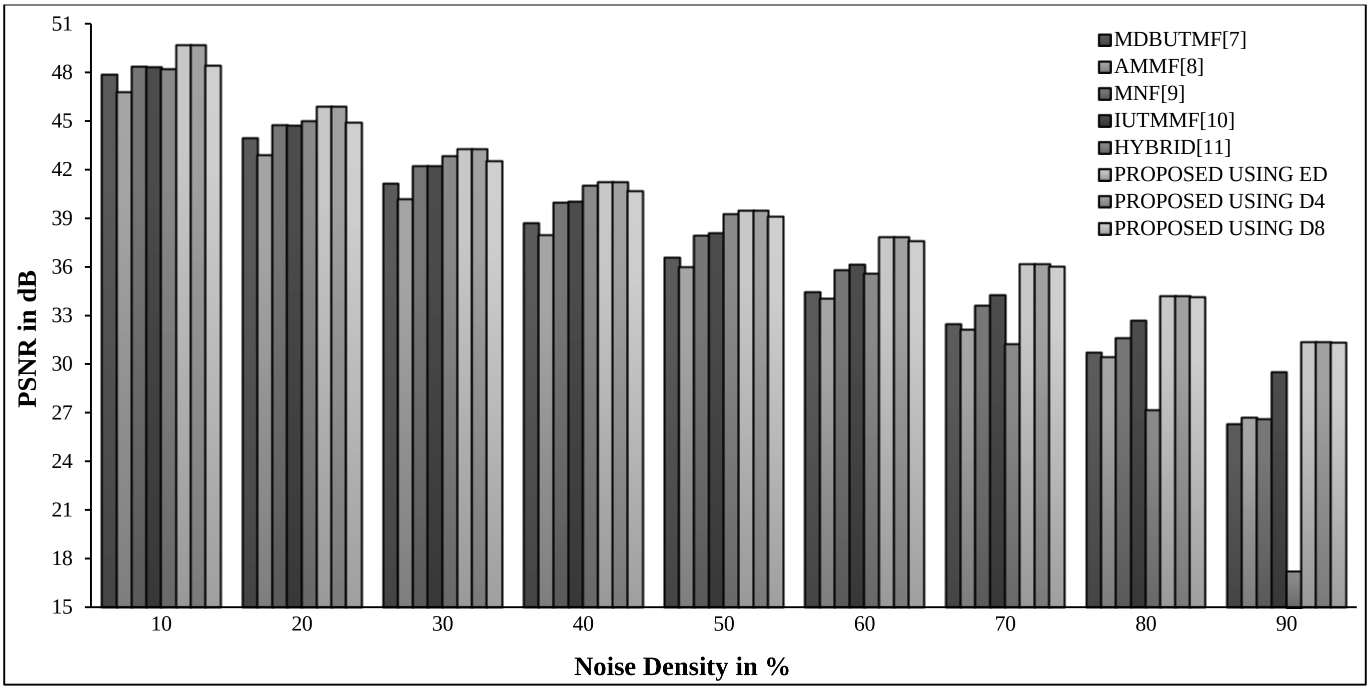


Fig.14. Comparison graph of average PSNR at different noise density for 200 Iris images

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