Adaptive Algorithm for Image Denoising Based on Curvelet Threshold

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Abstract
Image Denoising has remained a fundamental problem in the field of image processing. This paper proposes an adaptive threshold method for image denoising based on curvelet transform to estimate noise and remove it from digital images in order to achieve a good performance in this respect. The proposed adaptive threshold method is more efficient in estimate and reduce noise from images which have random, salt & pepper and Gaussian noise. Experimental results show that the proposed method demonstrates an improved denoising performance over related earlier techniques according to increasing of PSNR values of enhanced images by 0.044 at Random,1.05 at salt& pepper and 0.457 at Gaussian noise.

Key words:
Image denoising, Curvelet transform, Image enhancement, Adaptive threshold, Estimate noise and Reduce noise

1. Introduction

The noise of image is not usually easily removed in image processing. Noise statistical property and frequency spectrum distribution rule actually calculated according to image characteristic, there are many researchers developed many methods of removing noises that approximately are divided into space and transformation fields. The space field is data operation carried on the original image, and processes the image gray value, like neighborhood average method, Total Variation (TV) filter, ROF filter, wiener filter and so on.

In recent years, there is new multiscale transform based on wavelet transform called curvelet transform. It has good orientation characteristic due to its structural elements of curvelet transform include the parameters of dimension and location, and orientation parameter more. Therefore curvelet transform is better than wavelet in the expression of image edges, like geometry characteristic of curve .that give good result in image denosing.[1]

There are two algorithms that curvelet depend on one of them, first method based on unequally-spaced fast Fourier transforms (USFFT) and the second is based on the wrapping of specially selected Fourier samples [2].

The curvelete transform was designed to represent edges and other singularities along curves much more efficiently than traditional transforms, i.e. to represent an edge to squared error $1/N$ that will requires $1/N$ wavelets but it need only about $1/\sqrt{N}$ curvelets [1].

The paper is organized as follows. In the second section evolution of image enhancement presented. As well as image assessment measurements techniques are surveyed in the third section. The proposed adaptive threshold algorithm and the results are presented and discussed in the fourth section. Fifth section describes the experimental results. Finally, concluding remarks are given.

2. Evolution of image enhancement

Reducing noise from the original image is still a challenging problem for researchers. There have been several proposed algorithms to denoise images like Spatial-frequency filtering which refers to use low pass filters using Fast Fourier Transform (FFT). In frequency smoothing methods, Spatial filter like The wiener filtering [3], VISUShrink [4] is non-adaptive universal threshold, which depends only on number of data points. It has asymptotic equivalence suggesting best performance in terms of Mean Square Error (MSE) when the number of pixels reaches infinity, nonlinear median-type filters such as weighted median [5], adaptive threshold BayesShrink [6], Wiener filter in the wavelet domain yield optimal results when the signal corruption can be modeled as a Gaussian process and the accuracy criterion is the mean square error (MSE) [7] , relaxed median [8] have been developed to overcome this drawback in median filter , BayesShrink outperforms SUREShrink most of the times. Cross Validation [9] replaces wavelet coefficient with the weighted average of eighborhood coefficients to minimize generalized cross validation (GCV) function providing optimum threshold for every coefficient, NormalShrink is introduced with result better than Wiener Filtering, BayesShrink and SureShrink [10], Non Local Mean is an image denoising method that replaces each pixel by a weighted average of all the pixels in the image. Unfortunately, the method requires the computation of the weighting terms for all possible pairs of pixels [11],Fast Non Local Mean Algorithm[12], fuzzy filter remove noisy from image without remove fine detail of images[13],method are shifted to curvelet transom which outperforms the wavelet transform in enhance MRI images [14].Total Variation Filter was introduced by Rudin,

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Osher and Fatemi,as a regularizing criterion for solving inverse problems. It is efficient for regularizing images without smoothing the boundaries of the objects. ROF Filter is denoise method depend on total variation but in this case fixed point iteration is utilized. [2],

3. Image Assessment Techniques

Traditionally, image quality has been evaluated by human subjects. This method, though reliable, is expensive and too slow for real world applications, so there is computational models that can automatically predict perceptual image quality which known as image quality assessment techniques. Where $x(m,n)$ denotes the samples of original image, $\hat{x}(m,n)$ denotes the samples of distorted image. Where *M* and *N* are number of pixels in row and column directions, respectively , the techniques that used to assess the quality of images are:

1-Maximum Difference (MD)

The large value of Maximum Difference (MD) [15] means that image is poor quality. MD is defined as follow:

MD=Max $\left\| x(m,n) - \hat{x}(m,n)) \right\|$ (6)

2-Mean Square Error (MSE)

The simplest of image quality measurement is Mean Square Error (MSE). The large value of MSE means that image is poor quality. MSE is defined as follow:

$$\textbf{MSE}=\frac{1}{MN}\sum_{m=1}^{M}\sum_{n=2}^{N}(x(m,n)-\hat{x}(m,n))^2 . \quad (1)$$

3-Laplacian Mean Square Error (LMSE)

This measure is based on the importance of edges and objective boundaries in images for the human observer. The large value of Laplacian Mean Square Error (LMSE) means that image is poor quality. [16]

$$\text{LMSE}=\frac{\sum_{m=1}^{M}\sum_{n=1}^{N}[L(x(m,n))-L(\hat{x}()m,n)]^2}{\sum_{m}^{M}\sum_{n=1}^{N}[L(x(m,n))]^2} \quad (7)$$

Where: - $L(m,n)$ **is laplacian operator**

$$L(x(m,n))=x(m+1,n)+x(m-1,n)+x(m,n+1)+4x(mn)$$

$P_{j,l}$.

4-Image Quality Score (IQS):

1. Checking the SFM value between original image and distorted image.
2. If SFM values of distorted image are more than original image, PSNRS is used.
3. If SFM values of distorted image are less than original image, MDLMSE is used.

Where:-
$PSNRS = PSNR^{0.4}$
$MDLMSE = - (LMSE^{0.3} \times MD^{0.3})$ [16]

5-Uinversal Image Quality index

It was designed by modeling any distorted image as a combination of three factors [17]: loss of correlation, luminance distortion and contrast distortion.

$$Q=\frac{\sigma_{xy}}{\sigma_x\sigma_y}\cdot\frac{2\bar{x}\bar{y}}{(\bar{x})^2+(\bar{y})^2}\cdot\frac{2\sigma_x\sigma_y}{\sigma_x^2+\sigma_y^2}.$$

Where

$$\bar{x}=\frac{1}{N}\sum_{i=1}^{N}x_i, \quad \bar{y}=\frac{1}{N}\sum_{i=1}^{N}y_i$$

$$\sigma_x^2=\frac{1}{N-1}\sum_{i=1}^{N}(x_i-\bar{x})^2, \quad \sigma_y^2=\frac{1}{N-1}\sum_{i=1}^{N}(y_i-\bar{y})^2$$

$$\sigma_{xy}=\frac{1}{N-1}\sum_{i=1}^{N}(x_i-\bar{x})(y_i-\bar{y}).$$

6-Peak Signal to Noise Ratio (PSNR):

A high quality image has small value of Peak Signal to Noise Ratio (PSNR) [16]. PSNR is defined as follow:

$$\textbf{PSNR}=\left[10\log\frac{255^2}{MSE}\right]. \quad (2)$$

4. The proposed adaptive Threshold Algorithm

The proposed adaptive threshold method enhance gray scale images that has various types of noises such as random noise, salt & pepper noise, speckle noise and Gaussian noise. The method divides into the following main stages,

1- Compute norm of curvelet transform where curvelet normalized using the following equation.

$$c^{D,N}(j,\ell,k)=\frac{n}{\sqrt{L_{1,j}L_{2,j}}}c^{D}(j,\ell,k), \quad (1)$$

Where

$L_{1,j}$,$L_{2,j}$ are the side lengths of the parallelogram

2- Compute threshold in three steps:

- Calculate the arithmetic mean of pixels of distorted image, arithmetic mean indicate to central point of all values of pixels of distorted images.
- Compute the Spatial Frequency Measure (SFM) that characterizes the distorted image.
- Compute Difference Operator that detect edges of distorted image and detect the slope of the gray levels in the distorted image

Then compute threshold as the following:-

Threshold =(DOP(DI)*SFM(DI)* mean(DI)) + (mean(DI) *(s = n))

Where

DOP is the Difference Operator.
Mean is the arithmetic mean.
SFM is the Spatial Frequency measurement.
DI is the distorted image**.**
n is the number of coefficient of the curvelets.
s is the number of iteration

3-Apply warping Fast Discrete Curvelet Transform (FDCT) which can be calculated using the following equation

$$c^{D,O}(j,\ell,k) = \frac{1}{n^2} \sum_{n_1,n_2 \in \mathcal{R}_{j,\ell}} \hat{f}[n_1,n_2]\tilde{U}_{j,\ell}[n_1,n_2] e^{2\pi i(k_1 n_1/R_{1,j} + k_2 n_2/R_{2,j})}.$$

[18] on distorted image to move it from spatial domain to curvelete domain.

4-Apply computed threshold on distorted image.
5-Apply inverse FDCT on distorted image (after apply threshold on it) to move image from curvelete domain to spatial domain.
6-Remove imagine part of image that obtained from above step to obtain enhanced gray scale image
It is also represented in block diagram shown in Figure 1

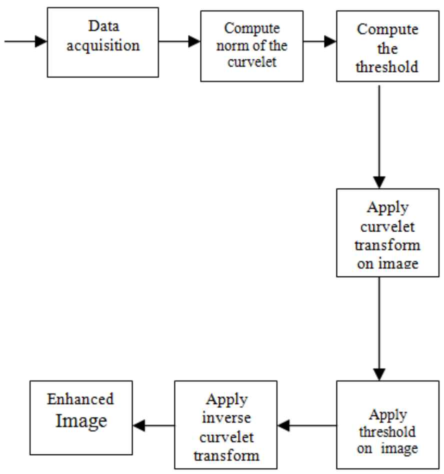

Fig. 1 block diagram of the proposed adaptive estimation method

The experiment are conducted on a group of gray scale test images like lena of size 512 X 512 at different types of noise Random noise at sigma=30, Salt & pepper noise at level 0.1.Gaussian noise at mean =0 and variance=0.1 and Speckle noise at level 0.1.The proposed adaptive threshold estimation method will enhance image using curvelet wrapping function [19].

The comparison of performance of ROF, TV, wiener filters, non local mean algorithm [20] and proposed algorithm on gray scale image lean will be shown in Figure 2, Image (a) is the original image, image (b) is image of Gaussian noise with mean=0 and variance=0.1, image (c) enhanced image with ROF filter with theta =5, image (d) is enhanced image with TV filter at λ=5, image (e) is enhanced image with non local mean algorithm, image (f) is enhanced image with wiener filter and image (g) is enhanced image via proposed method.


Image (a) Orgial image


Image (b) Gaussian noise imagw with mean=0 and variance =0.1


Image (c) ROF Filter at theta=5


Image (d) TV Filter at λ=5


Image (e) Non LocalMean Algorithm


Image (f) wiener Filter


Image (g) Proposed Algorithm

Figure 2. Enhanced images which has Gaussian noise at mean =0 and variance=0.1.

5. Experimental results

The adaptive method was implemented in MATLAB to compare the performance of our method with other methods; the experiments were done on the same images.
The following tables shows the values of Image Quality Assessment (MSE,MAE,PSNR) comparison of values of MAE,MSE and PSNR show that the proposed adaptive threshold estimation method has best performance with Random ,Salt & pepper and Gaussian noise.
Table 1 represent the MSE values of Lena, Cameraman and boat gray images at different types of noise (random, salt & pepper, Gaussian and speckle) to compare the performance of RPF,TV, wiener filters, NLMA and proposed algorithm .Best result was written in

bold font which mean proposed algorithm has best performance at lena and boat images at different type of noises but less in performance than TV filter in denoise speckle noise of cameraman image. MSE values represented in figures 3,4,5 where horizontal arsis represent type pf noise and vertical axis represent MSE value.

Table 1. The values of MSE of images

Method / Noise type	ROF	TV	NLF	winere	The Proposed Adaptive Method
Lena Test Image					
Random	0.0644	0.0620	0.0708	0.0632	**0.0616**
Salt & pepper	0.0427	0.0353	0.0414	0.0414	**0.0329**
Gaussian	0.0679	0.0527	0.0514	0.0511	**0.0476**
Speckle	0.0410	0.0306	0.0376	0.0376	**0.0306**
CameraMan Test Image					
Random	0.0943	0.0922	0.1023	0.0918	**0.0919**
Salt & pepper	0.0457	0.0381	0.0487	0.0598	**0.0363**
Gaussian	0.0771	0.0622	0.0664	0.1003	**0.0587**
Speckle	0.0404	**0.0276**	0.0396	0.0590	0.0300
Boat Test Image					
Random	0.0708	0.0677	0.0779	0.0679	**0.0669**
Salt & pepper	0.0479	0.0432	.0523	0.0613	**0.0400**
Gaussian	0.0730	0.0590	0.0615	0.0954	**0.0553**
Speckle	0.0479	0.0382	0.0487	0.0606	**0.0376**

Table 2 represent the MAE values of lean, cameraman and boat gray images at different types of noise (random, salt & pepper, Gaussian and speckle) to compare the performance of RPF,TV, wiener filters, NLMA and proposed algorithm . Best result was written in bold font which mean proposed algorithm has best performance at Lena ,cameraman and boat images at different type of noises. This MAE values represented in figures 6, 7, 8 where horizontal arsis represent type pf noise and vertical axis represent MSE value.

Table 3 represent the MSE values of lean, cameraman and boat gray images at different types of noise (random, salt & pepper, Gaussian and speckle) to compare the performance of RPF,TV, wiener filters, NLMA and proposed algorithm . Best result was written in bold font which mean proposed algorithm has best performance at Lena, cameraman and boat images at different type of noises. This PSNR values represented in figures 9,10,11 where horizontal arsis represent type pf noise and vertical axis represent MSE values

Table 2. The values of MAE of images

Method / Noise type	ROF	TV	NLF	winere	The Proposed Adaptive Method
Lena Test Image					
Random	0.0063	0.0057	0.0080	0.0060	**0.0057**
Salt & pepper	0.0033	0.0026	0.0038	0.0038	**0.0021**
Gaussian	0.0074	0.0046	0.0050	0.0050	**0.0041**
Speckle	0.0030	0.0020	0.0034	0.0034	**0.0018**
CamerMan Test Image					
Random	0.0943	0.0922	0.1023	0.0918	**0.0919**
Salt & pepper	0.0457	0.0381	0.0487	0.0598	**0.0363**
Gaussian	0.0771	0.0622	0.0664	0.1003	**0.0587**
Speckle	0.0404	**0.0276**	0.0396	0.0590	0.0300
Boat Test Image					
Random	0.0100	0.0092	0.0124	0.0090	**0.0089**
Salt & pepper	0.0043	0.0038	0.0060	0.0113	**0.0031**
Gaussian	0.0086	0.0058	0.0073	0.0146	**0.0055**
Speckle	0.0042	0.0031	0.0056	0.0065	**0.0029**

Table 3. The values of PSNR of images

Method / Noise type	ROF	TV	NLF	winere	The Proposed Adaptive Method
Lena Test Image					
Random	70.1448	70.5560	69.1270	70.3649	**70.5904**
Salt & pepper	72.8966	74.0157	72.3626	72.3482	**74.8875**
Gaussian	69.4624	71.5015	71.1634	71.1839	**71.9578**
Speckle	73.3926	75.1424	72.7791	72.7614	**75.5375**
CameraMan Test Image					
Random	66.5483	66.7818	65.7790	66.7639	**66.8364**
Salt & pepper	72.1020	72.7128	70.4637	66.9356	**74.0873**
Gaussian	68.4715	70.0196	68.7670	66.1242	**70.3106**
Speckle	72.9968	75.2685	71.0655	69.7734	**75.4841**
Boat Test Image					
Random	68.1390	68.5033	67.2095	68.5910	**68.6327**
Salt & pepper	71.7740	72.2768	70.3715	67.6138	**73.1878**
Gaussian	68.7939	70.4605	69.5228	66.4807	**70.7651**
Speckle	71.8562	73.1745	70.6253	70.0269	**73.4424**

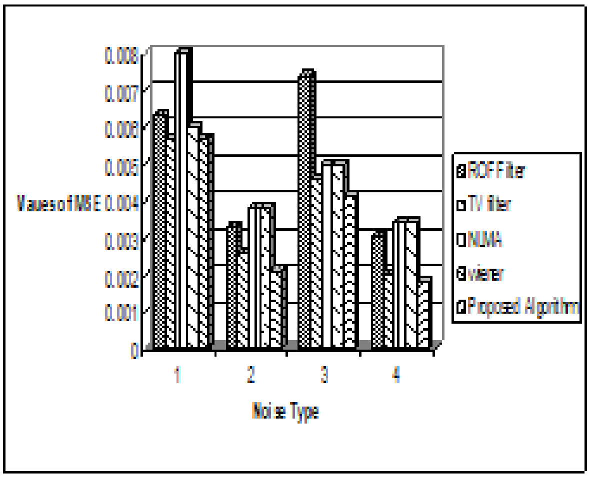

Figure 3 represent MSE values of Lena image

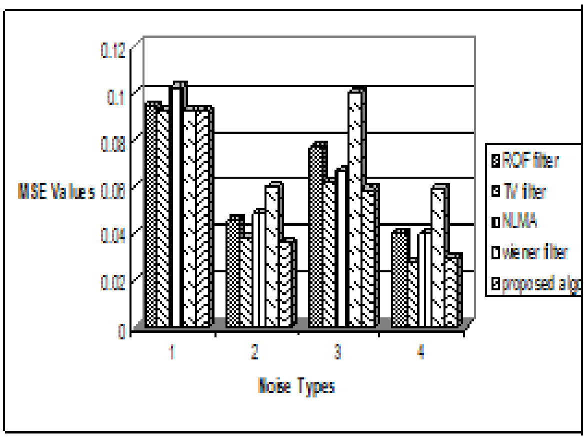

Figure 4 represent MSE values of camreaman image

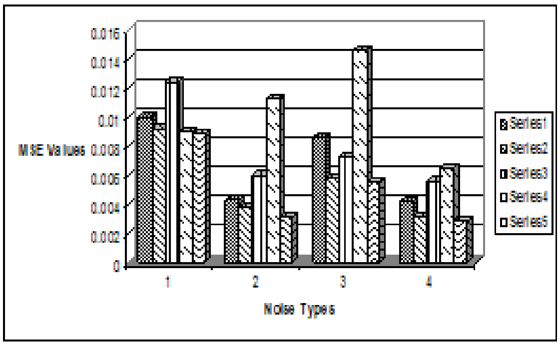

Figure 5 represent MSE values of Boat image

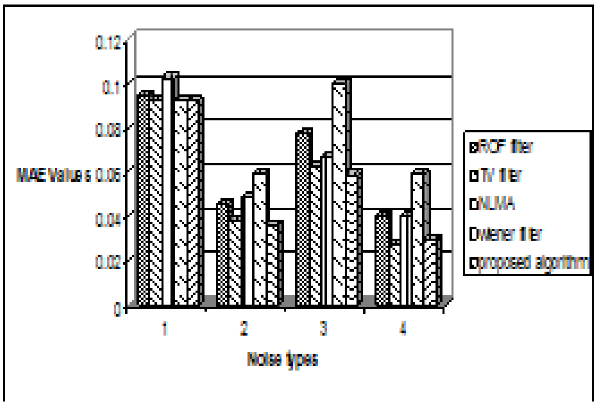

Figure 6 represent MAE values of lena image

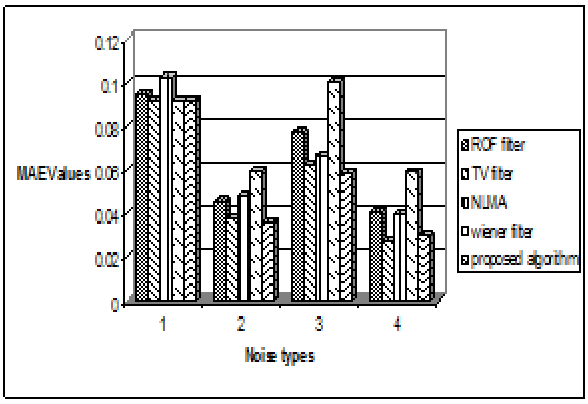

Figure 7 represent MAE values of cameraman image

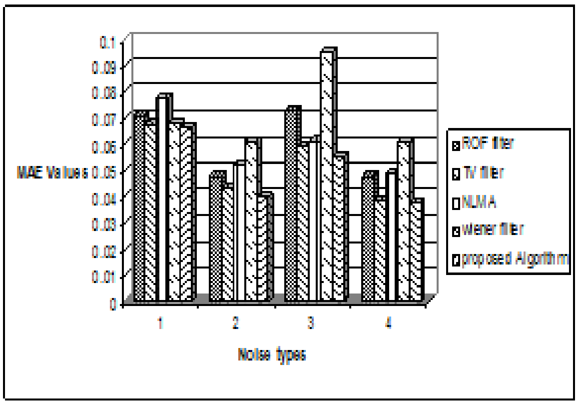

Figure 8 represent MAE values of Boat image

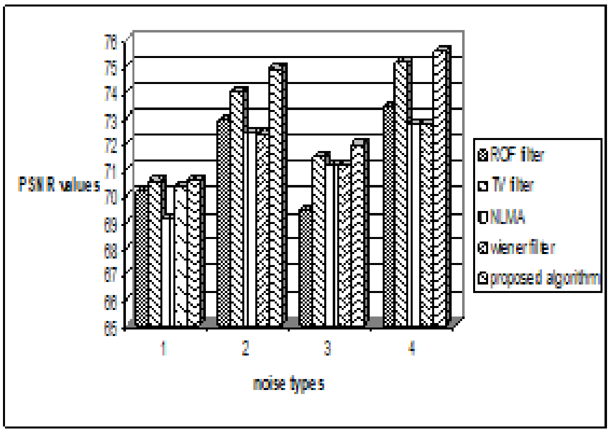

Figure 9 represent PSNR values of cameraman image

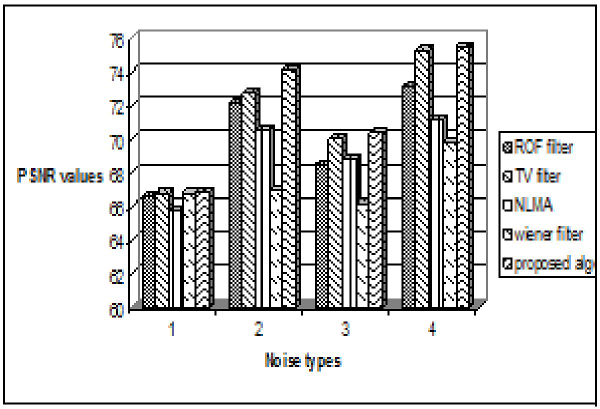

Figure 10 represent PSNR values of cameraman image

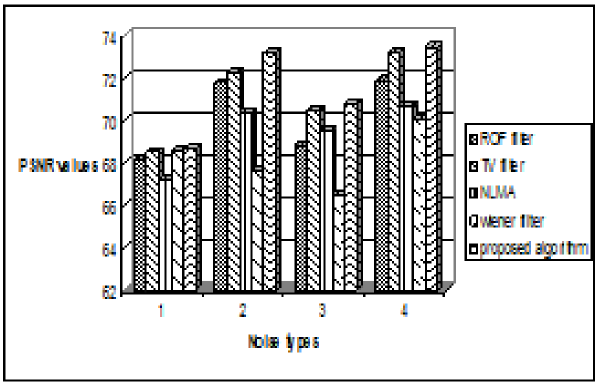

Figure 11 represent PSNR values of cameraman image

Where

x axis represent the noise types Random, Salt & pepper,Gaussian and speckle , y axis represent values of MSE at fig. 6 to fig. 8,MAE values from fig. 9 to fig.11 and PSNR values from fig. 12 to fig. 14

6. Conclusion

In this paper, we have proposed an adaptive threshold estimation method for image denoising in the curvelet domain by using mean, (Spatial Frequency Measure) SFM and (Difference Operator)DOP, experiment work on Lena, cameraman and boat gray test images at different type of noises (Random, Salt & pepper ,Gaussian ,Speckle) showed that the proposed adaptive threshold method success to estimate and reduce noise from image and it is more effective at reduce noise from image than (Rudin-Osher-Fatemi) ROF filter and Non Local Mean algorithm.

The evaluation of the results supports the conclusion that method has significantly better result than others. The proposed adaptive estimation method introduced better results than (Rudin-Osher-Fatemi) ROF filter ,Non Local Mean algorithm and Wiener filter at reduce noise (Random, Salt & pepper ,Gaussian) according to increasing of PSNR values of enhanced images by 0.044 at Random,1.05 at salt &pepper and 0.457 at Gaussian noise

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