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A Study of the Effects of Gaussian Noise on Image Features

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ABSTRACT

In this paper, the effect of noise on the features of digital images has been tested. Since most of the computer and communication systems can be affected by Gaussian noise which may come from different natural sources, it was interesting to measure the effect of this noise on image features. For this purpose, a data set of several images was used with Gaussian noise to generate the noisy images. Different Mean and Variance values were used each time with the same data set to measure wide variety of noise parameters. Then, four different enhancement filters were used to remove the Gaussian noise. A total of 10 features were selected for this study. The features from original images, noisy images, and enhanced images are measured and compared. The results show that some filters offended the features of the image more than the noise itself, and all the filters have similar effects on Texture features, Entropy, and two of Wavelet-based features. According to the Texture Features, the Average enhancement filter came up with the best results, but according to the Wavelet-based Features, the Motion enhancement filter came up with the best results. The software used in this paper is Matlab 2013.

Keywords: *Image Features, Gaussian Noise, Enhancement Filters***,** *Wavelet Transform*

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دراسة حول تأثيرات ضوضاء (Gaussian) على ميزات الصور

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الملخص

في هذا البحث، تم اجراء اختبار تأثير الضوضاء على ميزات الصور الرقمية حيث أن معظم أنظمة الحاسبات والاتصالات معرضة للتأثر بالضوضاء المعروفة بالـ (Gaussian Noise) التي قد تأتي من مصادر طبيعية مختلفة فكان من المثير للاهتمام أن يتم قياس تأثير هذه الضوضاء على ميزات الصور. لهذا الغرض، تم استخدام مجموعة من الصور المعرضة لـ (Gaussian Noise) لتوليد الصور المشوهة مع قيم مختلفة للمتوسط والتباين في كل مرة مع نفس مجموعة الصور وذلك لاجل قياس حالات متنوعة من تاثير هذه الضوضاء. ثم، استخدمت أربع مرشحات تعزيز مختلفة لإزالة الضوضاء (Gaussian Noise) واختيرت مجموعة من ١٠ ميزات لهذه الدراسة. ان الميزات من الصور الأصلية ، الصور المشوهة، والصور المعززة قد احتسبت وتمت المقارنة بينها. أظهرت النتائج ان بعض مرشحات التعزيز اثرت على ميزات الصور اكثر من الضوضاء (Gaussian Noise) نفسها، اضافة إلى أن بعض مرشحات التعزيز لها التاثير نفسه على ميزات الـ (Texture) و الـ (Entropy) واثنان من الميزات المعتمدة على التحويل (Wavelet). استنادا إلى ميزات الـ (Texture)، مرشح التعزيز المتوسط اعطت افضل النتائج، بينما استنادا إلى الميزات المعتمدة على التحويل (Wavelet) فان مرشح تعزيز الحركة اعطت افضل النتائج. البرنامج الذي تم استخدامه في هذا البحث هو Matlab 2013 .

الكلمات الدالة: ميزات الصور ، الضوضاء Gaussian Noise، مرشحات التعزيز ، التحويل (Wavelet).

1. INTRODUCTION

Digital images are vulnerable to different types of noise which affects the quality of the images. Noise is any undesired information that contaminates an image. The main source of noise in digital images arises during image acquisition (digitization) or during image transmission. The performance of image sensor is affected by variety of reasons such as environmental condition during image acquisition or by the quality of the sensing element themselves [1].

The criteria of the noise removal problem depends on the noise type by which the image is corrupting .In the field of reducing the image noise several type of linear and non linear filtering techniques have been proposed . Different approaches for reduction of noise and image enhancement have been considered, each of which has their own limitation and advantages [1]. Image enhancement deals with processing the image so that the resulted image become more suitable for a particullar application. The main goal of image enhancement and de-noising is to remove the noise as far as possible while retrieving the important information and edges of the images [2, 3].

The problem is that most techniques to reduce or remove noise always end up softening the image and affecting image features, therefore studying the effect of these techniques on image features is very important. In [4], the authors studied the effect of Salt and Pepper noise on two features of medical images (Mean and Variance) and compared it with these features after applying Median enhancement filter.

In this paper, the effect of noise and enhancement filters on image features were studied and compared. The Gaussian noise was considered since it appears commonly on images from natural sources, and different methods for reduction of noise and image enhancement have been considered. Then, features from 3 different categories, a total of 10 features, were selected to measure the effect of noise and these filters on image features. Finally, the Mean Square Error (MSE) between the original image, noisy image, and enhanced image features were compared. Based on this comparison, the effect of these techniques on image features was analyzed.

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2. The Noise Model

Image noise is the random variation of brightness or color information in images produced by the sensor and circuitry of a scanner or digital camera. Noise produces undesirable effects such as artifacts, unrealistic edges, unseen lines, corners, blurred objects and disturbs background scenes. Noise is very difficult to remove it from the digital images without the prior knowledge of noise model. That is why, review of noise models are essential in the study of image de-noising techniques [5].

There are several types of noise that can affect images. Some of these noise models are Gaussian noise, White noise, Fractal noise, Salt & Pepper noise, Periodic noise, Quantization noise, Speckle noise, Poisson noise, Poisson-Gaussian noise, Structured noise, Gamma noise, and Rayleigh noise [6]. The three common types of image noise are: Gaussian noise, Salt & Pepper noise, and Speckle noise [7]. The Gaussian noise is tested in this paper for being the most common noises that affects images naturally.

2.1. The Gaussian Noise

The Gaussian noise, also called normal noise, is caused by natural sources such as thermal vibration of atoms and discrete nature of radiation of warm objects [6].Gaussian noise generally disturbs the gray values in digital images. That is why Gaussian noise model essentially designed and characteristics by its PDF (Probability Density Function) or normalizes histogram with respect to gray value [5]. This is given as:

$$p(z) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(z-\bar{z})^2}{2\sigma^2}} \qquad \text{.................................} \quad (1)$$

where z represents the intensity, $\bar{z}$ is the mean (average) value of z, and σ is its standard deviation. The standard deviation squared σ^2 is called the variance.

Generally Gaussian noise mathematical model represents the correct approximation of real world scenarios. In this noise model, the mean value is zero; variance is 0.1 and 256 gray levels in terms of its PDF (Probability Density Function), which is shown in Fig. (1) .

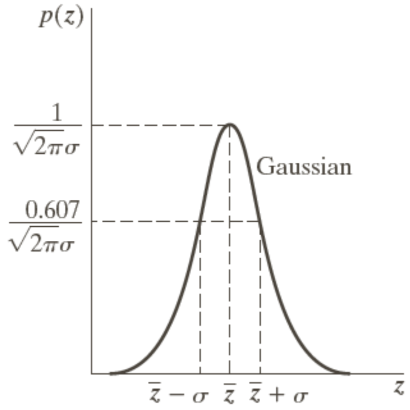

Fig. (1): PDF of Gaussian Noise [6]

3. Enhancement Filters

Filtering in an image processing is a basis function that is used to achieve many tasks such as noise reduction, interpolation, and re-sampling. Filtering image data is a standard process used in almost all image processing systems. The choice of filter is determined by the nature of the task performed by filter and behavior and type of the data. Filters are used to remove noise from digital image while keeping the details of image preserved is a necessary part of image processing [1]. The applications of image enhancement are Aerial imaging, Satellite imaging, Medical imaging, Digital camera application, Remote sensing [8].

Linear filtering can be used to remove certain types of noise. Certain filters, such as averaging or Gaussian filters, are appropriate for this purpose. The Enhancement filters that were used are: the averaging enhancement filter, the Gaussian Low Pass Filter, the Circular Averaging Filter (Disk), and the Motion Filter.

3.1. Averaging Filter

The Averaging Filter is a simple linear filter which is easy to implement for smoothing images. It is often used to reduce noise in images. The Averaging Filter is a linear filter which uses a mask over each pixel in the signal. Each of the components of the pixels which fall under the mask are averaged together to form a single pixel. This filter is also called as mean filter. The Averaging Filter is poor in edge preserving [2]. The Averaging filter is defined by:

$$g(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x+s, y+t) \qquad \text{……………………………….. (2)}$$

where f(x,y) is the original image with size M x N, and the filter size is 3 x 3.

$$w_i = \frac{1}{9} \qquad \text{.................................. (3)}$$

where i = 1 to 9, and $w(-1,-1) = w_1, w(-1,0) = w_2, ... , w(1,1) = w_9$.

3.2. Gaussian Low Pass Filter

The Gaussian filter is a nonlinear filter that has a bell shape, and the standard deviation controls the "tightness" of the bell [6]. The Gaussian function of two variables has the basic form :

$$h(x,y) = e^{-\frac{x^2+y^2}{2\sigma^2}} \qquad \text{.................................. (4)}$$

Where σ is the standard deviation and the coordinates x and y are integers. To generate the mask from this function, we sample it about its center. Thus, $w_1 = h(-1,-1)$, $w_2 = h(-1,0)$, ... , $w_9 = h(1,1)$.

3.3. Circular Averaging Filter (Disk Filter)

The Circular averaging filter is a pillbox within the square matrix of size (2 x radius+1). The radius used in this paper is 5. This filter has the same equation of the Averaging filter with different w values.

3.4. The Motion Filter

The Linear motion filter used to represent the linear motion of the camera during the acquisition of the image. The Linear motion can be modeled using the degradation function [6]:

$$H(u,v) = \frac{T}{\pi\,(ua+vb)} \sin[\pi(ua+vb)]\, e^{-j\pi(ua+vb)} \qquad \text{.................................. (5)}$$

As seen from the equation, this function is in frequency domain. So, this filter considered one of the frequency domain filters. The output image from this filter can be computed using:

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$$g(x,y) = \mathcal{L}^{-1}\,[H(u,v)F(u,v)] \quad \text{……………………………… (6)}$$

Where F(u,v) is the Fourier Transform of the original image f(x,y), and $\mathcal{L}^{-1}$ is the inverse Fourier. Although this filter isn't used to remove Gaussian noise, it was interesting to see how this filter will affect image features compared to the previous filters.

4. THE PROPOSED ALGORITHM

Many techniques used to remove certain types of noise. The problem is that most techniques that reduce or remove noise always soften the image as well as affect the image features. The decision of the best filter for a certain type of noise should consider the affected feature in addition to the visual apperance.

In this paper, a new algorithm proposed to study the effect of different enhancement filters on image features. A data set of 100 images was used for this study. These images were taken from [6] being a dependable source of data set. The Gaussian noise first applied to each image, and then the four enhancement filter is applied to the noisy images. Some examples of applying Gaussian noise to an image and then the enhancement filters are shown in Fig. (2) and Fig. (3) .

Fig. (2): Example 1 of an image (camera man) from the data base

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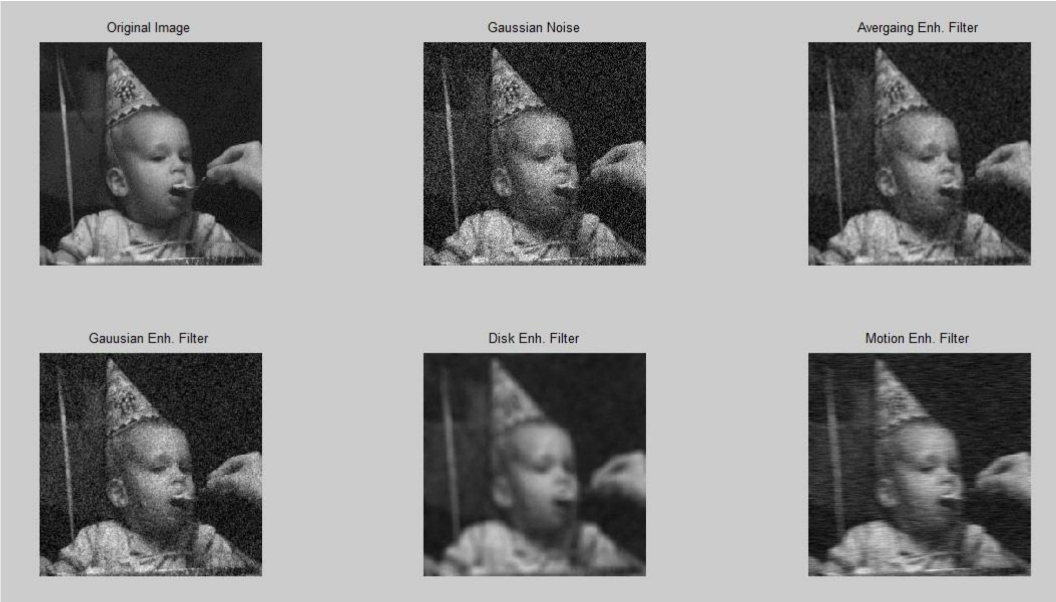

Fig. (3): Example 2 of an image (the child) from the data base

4.1. Different Noise Parameters

Since this paper need to study the effect of Gaussian noise with varity range of paprameters, Nine different cases of noise parameters were used in this paper. The different cases of used mean and variance for Gaussian noise are shown in Fig. (4).

Case 1 Noise Mean =0 Noise Variance = 0.01	Case 2 Noise Mean =0.15 Noise Variance = 0.01	Case 3 Noise Mean =0.3 Noise Variance = 0.01
Case 4 Noise Mean =0 Noise Variance = 0.02	Case 5 Noise Mean =0.15 Noise Variance = 0.02	Case 6 Noise Mean =0.3 Noise Variance = 0.02
Case 7 Noise Mean =0 Noise Variance = 0.04	Case 8 Noise Mean =0.15 Noise Variance = 0.04	Case 9 Noise Mean =0.3 Noise Variance = 0.04

Fig. (4): Different mean and variance cases of the Gaussian noise

Next, various type of features extracted from all the images. The choice of features was very important task and different categories was considered which is described in the next section.

4.2. Image Features

In this paper, various types of features were developed and compared. The features that were tested and evaluated include the mean, variance, entropy, contrast, correlation, energy, homogeneity, haar diagonal, haar Vertical, and haar Horizontal. There are three main sources for the generation of these useful features:

1. Image-based Features: Features that can be calculated directly from the image data.
2. Texture-based Features: Features that could be calculated indirectly using the co-occurrence matrix.
3. Transform-based Features: Features that take advantage of a standard coordinate system.

4.2.1. Image-based Features [6]

Image-based features can be used to represent various properties of pixels and their neighborhoods. Mean and Variance features are extracted directly from the images, as below:

$$Mean\ (\mu) = \sum_{i=0}^{L-1} z_i\, p(z_i) \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\ (7)$$

$$Variance\ (\sigma^2) = \sum_{i=0}^{L-1} (z_i - \mu)^2\, p(z_i) \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(8)$$

Where z represents the intensity value, $p(z_i)$ is the probability of these values, given $i = 0\ , 1, 2, 3, \dots \dots , L - 1$, where L is 256 for 8-bit image.

The Entropy indicator measures the disorder or randomness of the grey level distribution of an image. Its highest value is reached when all elements are equal.

$$Entropy\ e(z) = -\sum_{i=0}^{L-1} p(z_i) log_2 p(z_i) \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\ (9)$$

4.2.2. Texture-based Features [6]

The properties of an image texture are detected indirectly by using the co-occurrence matrix $\boldsymbol{G}$, Let Q be an operator that defines the position of two pixels relative to each other, and consider the image f with L possible intensity levels. The matrix $\boldsymbol{G}$ has elements g_{ij} is the number of times that pixel pairs with intensities z_i and z_i occur in f in the position specified by Q, where $1\ \leq i, j\ \leq L$.

The total number, *n*, of pixel pairs that satisfy Q is equal to the sum of the elements of $\boldsymbol{G}$**.** Then the quantity

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$$p_{ij} = \frac{g_{ij}}{n} \quad \text{……………………………. (10)}$$

is an estimate of the probability that a pair of points satisfying Q will have values (z_i, z_j).

Correlation is the measure of how a pixel correlated to its neighbors over the entire image.

$$Correlation = \sum_{i=1}^{K}\sum_{j=1}^{K}\frac{(i - m_r)(j - m_c)p_{ij}}{\sigma_r\ \sigma_c} \quad \text{……………………………. (11)}$$

Where $\sigma_r \neq 0, \sigma_c \neq 0$

$$m_r = \sum_{i=1}^{K} i \sum_{j=1}^{K} p_{ij} \quad \text{……………………………. (12)}$$

$$m_c = \sum_{i=1}^{K} j \sum_{j=1}^{K} p_{ij} \quad \text{……………………………. (13)}$$

$$\sigma_r^2 = \sum_{i=1}^{K}(i - m_r)^2 \sum_{j=1}^{K} p_{ij} \quad \text{……………………………. (14)}$$

$$\sigma_c^2 = \sum_{i=1}^{K}(j - m_c)^2 \sum_{j=1}^{K} p_{ij} \quad \text{……………………………. (15)}$$

Homogeneity is measures the spatial closeness of the distribution of elements in $\boldsymbol{G}$ to the diagonal.

$$Homogeneity = \sum_{i=1}^{K}\sum_{j=1}^{K}\frac{p_{ij}}{1 + |i - j|} \quad \text{……………………………. (16)}$$

Energy is a measure of the number of repeated pairs.

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$$Energy = \sum_{i=1}^{K}\sum_{j=1}^{K} {p_{ij}}^2 \quad \text{.................................... (17)}$$

Contrast is a measure of intensity contrast between a pixel and its neighbors over the entire image.

$$Contrast = \sum_{i=1}^{K}\sum_{j=1}^{K} (i-j)^2\, p_{ij} \quad \text{................................(18)}$$

4.2.3. Transform-based Features

Wavelet transform is an effective tool for feature extraction, because they allow analysis of images at various levels of resolution. They are good at isolating the discontinuities at edge points. Haar wavelet is one of the oldest and simplest wavelet. The Discrete Wavelet Transform (DWT) uses the Haar functions in image coding, edge extraction, it is conceptually simple, fast and memory efficient, since it can be calculated in place without a temporary array and it is exactly reversible without the edge effects that represents a problem with other wavelet transforms [9]. The structure of the 3-level wavelet decomposition is shown in Fig. (4) :

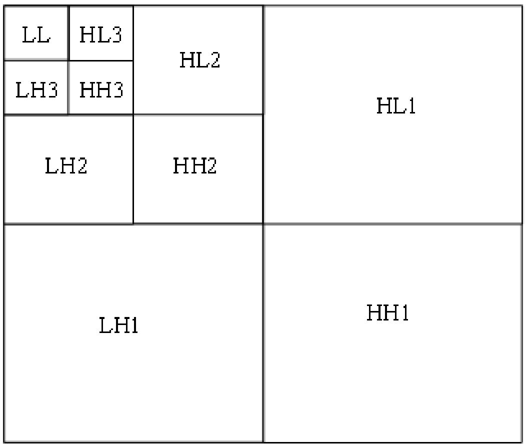

Fig. (4): Structure of Wavelet Decomposition

To obtain the wavelet features, Haar wavelet is applied to the image and performed two levels of wavelet transform. After performing the second level of wavelet transform, three features are extracted (HL, LH and HH) from the result image. The computation of these three features is described in the following equations:

$$H = \frac{1}{M\,N}\sum_{i=1}^{M}\sum_{j=1}^{N} h(i,j) \quad \text{.................................. (19)}$$

$$V = \frac{1}{M\,N}\sum_{i=1}^{M}\sum_{j=1}^{N} v(i,j) \quad \text{.................................. (20)}$$

$$D = \frac{1}{M\,N}\sum_{i=1}^{M}\sum_{j=1}^{N} d(i,j) \quad \text{.................................. (21)}$$

The parameters H, V, and D are the coefficients of the horizontal, vertical, and diagonal bands of the image. Pixel positions are defined by i and j symbols which represent rows and columns in each band.

4.3. The Mean Square Error

The Mean Square Error (MSE) used as performance measure in this paper. The MSE used for this task in the literature [3,7,10].The MSE is the cumulative square error between the filtered and the original image defined by:

$$MSE = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}[f(x,y) - \hat{f}(x,y)]^2 \quad \text{.................................. (22)}$$

Where, f is the original image and $\hat{f}$ is the noisy or filtered image. The dimension of the images is M x N. Thus MSE should be as low as possible for effective.

4.4. The proposed Algorithm

Assigning the best filters according to Gaussian noise effects are done by the following steps:

1- Start

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2- Set k=1 as a counter of images, i=0 as the Case of Noise, and j=0 as a counter of filters.

3- Extract and save the required features, as it was denoted in section 4.2

4- Increase (i)

5- Apply the case (i) of the Gaussian Noise to the (k) image

6- Repeat step 3.

7- Calculate the (MSE) between all the original image feature values and the noisy image feature values.

8- Increase (j)

9- Apply Enhancement filter type (j)

10- Repeat step 3

11- Calculate (MSE) between all the original image feature values and all the enhanced image feature values.

12- If j < (No. of filters, here 4,) then go to step (8),

13- Rank the (MSE) values from the least to the most, as from 1 to 5 respectively, of all features.

14- If i < (No. of Noise cases, here 9,) then Go to step (4)

15- Increase (k)

16- If k < No. of images, Go to step (3)

17- Set i=0

18- Increase (i)

19- For the noise case (i), find the average value of the ranked MSE of all the features, according to all the images.

20- If i < (No. of Noise cases, here 9,) then go to step (18)

21- Finally, find the average value of the ranked MSE of all features according to all Noise Cases, then rank the result too.

22- End.

5. RESULTS AND DISCUSSION

Different parameters are used for the Gaussian noise to evaluate the performance of each filter compared to the noise. The results obtained for each of the 9 cases individually measuring the effect of each filter on all the features. For each feature, the MSE were measured between the original images and the noisy images, then the MSE measured between the original images and enhanced filter images. The filter with the least MSE value considered the best in term of keeping the feature and ranked the first. The filter with the next least MSE value considerd the second and so on. Table (1) represents the results obtained from case no.1 with mean = 0 and variance = 0.01 for the gaussian noise. For each feature, the numbers in the column represents the rank compared to the others.

Table (1): Case 1 Features Rank

Average MSE Of Noise and Filters	Case 1 – Features (Normal Noise parameters)									
	Mean	**Variance**	**Entropy**	**Horizontal**	**Vertical**	**Diagonal**	**Contrast**	**Correlation**	**Energy**	**Homogeneity**
Noise	٤	٣	٤	٥	١	٤	٥	٥	٥	٥
Average Enh.	٥	٢	١	٤	٤	٥	١	١	١	١
Gaussian Enh.	٣	١	٥	٣	٢	٣	٢	٢	٣	٣
Disk Enh.	٢	٥	٣	٢	٣	١	٤	٤	٤	٤
Motion Enh.	١	٤	٢	١	٥	٢	٣	٣	٢	٢

The following points should be noted:

(a) The texture-based features responsed similarly for all the filters. The average enhanced filter were the best filter to preserve these features, and all the other filters had resulted images better than the noisy image. The motion filter had suprising results improving the noisy features instead of blurring and increasing noise effect of the image.

(b) For the wavelet-based features, the Horizontal and Diagonal features affected similarly. The Average enhancement filter were the worst according to Horizontal and Diagonal features while the Dick and Motion filters considered the best. On the other hands, all the filters made the Vertical feature worse the noise itself.

(c) The image-based features had different results, but the Entropy feature responsed in a similar way to the texture-based features.

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Since we have mean and variance as the gaussian noise parameters. We show the results of increasing the mean (case 3) and increasing the variance (case 7) to see how they affect the results comapring with case 1. Tables (2) and (3) show the results for Case 3 and Case 7 respectively.

Table (2): Case 3 Features Rank

Average MSE Of Noise and Filters	Case 3 – Features (Increased Mean Parameter of the Noise)									
	Mean	Variance	Entropy	Horizontal	Vertical	Diagonal	Contrast	Correlation	Energy	Homogeneity
Noise	٢	٢	٥	٤	٥	٥	٥	٥	٤	٥
Average Enh.	٣	٣	٢	٥	١	٤	١	١	١	١
Gaussian Enh.	٥	١	١	٢	٣	٣	٢	٢	٢	٢
Disk Enh.	٤	٥	٤	٣	٤	٢	٤	٤	٥	٤
Motion Enh.	١	٤	٣	١	٢	١	٣	٣	٣	٣

Table (3): Case 7 Features Rank

Average MSE of Noise and Filters	Case 7 – Features (Increased Variance Parameter of the Noise)									
	Mean	Variance	Entropy	Horizontal	Vertical	Diagonal	Contrast	Correlation	Energy	Homogeneity
Noise	٣	٤	٣	٥	١	٤	٥	٥	٥	٥
Average Enh.	٥	١	١	٤	٣	٥	١	١	١	١
Gaussian Enh.	٤	٢	٥	٣	٢	٣	٤	٤	٣	٤
Disk Enh.	١	٥	٤	٢	٥	٢	٣	٣	٤	٣
Motion Enh.	٢	٣	٢	١	٤	١	٢	٢	٢	٢

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The results in Table (2) and (3) show that changing the mean or variance didn't have a major impcat on filters effect on the features. The overall average results for all the 9 cases summarized in Table (4).

Table (4): All Cases Features Rank

Average MSE of Noise and Filters	All Cases – Features									
	Mean	Variance	Entropy	Horizontal	Vertical	Diagonal	Contrast	Correlation	Energy	Homogeneity
Noise	٢	٣	٥	٥	٤	٤	٥	٥	٥	٥
Average Enh.	٤	٢	١	٤	٢	٥	١	١	١	١
Gaussian Enh.	٥	١	٤	٣	٣	٣	٣	٣	٣	٣
Disk Enh.	٣	٥	٣	٢	٥	٢	٤	٤	٤	٤
Motion Enh.	١	٤	٢	١	١	١	٢	٢	٢	٢

It is interesting to observe the following results from each group of features:

(a) The texture-based features responsed similarly for all the filters. The average enhanced filter were the best filter to preserve these features, and all the other filters had resulted images better than the noisy image in term of keeping these features. The motion filter had suprising results ranking the second and improving the noisy features instead of blurring and increasing noise effect of the image.

(b) For the wavelet-based features, the Horizontal and Diagonal features affected similarly by all the enhanced filters. The Average enhancement filter were the worst according to Horizontal and Diagonal features while the Motion filter considered the best. On the other hands, the disk enhanced filter made the Vertical feature worse compared to the noisy image.

(c) The image-based features had random results, but the Entropy feature responsed in a similar way to the texture-based features for all the filters.

6. CONCLUSION AND FUTURE WORK

From the results obtained by the proposed algorithm, it can be concluded that:

1- Different filters have similar effects on Texture features.

2- According to the Texture Features, the Average enhancement filter came up with the best results.

3- According to the Wavelet-based Features, the Motion filter came up with the best results.

4- Different Filter responses according to image features could be achieved after applying Gaussian Noise with variable parameters.

5- Some Filters, like disk enhanced filter, offended the features of an image more than the noise itself.

6- Changing the Gaussian noise parameters (Mean and Variance) has no effect on filters and effects on image features, especially texture features.

For Future work, the other enhanced filters can be tested and more features can be included. For a general case, the other types of noise can be considered and an overall result of different filters affecting the features can be calculated and analyzed.

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