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IMAGE DENOISING USING SPATIAL DOMAIN FILTERS

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ABSTRACT

In image processing, the first pre-processing step is to denoise an image and it is supposed to be one of the most important tasks. In order to perform image denoising, an image is processed in such a way that various restoration techniques are used to remove induced noise as image may be corrupted with noise during acquisition, transmission or, compression process. Noise is a very common problem in images due to which the visual quality of an image is degraded and it may be Additive white gaussian noise, Impulsive noise and Multiplicative noise etc. The main aim of restoration techniques is to produce an image that closely resembles to the original image. In this research work, noisy images are generated by introducing various types of noise models in the original noise-free image and image denoising is performed by applying various types of spatial filters to different noise models. As far as the quality of an image is concerned here, it is examined by objective evaluation of an image. In this paper, one of the most important metrics called peak signal to noise ratio (PSNR in dB) is used which shows the filtering performance of a particular spatial domain filter and it also gives quantitative information of the noisy and denoised image.

Keywords:Image Processing, Image Denoising, Image Restoration, Noise Models, Spatial Domain Filters, Noisy Image, Denoised/Filtered Image, Peak Signal to Noise Ratio (PSNR).

I. INTRODUCTION

Image Denoising/ Noise Reduction is one of the traditional crisis in image processing [1]. As far as image denoising is concerned, it has remained a major problem in the field of image processing [2]. Often, images are corrupted by noise due to some imperfections in image acquisition systems &transmission channels that results in image degradation which in turn causes a significant reduction of image quality and this makes high-level vision tasks like recognition, 3D reconstruction, or scene interpretation much more difficult. There are several reasons that may cause an image degradation such as blur, motion and noise [3] but denoising has been always a major concern in image processing since decades [4]. Thus image denoising is itself an important image processing task as well as an important pre-processing step in image processing pipeline[5].The operation which is performed on an image affected by unwanted noise is referred to as an image denoising as unwanted noise adds spurious and extraneous information to an original image. This kind of unwanted noise leads to destruction of minute details in the image and such a noisy image is undesirable for human perception and for machine tasks too. Image denoising is performed to reduce or remove the noise while retaining most of the important signal features as it is [6].

The technique in which a noise free image is recovered from a corrupted and degraded image is referred to as an Image Restoration and this is one of the prime areas of image processing. Such techniques are based on mathematical & statistical models of image degradation and these techniques are oriented towards modeling the degradations and then an inverse procedure is applied to get an approximation of the original image [7]. Generally, denoising and de-blurring tasks come under this category. Thus image denoising is one of the most effective and efficient restoration process [8].

Digital filters are used to remove noise from the degraded image as any noise in the image can cause serious errors [9]. Thus the filters are the inverse degradation models of the image and when they are applied to a corrupted or degraded image, an original image can be reconstructed. As far as an image is concerned, edges and fine details are actually the high frequency contents and carry very important information. So, those filters are highly suitable for digital image filtering which can efficiently preserve edge and image detail [10]. The filters can be broadly classified into two major types i.e. Spatial Domain Filters and Transform Domain Filters. Such filters are designed in such a way that they can be used for one specific type of degradation & noise model and some filters can be useful for other types as well but no image restoration technique is universal that is suitable for all types of noise models [11]. In order to remove the noise, the noisy signal has to be passed through a filter which in turn removes the undesirable components while retaining the desirable one and the filters used for image denoising may be linear or non-linear depending on the type of noise [12].

In this paper, various spatial domain filters used for the removal of noise are discussed. These filters are applied on different noisy images having different types of noise models induced, their performance is evaluated in terms of PSNR and noisy & denoised signals are compared on the basis of PSNR.

II. NOISE MODELS

It is to be noted that the noise is undesired information which contaminates the original image. There are various types of noise that corrupts an image and the noise may be present in an image either in an additive form or in multiplicative form [7] but for an efficient denoising technique, information about the type of noise present in the degraded image is very important. A model comprises of image degradation process as well as image restoration process is shown in figure (1).

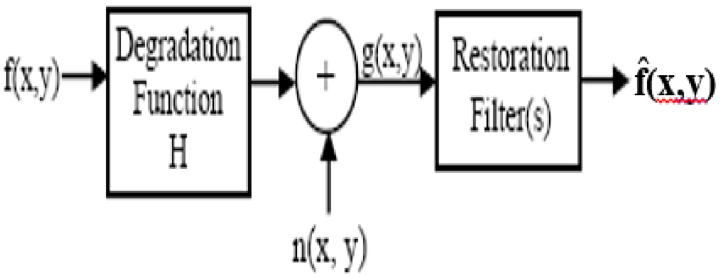

Fig. (1) Model of an Image Degradation/Restoration Process

Here, the degradation function and inverse degradation function can be mathematically represented by following equations:

$$g(x, y) = f(x, y) * h(x, y) + n(x, y) \quad (1)$$

$$\hat{f}(x, y) = D \, . \, g(x, y) \quad (2)$$

where, f(x,y) is the original noise free image, h(x,y) be the degradation function, n(x,y) is the additive noise model induced in the image and g(x,y) is the resulting noisy image [13]. Here, ‘*’ denotes convolution, ‘D’ be the inverse degradation function and $\hat{f}(x,y)$ is the reconstructed or, denoised image achieved by applying the restoration model. The various types of noise models are discussed below:

2.1 GAUSSIAN NOISE

It is one of the most commonly found noise in images and also called Additive White Gaussian Noise (AWGN) or normal noise. This type of noise is generally added to an image during image acquisition like sensor noise which is caused by low light, high temperature and transmission such as electronic circuit noise or Amplifier noise [14].The Probability Density Function (PDF) of Gaussian distribution [15] is given by equation (3) and its plot is shown in figure (2).

$$P(z) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(z-\mu)^2}{2\sigma^2}} \qquad (3)$$

where, z represents the gray level, μ is the mean or average value of z, σ be the standard deviation of the noise and σ^2 is the variance of z.

2.2 SALT & PEPPER NOISE

Another kind of noise that is present during the image transmission is Salt &Pepper noise [16]. Salt and pepper noise is also called an Impulse noise or Spike noise. It appears as white and/or black impulse of the image and caused due to malfunctioning of pixels in camera sensors, faulty memory locations in hardware, or transmission in a noisy channel [17]. Due to this type of noise, white and black spots are appeared in gray scale images. In other words, salt &pepper noise results in dark pixels in bright regions and bright pixels in dark regions in an image [18].The PDF of Impulse noise is given by equation (4) and it is represented graphically as shown in figure (3).

$$P(z) = \begin{cases} p_a, & \text{for } z = a \\ p_b, & \text{for } z = b \\ 0, & \text{otherwise} \end{cases} \qquad (4)$$

2.3 POISSON NOISE

The Poisson noise is a type of electronic noise and it is also referred to as Photon noise or Shot noise. If number of photons sensed by the sensor is not sufficient enough to provide detectable statistical information, then such type of noise occurs having Poisson distribution [19]. The PDF of Poisson Noise [13] is given by equation (5) and its plot is shown in figure (4).

$$P(z) = \left(e^{-\lambda} \frac{\lambda^z}{z!}\right), \quad \text{for } z = 0,1,2, \dots \dots \dots \qquad (5)$$

where, λ being the expectation value and $\lambda > 0$. It is also known as the event rate or the rate parameter.

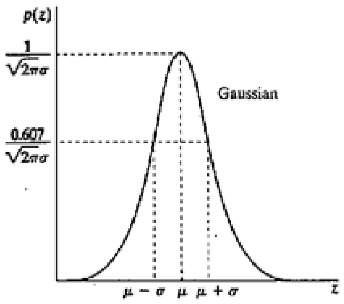

Fig. (2) PDF of Gaussian Noise

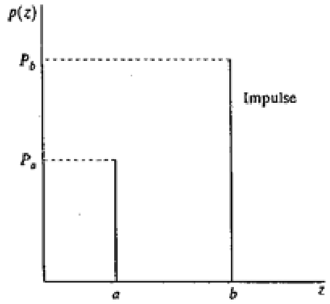

Fig. (3) PDF of Salt & Pepper Noise

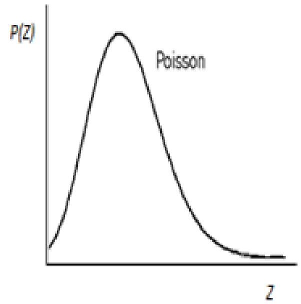

Fig. (4) PDF of Poisson Noise

2.4 UNIFORM NOISE

The Uniform noise arises due to quantization of pixels of an image to a number of discrete levels. Hence it is also known as Quantization noise and has approximately uniform distribution. Thus various levels of gray values of the noise are uniformly distributed over a specified range and this type of noise provides one of the most neutral noise. The PDF of Uniform noise [13] is given by equation (6) and its plot is shown in figure (5).

$$P(z) = \begin{cases} \frac{1}{(b-a)}, & \text{for } a \leq z \leq b \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

The mean and variance of Uniform noise are defined as:

$$\mu = \frac{(a+b)}{2} \quad \text{and} \quad \sigma^2 = \frac{(b-a)^2}{12}$$

2.5 RAYLEIGH NOISE

This type of noise can be modeled by the Rayleigh distribution and is typically found in RADAR range and velocity images. The PDF of Rayleigh noise is given by equation (7) and it is represented graphically as shown in figure (6).

$$P(z) = \begin{cases} \frac{2}{b}(z-a)e^{\frac{-(z-a)^2}{b}}, & \text{for } z \geq a \\ 0, & for\ z < a \end{cases} \quad (7)$$

The mean and variance of Rayleigh noise are given as:

$$\mu = a + \sqrt{\frac{\pi b}{4}} \quad \text{and} \quad \sigma^2 = \frac{b(4-\pi)}{4}$$

2.6 GAMMA NOISE

The Gamma noise is also known as Erlang noise. The PDF of Gamma noise is given by equation (8) and its plot is shown in figure (7).

$$P(z) = \begin{cases} \frac{a^b z^{(b-1)}}{(b-1)!} e^{-az}, & \text{for } z \geq 0 \\ 0, & for\ z < 0 \end{cases} \quad (8)$$

where, a >0 and b is a positive integer.

The mean and variance of Gamma noise are given as:

$\mu = \frac{b}{a}$ and $\sigma^2 = \frac{b}{a^2}$

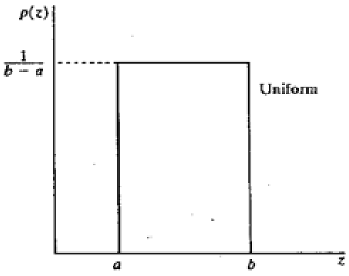

Fig. (5) PDF of Uniform Noise

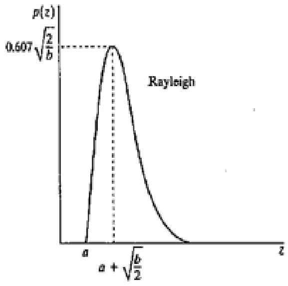

Fig. (6) PDF of Rayleigh Noise

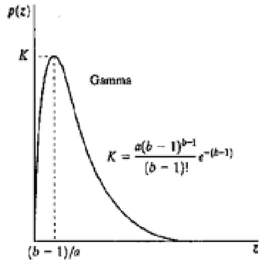

Fig. (7) PDF of Gamma Noise

2.7 EXPONENTIAL NOISE

This type of noise is a special kind of Gamma noise having value of positive integer b equal to unity. The PDF for Exponential noise is given by equation (9) and it is represented graphically as shown in figure (8).

$$P(z) = \begin{cases} ae^{-az}, & \text{for } z \geq 0 \\ 0, & for\ z < 0 \end{cases} \tag{9}$$

The mean and variance of Exponential noise can be defined as:

$\mu = \frac{1}{a}$ and $\sigma^2 = \frac{1}{a^2}$

2.8 SPECKLE NOISE

The Speckle noise is a granular noise, multiplicative in nature and severely corrupts an image [20]. When the magnitude of image pixel is high then the noise will also be high. Thus, this type of noise is a signal dependent noise and it is also known as multiplicative noise. As far as speckle noise is concerned, it is usually encountered in almost all coherent imaging systems like laser, acoustics, SAR (Synthetic Aperture Radar), bio-medical applications like ultrasonic imaging. Such type of noise reduces the image resolution and contrast due to which the diagnostic value of this imaging modality is affected. Hence, reduction of speckle noise is an essential pre-processing step especially in the case of ultrasound imaging used for medical imaging. This particular noise follows a gamma distribution [8] and the plot of its PDF is shown in figure (9).

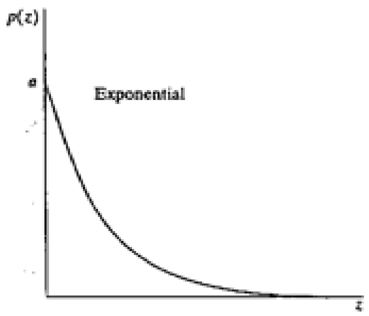

Fig. (8) PDF of Exponential Noise

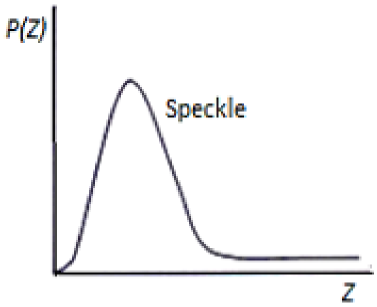

Fig. (9) PDF of Speckle Noise

III. IMAGE DENOISING FILTERS IN SPATIAL DOMAIN

By using various filters, the noise in the noisy image can be filtered out while retaining the desirable components. Thus filter is supposed to be one of the most important subsystem of any signal processing systems. In the spatial domain, filters are broadly classified into two major categories i.e. linear filters and non-linear filters. In linear filtering, lines &other fine details present in the image are destroyed and sharp edges are generally blurred. In order to preserve signal structure especially edge information, non-linear filtering techniques are used and become more popular. The median filter first suggested by Tukey in 1971 is the most popular order statistics filter among non-linear image filters [10]. Actually, the type and amount of noise present in an image decides the type of filter to be used for denoising a particular noisy image because various filters are capable of removing various types of noise efficiently and some of the filters under spatial domain category are discussed below:

3.1 ARITHMETIC MEAN FILTER

The filtering operation which is performed directly on the image pixels is referred to as Spatial Filtering and in this filtering process, the filter mask is simply moved from one point to another point in an image. The arithmetic mean filter is supposed to be one of the most simplest linear filter among the existing spatial filters and it is also known as the averaging filter because its output is actually the average of all pixels lying in the neighbourhood of the filter mask. In other words, it simply determines the average value of all intensities of the neighbourhood of the centre pixel in an input image and this particular centre pixel is replaced by the average value in the output image. This filter is also called a smoothing filter because it decreases the variations of intensity between adjacent pixels [11] but it blurs the edges of the image and is commonly useful in removing irrelevant details from an image [13]. Mathematically, the mean filter can be represented by equation (10):

$$\hat{f}(x,y) = \frac{1}{(mn)} \sum \{g(s,t)\} \qquad \text{where, } (s,t) \in s_{xy} \tag{10}$$

Here, the filter operates on (m x n) mask, S_{xy} represents the set of coordinates in a rectangular subimage window having a center at (x,y). This particular filter calculates the mean or, average of the corrupted image g(x,y) under the area S_{xy}, and $\hat{f}(x,y)$ represents the reconstructed or, restored image. Generally, linear filters are used for noise suppression [19].

3.2 MEDIAN FILTER

The median filter is one of the most popular order statistic or, rank filter due to its edge preserving nature [21]. It is most commonly used non-linear filter and non-linear filter can be effectively used in noise reduction. In this particular filter, the pixel value of image is actually replaced by the median value. The median filter is excellent at noise removal and can be mathematically represented by equation (11):

$$\hat{f}(x,y) = \text{median}\ \{g(s,t)\} \qquad \text{where, } (s,t) \in s_{xy} \tag{11}$$

3.3 MINIMUM (MIN) FILTER

The minimum filter is also referred to as the 0^{th} percentile filter. This type of filter replaces the value of the pixel with the minimum intensity level of the neighbourhood of that pixel and it actually finds the darkest points in an image [21]. The min filter can be mathematically represented by equation (12):

$$\hat{f}(x,y) = \min\{g(s,t)\} \qquad \text{where, } (s,t) \in s_{xy} \qquad (12)$$

IV. RESULTS & DISCUSSION

To perform the simulation, matlab software is used. Here, the original image shown in figure (10) is a standard grayscale cameraman image of size256 x 256.

Fig. (10) Original Image (cameraman Image)

The main aim is to introduce different types of noises in an original image and filtering out them using various types of filters. The results obtained are discussed and shown in figures (11) to (18).

- Firstly, noisy image shown in figure (11a) is created by adding gaussian noise to an original image which is then filtered out by median filter. Now, the filtered image shown in figure (11b) is produced which resembles to an original image. It shows that the median filter is the best to discard gaussian noise.

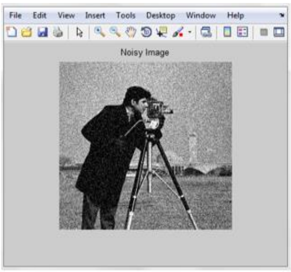

Fig. (11a) Noisy Image (Gaussian noise)

Fig. (11b) Median Filtered Image

- Again, noisy image shown in figure (12a) is generated by introducing salt & pepper noise in an original image and this type of noise is well filtered out by using median filter that gives us a filtered image as shown in figure (12b). With this filter, the salt & pepper noise is almost completely filtered out and the final image looks like the original one. As far as the quality and clarity of filtered image is concerned, median filter gives better performance.

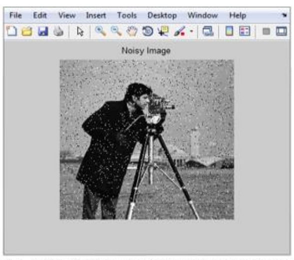

Fig. (12a) Noisy Image (Salt & Pepper noise)

Fig. (12b) Median Filtered Image

- After this, the poisson noise is added to an original image to generate a noisy image shown in figure (13a), then this noise is filtered out by using median filter. Hence, filtered image shown in figure (13b) is created but the final image shows that this filter does not completely remove the noise.

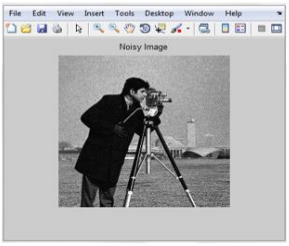

Fig. (13a) Noisy Image (Poisson noise)

Fig. (13b) Median Filtered Image

- Now, the noisy image shown in figure (14a) is created by adding uniform noise to an original image. This type of noise is filtered out by using min filter and the filtered image shown in figure (14b) looks like an original image but not exactly same. It means that this type of filter does not remove the noise completely but partially.

Fig. (14a) Noisy Image (Uniform noise)

Fig. (14b) Minimum Filtered Image

- Another noise that is added to an original image is of rayleigh type and the noisy image is shown in figure (15a). To filter out this noise from the noisy image, min filter is used and the filtered image shown in figure (15b) is generated but the quality of the final image is not good.

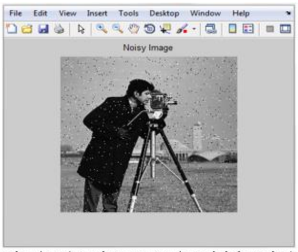

Fig. (15a) Noisy Image (Rayleigh noise)

Fig. (15b) Minimum Filtered Image

- Now, the noisy image shown in figure (16a) is generated by adding exponential noise to an original one and noise filtering is accomplished by using arithmetic mean filter. This filter removes the noise to a certain extent and thus, the filtered image produced is shown in figure (16b).

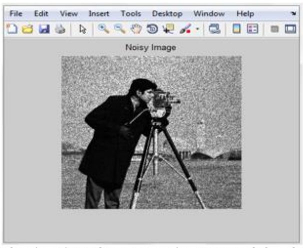

Fig. (16a) Noisy Image (Exponential noise)

Fig. (16b) Arithmetic Mean Filtered Image

- Another noise that corrupts an original image is the gamma noise and a noisy image is generated which is shown in figure (17a). To remove this noise, median filter is used and the filtered image shown in figure (17b) is obtained which closely resembles to that of the original image. It means that the median filter is best fit for the gamma noise.

Fig. (17a) Noisy Image (Gamma noise)

Fig. (17b) Median Filtered Image

- Finally, the noise that corrupts an original image is the speckle noise and the noisy image is shown in figure (18a). In order to discard this type of noise, median filter is used. It gives best result in terms of clarity of an image that can be depicted from figure (18b).

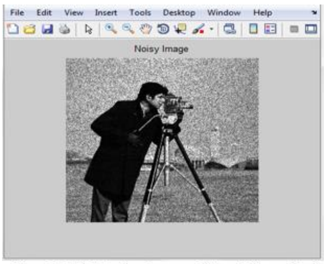

Fig. (18a) Noisy Image (Speckle noise)

Fig. (18b) Median Filtered Image

In this research work, the quantitative performance of the spatial filters is accessed by one of the most important quality metrics i.e., peak signal to noise ratio (PSNR) measured in decibel (dB) and for gray scale, it can be mathematically represented by equation (13):

$$\text{PSNR} = 10\log_{10}\left(\frac{255^2}{\text{MSE}}\right) \quad (13)$$

where, MSE is the mean square error between the original and the denoised image.

Table (1) depicts the filtering performance of various spatial domain filters in terms of PSNR operated on cameraman image. Here, PSNR of noisy and denoised/filtered signals is calculated.

Table 1: PSNR of Noisy and Denoised Signals for various Noise Models

S.No.	Type of Noise Models	Type of Spatial Domain Filters	PSNR of Noisy Signal (dB)	PSNR of Denoised Signal (dB)
1.	Gaussian	Median	20.37	24.28
2.	Salt & Pepper	Median	17.94	26.82
3.	Poisson	Median	21.23	24.98
4.	Uniform	Minimum	16.28	19.12
5.	Rayleigh	Minimum	17.01	20.76
6.	Exponential	Arithmetic Mean	16.98	20.98
7.	Gamma	Median	19.25	23.89
8.	Speckle	Median	18.62	22.31

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The graph shown in figure (19) provides the comparison between noisy and denoised signals on the basis of PSNR for various noise models.

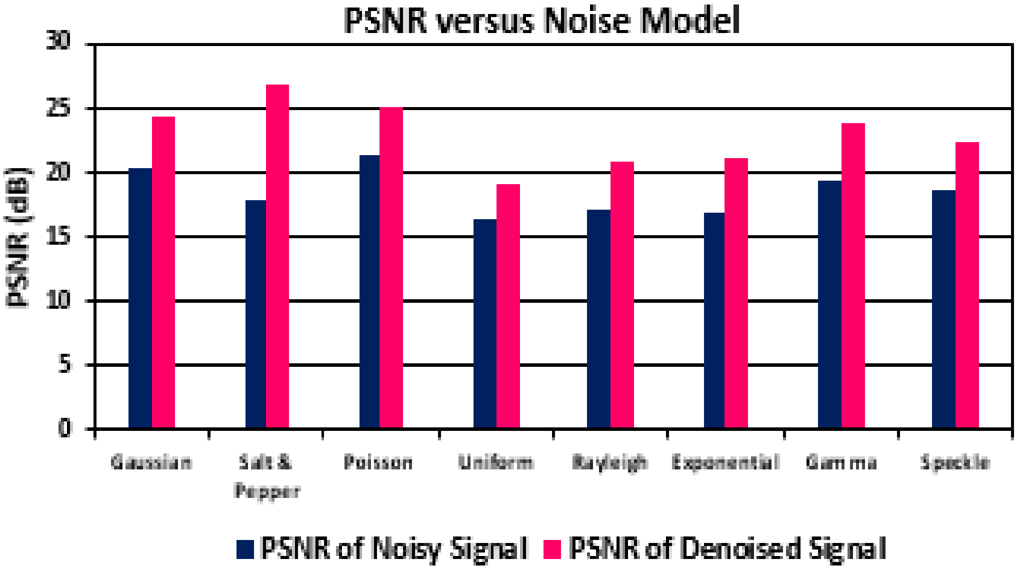

Fig. (19) Comparison between Noisy & Denoised Signals on the basis of PSNR (dB) for various Noise Models

The more the value of PSNR of denoised signal with respect to the PSNR of noisy signal, the better is the quality of the filtered/denoised image.

V. CONCLUSION

In this research work, the concept of image degradation and restoration has been discussed. Here, the eight different types of noise models including gaussian, salt & pepper, poisson, uniform, rayleigh, exponential, gamma and speckle noise have been discussed and simulated on the standard cameraman image. The linear and non-linear spatial domain filtering techniques also have been discussed. Then different spatial filters including arithmetic mean, median and min filter have been discussed and applied on various noisy images to filter out the noise. The performance of various filters has been evaluated on the basis of PSNR. According to the simulation results, the best filter is the median filter to remove gaussian, salt & pepper, poisson, gamma and speckle noise respectively while min filter removes uniform & rayleigh noise efficiently and arithmetic mean filter performs well in removing exponential noise. On the other hand, there are certain limitations of image filtering in spatial domain as it does not remove the noise from the degraded image completely rather partially and increase in the density of noise in an image would result in the blurred image after filtering which is undesirable. But irrespective of these limitations, most of the spatial filters reconstructs the original image from the degraded image efficiently and effectively.

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