Various Types of Noise and Filtering Techniques for Digital Images: A Comprehensive Study

Abhishek Gupta*, Ramapati Mishra**, Ashutosh Kumar Singh***
*Research Scholar, **Professor, ***Associate Professor
Electronics and Communication Engineering Department
Institute of Engineering and Technology, Dr. Ram Manohar Lohia Avadh University, Ayodhya, India

Abstract-

While capturing, processing, transmitting and reproducing, images are frequently affected by noise. A primary goal of image processing is to restore the original image after the noise has been removed. Without previous understanding of the noise model, removing noise from digital pictures or documents is extremely challenging job. As a result, while studying picture de-noising algorithms, a review of noise models is necessary. We present a quick review of several noise models in this work. We can assume that the noise model is spatial invariant that is not dependent of spatial location. We offer a comprehensive and quantitative study of noise models in digital images. To enhance the quality of images by removing various types of noise, a number of filtering techniques are used.

Keywords- Gaussian noise, Exponential noise, Rayleigh noise, Speckle noise, Erlang noise, Probability density function (PDF)

I. INTRODUCTION

Noise not only lowers picture quality, but it may also lead to the loss of important information that is hidden inside images. Noise in digital image processing has been addressed in all the existing studies; it usually occurs during the image acquisition, processing and transmission stages. The original information in the picture, speech and video transmission is disrupted by the presence of noise. Additive, multiplicative and mixed noise are the three types of noise. In this context, researchers may wonder how much of the original signal has been distorted, how we might recover the original signal and which noise model is linked with the noisy image [12].

To remove the noise from images is very important aspect in image processing since, it is very useful for the analysis of images. So, to enhance the quality of images by removing various types of noise, a number of filtering techniques can be used. In the purview of image processing, these de-noising approaches are known as filters. A diverse variety of fil ters are available in the existing literature. The most common filtering techniques that are widely used in image de-noising are linear and non-linear filtering techniques [5]. This article discusses the most commonly used filters in image de-noising techniques.

II. NOISE

Noise is a random variation in digital images that may cause different intensity value of pixels instead of true pixel values. Noise not only lowers picture quality, but it may also lead to the loss of important information that is hidden inside images. Noise affects the picture elements or pixel values of an image, which may result in variation of colour or brightness. Noise is generally added in the digital image during its acquisition or transmission [3].

The quality of image sensors is altered by various parameters like atmospheric conditions at the time of image acquisitions as well as the quality of sensor itself. Digital images are degraded during its acquisition and transmission due to the electromagnetic interference in the channel [4].

The major sources of noise in digital images are caused from environmental disturbances, insufficient light levels, image sensor and interference in the transmission channel. So, we can assume that the noise model is spatial invariant that is not dependent of spatial location.

A. Noise Models

A noisy image can be modelled by an equation as follows:

$$g(x, y) = f(x, y) + \eta(x, y)$$

Where, f(x, y) = Original image

η (x, y) = Noise added to the original image

g (x, y) = Resulting image with noise

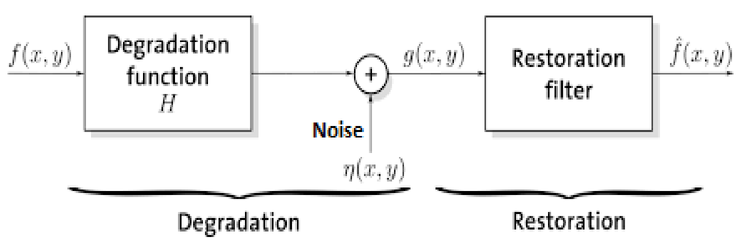

Figure 1-3: Image degradation model

B. Classification of Noise

In image processing, there are many different forms of noise that impact the image in different ways. Some of the most common types of noise are explained as follows:

1) Gaussian Noise

This noise primarily occurs in images during its acquisition. It has the same Probability Density Function (PDF) as the normal distribution, commonly known as the Gaussian distribution. It is also known as electronic noise since it arises in amplifiers or detectors. These noise models are mostly used because of its tractability in both spatial and frequency domain [6]. The PDF of Gaussian random variable can be defined by the following equation:

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

Where, z = Intensity

$\bar{z}$ = Mean value of z

σ = Standard deviation

σ^2 = Variance of z

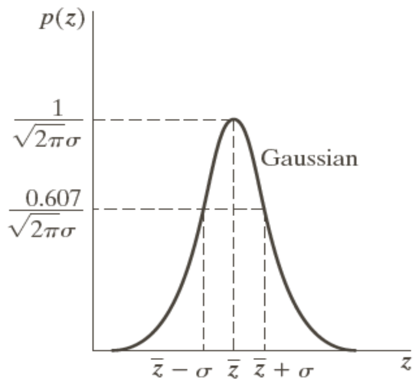

Figure 1-4: PDF of Gaussian noise

2) *Rayleigh Noise*

The PDF of Rayleigh noise is given by the equation as follows:

$$p(z) = \begin{cases} \frac{2}{b}(z-a)e^{-(z-a)^2/b} & z \geq a \\ 0 & z < a \end{cases}$$

The density's mean and variance are calculated as follows:

$$\mu = a + \sqrt{\frac{\pi b}{4}}$$

$$\sigma^2 = \frac{b(4-\pi)}{4}$$

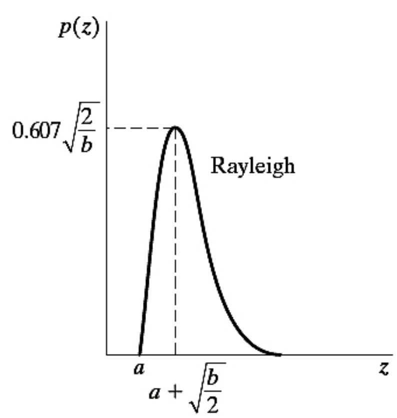

Figure 1-5: PDF of Rayleigh noise

3) Exponential Noise

The PDF of exponential noise is defined as follows:

$$p(z) = \begin{cases} ae^{-az} & z \geq 0 \\ 0 & z < 0 \end{cases}$$

Where, a>0

The density's mean and variance are calculated as follows:

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

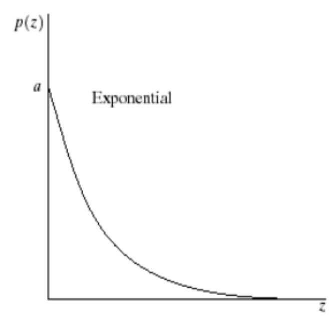

Figure 1-6: PDF of exponential noise

4) Speckle Noise

This type of noise is multiplicative in nature. In an image, speckle noise might seem similar to Gaussian noise. Its probability density function follows gamma distribution [2].

5) Impulse Noise

It is referred to as the salt and pepper noise because, black dots appear in bright regions and white dots appears in dark regions as a result of this noise. This noise primarily occurs during transmission or conversion process. Salt noise has a pixel value of 255 in an 8-bit picture, while pepper noise has a pixel value of 0. The following is the PDF for Impulse noise:

$$p(z) = \begin{cases} P_a & for \quad z = a \\ P_b & for \quad z = b \\ 0 & otherwise \end{cases}$$

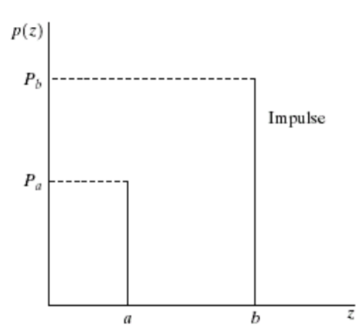

Figure 1-7: PDF of impulse noise

6) *Uniform Noise*

Uniform noise is also called as Quantization noise due to the fact that it is made by converting the pixels of a detected image into discrete levels. It has usually uniform distribution. The PDF of uniform or quantization noise is given as follows:

$$p(z) = \begin{cases} \dfrac{1}{b-a} & if\ a \le z \le b \\ 0 & otherwise \end{cases}$$

The mean and variance of uniform noise are given as follows:

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

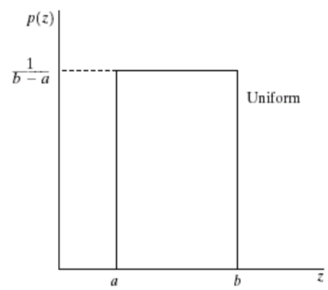

Figure 1-8: PDF of uniform noise

7) *Erlang (Gamma) Noise*

The PDF of Erlang or gamma noise is given as follows:

$$p(z) = \begin{cases} \dfrac{a^b z^{b-1}}{(b-1)!} e^{-az} & z \ge 0 \\ 0 & z < 0 \end{cases}$$

The mean of this density is given by:

$$\mu = \frac{b}{a}$$

And, the variance of this density is given by:

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

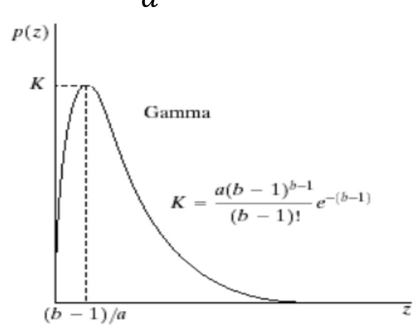

Figure 1-9: PDF of Erlang noise

C. Image Filtering Techniques

The retrieval of the original picture without noise is a key problem in digital image processing. So, to enhance the quality of images by removing various types of noise, a number of filtering techniques can be used. We can maintain picture features while also improving the quality of a complex degraded image by employing multiple filters. Filters are unique tools that take a picture as input, apply an algorithm to it, and then return the image in a changed version with reduced or no noise impact.

In the realm of image processing, picture de-noising is a critical task. De-noising a picture can be done in a variety of methods. The most essential feature of a good image de-noising model is that it should eliminate all noise from pictures while also restoring the edges. Previously, linear filters were employed to de-noise pictures; however linear filters perform poorly when dealing with non-additive disturbances. In case of non-linearities or non-Gaussian statistics system the performance of linear filters is also not so good. The linear filters are used frequently because of its fast processing operation but it lacks in preserving edges Non-linear filters, on the other hand, can maintain text edges but are limited by slow processing [11].

To remove the noise from images is very important aspect in image processing since it is very useful for the analysis of images. There are plenty of image de-noising techniques available, but an ideal filter must remove the noise completely from a complex image as well as restore every single detail available in the original image. Image filters can be primarily categorized as averaging filter, adaptive filter and order statistics filter [10].

The most common filters that are widely used in image de-noising are linear and non-linear filtering techniques. The outcome of a linear filtering technique is linear, whereas the output of a non-linear filtering approach is non-linear. A mean filter is a sort of linear spatial filter that transforms a noisy pixel value to the mean of its neighbours [7]. The most widely used filters in image de-noising techniques are discussed as follows:

1) Mean Filter

Mean filter is a type of spatial filter which is used when additive noise is present in the image. It is a simple and easy filter that can be used to reduce the amount of intensity variation between one pixel and the next. The idea of mean filtering is simply to replace each pixel value in an image with the mean value of its neighbours. There are three types of mean filters.

i) Arithmetic Mean Filter

Arithmetic mean filter is the simplest mean filter. This filter computes the average or mean value of the noisy image in a specific area and the arithmetic mean calculated in the pixel region is then used to find the restored image. The restoration of image can be given by the below equation.

$$\hat{f}(x,y) = \frac{1}{mn} \sum_{(s,t)\in S_{xy}} g(s,t)$$

Where, 1/mn is the coefficient value of spatial filter (m X n size).

g(s, t) is the function that represents pixel value of noisy image on (s, t) coordinates inside a rectangular window.

ii) Geometric Mean Filter

A new pixel value for image restoration can be calculated using geometric mean filter expression as follows

$$\hat{f}(x,y) = \left[\prod_{(s,t)\in S_{xy}} g(s,t) \right]^{\frac{1}{mn}}$$

iii) Harmonic Mean Filter

The harmonic mean filter efficiently work on Gaussian noise as well as on salt noise but fails when pepper noise is present. The image is restored using harmonic mean filter by the below expression

$$\hat{f}(x,y) = \frac{mn}{\sum_{(s,t)\in S_{xy}} \frac{1}{g(s,t)}}$$

2) Median Filter

Median filter is the best known order statistic filter, but it works very efficiently for images in which unipolar as well as bipolar impulse noise is present. Median filter changes the pixel value with the median of neighbourhood pixels. But, the problem with this filter is that all the pixels are replaced with the median of the window regardless of the pixel is uncorrupted. That makes the overall visual quality of the image poor. Moreover, the median filter alone fails to restore the edges as well [7].

The median filter can be defined by the expression as below

$$\hat{f}(x,y) = \underset{(s,t)\in S_{xy}}{\text{median}} \{g(s,t)\}$$

Where, g(s, t) defines the pixel intensity value that is located with (s, t) coordinates inside the window.

Median filter can remove impulse noise easily without reducing the sharpness of a complex image. The median is calculated in this filter by grouping the pixel values from the neighbourhood into numerical order and then replacing the pixel value with the value of the middle pixel.

3) *Maximum & Minimum Filter*

The maximum and minimum filter is a linear filter that chooses the maximum and minimum pixel values from a vicinity of distorted pixels and replicates them with those values. The maximum and minimum values are found from all the neighbourhood pixels and stored the resulting values. Finally, each pixel is replaced with the resulting value which is generated for its neighbourhood pixels [7].

The Maximum filter is used to find the brightest point in a complex image and pepper noise is also reduced after maximum operation. It is defined by the below expression

$$\hat{f}(x,y) = \max_{(s,t)\in S_{xy}} \{g(s,t)\}$$

The Minimum filter is used to find the darkest point in a complex image. After the application of minimum filter, salt noise reduces rapidly. It is defined by the expression as follows:

$$\hat{f}(x,y) = \min_{(s,t)\in S_{xy}} \{g(s,t)\}$$

4) Alpha-Trimmed Mean Filter

The alpha-trimmed filter is the best suitable for noise combinations such as impulse noise with Gaussian noise. The trimming parameter α is used to control the number of input values which are dropped from the average value and depending on the value of α, this filter rejects the smaller and the larger data. Moreover, various metrics of images and complexity are considered for further analysis. The alpha-trimmed mean filter is defined by the following equation:

$$\hat{f}(x,y) = \frac{1}{mn-d} \sum_{(s,t)\in S_{xy}} g_r(s,t)$$

5) Gaussian Filter

A Gaussian filter is a linear filter that selects weights depending on the Gaussian function's shape. Gaussian smoothing filters, whether in the spatial or frequency domain, are a type of low-pass filter that may be used to eliminate noise that follow a normal distribution. As a result, it has a wide range of possible image processing applications. [9].

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

6) Weiner Filter

The Wiener filter is based on the idea that images and noise are random processes, with the objective of estimating the undistorted image with the least mean square error (MSE) possible. The Wiener filter, in other words, is a linear estimation method [1].

The Wiener filter is a statistical approach for filtering data. To create this filter, we require the original picture's spectral characteristics, noise, and a linear time-variant filter whose output must be close to the original image. [8].

III. CONCLUSION

Image noise is seen during its capture and transmission. Image denoising is the first stage in image processing. Various noise models accessible in digital images have been examined and presented in this article. In digital pictures, noise models are also constructed utilising a probability density function with mean and variance. In this article, we discussed several filtering algorithms that have been described in the literature. Each filter has its unique set of characteristics. The suitable filter is selected based on the type of the noise and the amount of filtering required. We believe that our work will serve as a useful resource for researchers and of course, newcomers to the field of image processing.

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AUTHORS

Abhishek Gupta received B.Tech degree in Electronics Engineering from Institute of Engineering and Technology, Lucknow in 2013. Presently, he is working in the Department of Technical Education, Uttar Pradesh. Currently, pursuing his M.Tech degree from Institute of Engineering and Technology, Dr. Ram Manohar Lohia Avadh University, Ayodhya. His area of interest includes Image Processing and Digital Signal Processing.
E-mail: abhishekdte@gmail.com

Ramapati Mishra received B.Tech degree in Electronics and Communication Engineering in 1990, M.Tech degree in Electronics (optical communication) in 2000 and Ph.D. in Electronics (optical Amplifiers in optical communication) in 2010. He is a member of IEEE, IETE and IEI. He has published around 20 research papers in various national and international journals and conferences. He has guided about 12 M.Tech. Thesis and is also supervising Ph.D. work. His research interest includes Radar Technology, Optical communication and Digital Signal Processing. (CORRESPONDING AUTHOR)
E-mail: director.rpm@gmail.com

Ashutosh Kumar Singh received B.Tech degree in Electronics and Communication Engineering from P.S.I.T., Kanpur in 2008, M.Tech degree in Digital Systems from M.M.M. Engineering College in 2011, Gorakhpur and Ph.D. from University of Allahabad in 2018. He has published around 25 research papers in various national and international journals and conferences. His research interest includes Digital Systems, Optical Communication, Optical Networks, Survivable Optical Networks and Digital Signal Processing.
E-mail: aksinghelectronics@gmail.com