De-Noising of AWGN, Speckle, Poisson, Amplifier, Blurredness and Impulse type Noises from Digital images using Linear, FIR, Median and Adaptive Filtering Techniques

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Abstract: Image denoising is very important during enhancement of image. Original Image is generally corrupted with various types of noise. The noise present in the images may appear as additive or multiplicative components. The most challenging problem is removing that noise from an Image while preserving its details. Several noise removal techniques have been developed so far each having its own advantages and disadvantages. The focus of this paper is to study various spatial filters and to remove different types of noise.
Keywords: Image denoising, Additive or Multiplicative Noise, Peak Signal to Noise Ratio.

1. INTRODUCTION

Digital images play a crucial role in different areas like television, remote sensing, ultrasound, CT scan etc. They are also used in various research areas like Uranology. Images captured by different devices generally add the different types of noise in them while capturing due to faulty instruments or wrong methods of data capturing. Sometimes noise is added to an image during its transmission over various media. So, denoising the image is an essential task and it is generally done before considering the image for various purposes. An Ideal denoising technique should be able to remove most of noise from image while preserving its fine details [17].

Image denoising is considered as an important step and is generally done prior to processing of an image. It shows the process of recovering a good estimate of the original image from a corrupted image without modifying the useful structure in the image such as edges, discontinuities and fine details [9]. Generally speaking, denoising is the process of removing the unwanted noise from the corrupted image and reconstructing the original image. The main challenge is to design such noise removing techniques which should be able to remove most of noise from noisy image with minimum or no loss of its significant details [13]. It has many applications in other domains like object recognition, digital entertainment, and remote sensing imaging etc. As the number of image sensors per unit area increases, camera devices capture the noise with the image more often. Denoising techniques have become a vital step for improving the visual quality of images which are degraded by different types of noise [2] [6] [7].

Noise can be categorized as Gaussian noise, Uniform noise, Impulse noise (salt and pepper noise)[14][12] Erlang noise/Gamma noise, Rayleigh noise and Speckle noise each having its own probability density function.

2. NOISE MODELS

Noise is generally added to image during image capturing or due to faulty image capturing hardware. For e.g. during acquiring images with CCD camera, the two major factors which affect the amount of noise in the image are sensor temperature and light levels. Images are also corrupted during transmission due to interference in the channel [11].
The degradation process is shown below. Here degradation function and additive noise, both are added to the original input image f(x,y) to produce a degraded image g(x,y).Given g(x,y), some idea about the degradation function H and additive noise term n(x.y), one can achieve the estimate f^(x,y), of the original input image by using the restoration model. In general, the more one has idea about H and n(x,y), the closer estimate to f(x,y) one will obtain. The degradation model can be represented with the following equation.

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

Here f(x,y) is the original image pixel value and n(x,y) is the additive noise, h(x,y) be the degradation function and g(x ,y) is the resulting noise image[19].
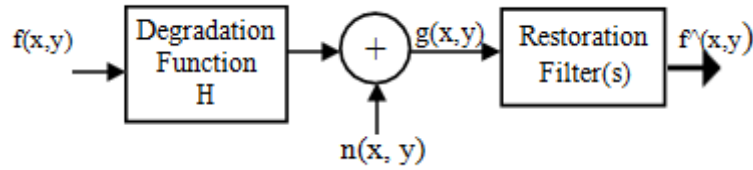
Fig. A model of the image degradation/restoration process

The Different types of Noise models are described below:

2.1 Gaussian Noise or Amplifier Noise

It is also known as Gaussian distribution. It has a probability density function (PDF) of the normal distribution. This noise is added to image during image acquisition like sensor noise caused by low light, high temperature, transmission e.g. electronic circuit noise [7]. This noise can be removed by using spatial filtering (mean filtering, median filtering and Gaussian smoothing) by smoothing the image but smoothing also blurs the fine-scaled image edges and details [4]. The PDF of Gaussian Noise is shown in the following equation and figure:
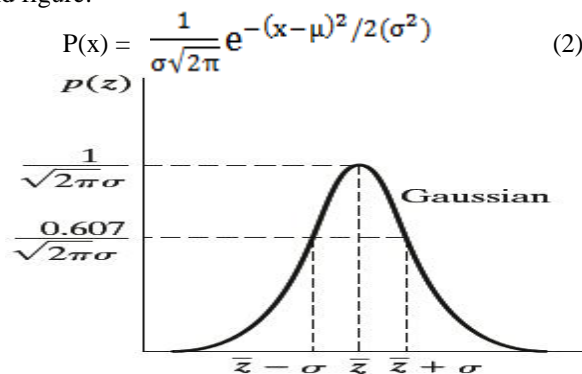
$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2(\sigma^2)} \qquad (2)$$

Fig. PDF of Gaussian Noise

2.2 Impulse Noise

The Impulse noise is also known as Salt & Pepper noise or Spike noise. It is caused by malfunctioning pixels in camera sensors, faulty memory locations in hardware, or transmission in a noisy channel [1]. It is always Independent and uncorrelated to image pixels. Its two types are the salt-and- pepper noise and the random-valued noise. In salt and pepper type of noise, the noisy pixels takes either salt value (gray level -225) or pepper value (grey level -0) and it appears as black and white spots on the images In case of random valued impulse noise, noise can take any gray level value from zero to 225. In this case also noise is randomly distributed over the entire image and probability of occurrence of any gray level value as noise will be same [5].

Reasons for Salt and Pepper Noise:
1) Due to failure of memory cells or wrong working of sensor cells of camera.
2) Due to synchronization errors while transmitting image over media [18].

The PDF of Impulse noise is shown in following equation and figure:

$$P(z) = \begin{cases} P_a & \text{for } z = a \\ P_b & \text{for } z = b \\ 0 & \text{otherwise} \end{cases} \qquad (3)$$

The PDF of Impulse noise is shown in following equation and figure:

Fig. PDF of Impulse (Salt & pepper) Noise

2.3 Speckle Noise

Speckle noise is a granular noise. This noise generally degrades Synthetic Aperture Radar (SAR) images to large extent. This noise is generally caused due to random ups and downs in the signal coming back from an object that is smaller than a single image-processing element. It is also caused by consistent processing of backscattered signals from a no of distributed targets. This noise also increases the mean grey level of affecting image. This noise creates a lot of difficulty in interpreting the image [20].

2.4 Poisson Noise

Poisson noise is also known as Photon noise. It arises when number of photons sensed by the sensor is not sufficient to provide detectable statistical information [16]. This noise has root mean square value proportional to square root intensity of the image. Different pixels are suffered by independent noise values. The photon noise and other sensor based noise corrupt the signal at different proportions [15]. The PDF of Poisson Noise is shown in following equation and figure:

$$p(x) = \frac{e^{-\lambda}\lambda^x}{x!} \ for \ \lambda>0 \ \text{and} \ x=0,1,2.. \quad (4)$$
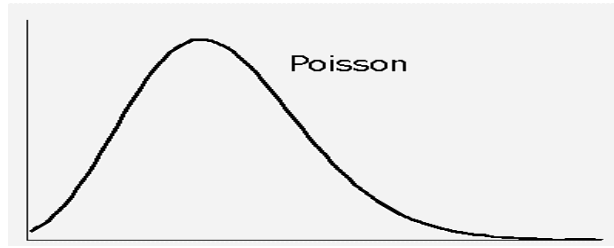

Fig. PDF of Poisson Noise

2.5 Uniform Noise

The Uniform noise caused by quantizing the pixels of image to a number of distinct levels is known as Quantization noise. It has approximately uniform distribution. In this type of noise, the level of the grey values of the noise is uniformly distributed over a specified range. It can be used to create any type of noise distribution. This type of noise is mostly used to evaluate the performance of image restoration algorithms. This noise provides the most neutral or unbiased noise [10]. The PDF, mean and variance of Uniform Noise is shown below:

$$P(z)= \frac{1}{(b-a)}, \quad if \ a \leq z \leq b \qquad (5)$$
$$0 \ , \quad \text{otherwise}$$

$$\mu = (a+b)/2 \qquad (6)$$
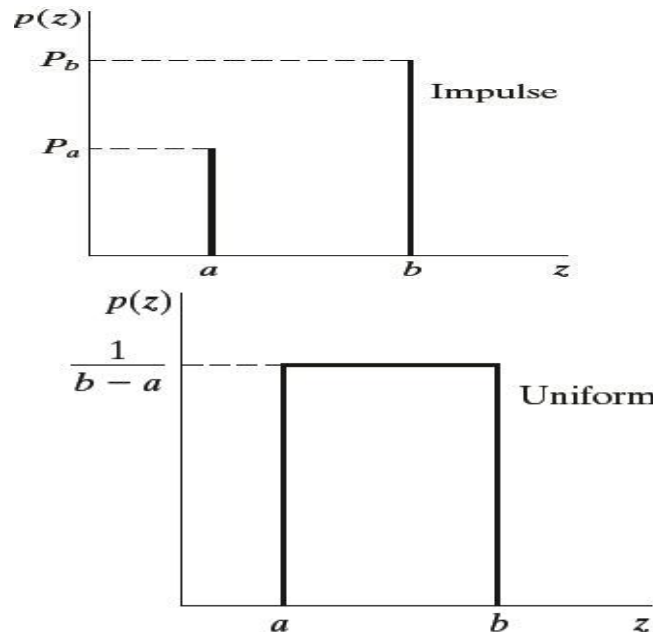
$$\sigma^2 = (b-a)^2/12 \qquad (7)$$

Fig. PDF of uniform noise

2.6 Rayleigh Noise

Radar range and velocity images typically contain noise that can be modeled by the Rayleigh distribution [18]. The PDF, mean and variance of Rayleigh Noise is given below:

$$P(z)=\begin{cases} \frac{2}{b}(z-a) \ e^{\frac{-(z-a)}{b}} & \text{for } z \geq a \\ 0 & \text{otherwise} \end{cases} \qquad (8)$$

$$\mu = a + \sqrt{\pi b/4} \qquad (9)$$

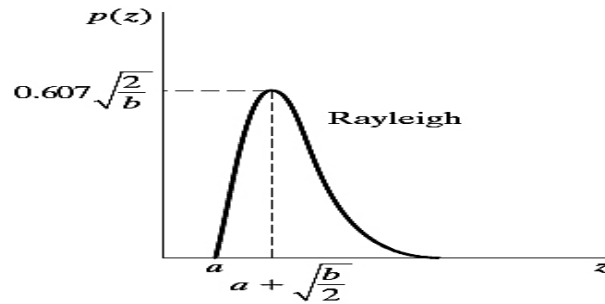$$\sigma^2 = \frac{b(4-\mu)}{4} \qquad (10)$$

Fig. PDF of Rayleigh Noise

2.7 Gamma Noise

This type of noise can be obtained by the low-pass filtering of laser based images [18]. The PDF, mean and variance of Gamma Noise is given below:

$$P(z)=\begin{cases} \dfrac{a^z z^{b-1}}{(b-1)!}e^{-az} & ,\text{for } z < a \\ 0 & z \ge 0 \end{cases} \qquad (11)$$
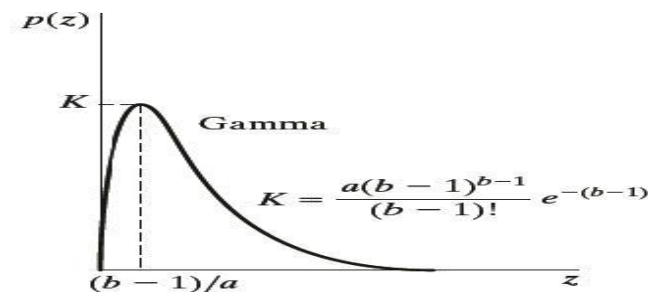
$$\mu=b/a \qquad (12)$$
$$\sigma^2=b/a^2 \qquad (13)$$

Fig. PDF of Gamma noise

3. IMAGE DENOISING TECHNIQUES

There are different Image denoising techniques developed so far each having its own advantages and limitation. One should choose the technique according to the type and amount of noise present in the image. One should also consider the other factors like performance in denoising the image, computational time, and computational cost.

Denoising can be done in various domains like Spatial Domain, Frequency Domain and Wavelet Domain. The Spatial domain method is discussed below.

3.1 SPATIAL DOMAIN

Here filtering is used for image noise removal. Filtering is a technique in image processing which is used for different tasks like noise reduction, interpolation, and re-sampling. It is mostly used in all image processing systems. The choice of filter depends upon the type and amount of noise present in an image because different filters can remove different types of noise efficiently.

Spatial Domain has following types of filters:

3.1.1 Linear Filters:

Linear filters are used to remove certain type of noise. Here filtering is generally done by blurring the image. These filters blur the edges and destroy the fine details of an image. They have poor performance in removing signal dependent noise. Gaussian and Averaging filters are commonly used linear filters [8]. They are of following types:

3.1.1.1 Gaussian Filter:

Gaussian filter is a non-uniform low pass filter. Gaussian filter is used to blur images and remove noise and detail. It does not remove salt & pepper noise effectively [3].

3.1.1.2 Average Filter:

The output of average filter is simply the average of pixels contained in the neighborhood of filter mask. It calculates the average of all intensities of the neighborhood of the central pixel and replaces the pixel with that average value. It is mostly used in removing irrelevant details from an image. It has a limitation that it blurs the edges of the image [19].

3.1.2 Non-Linear Filters:

In recent years, a variety of non-linear filters such as median filter, min filter, and max filter have been developed to overcome the shortcoming of linear filter. Non-linear filters exhibit better performance than linear filters [10]. They are discussed below:

3.1.2.1 Mean Filter:

It is one of the simplest filters among the existing spatial filters. It uses a filter window which is usually square. The filter window replaces the center value in the window with the average mean of all the pixels values in the kernel or window.

3.1.2.2 Median Filter:

It is also known as order statistics filter. It is most popular and commonly used non linear filter. It removes noise by smoothing the images. This filter also lowers the intensity variation between one and other pixels of an image. In this filter, the pixel value of image is replaced with the median value. The median value is calculated by first arranging all the pixel values in ascending order and then replaces the pixel being calculated with the middle pixel value. If the neighboring pixel of image which is to be consider, contains and even number of pixels, then it replaces the pixel with average of two middle pixel values. The median filter gives best result when the impulse noise percentage is less than 0.1. It does not perform well in removing high density salt & pepper noise [19]. The mean filter can be represented by the following equation:

$$f^\wedge(x,y)=median\{g(s,t)\} \ where \ (s, t) \in S_{xy} \quad (14)$$

Here S_{xy} corresponds to the set of coordinates in a rectangular sub image window which has center at (x,y). The median filter calculates the median of the corrupted image g(x,y) under the area S_{xy}. Here f^(x,y) represents the restored image.

3.1.2.3 Min Filter:

Min filter is also known as 0th percentile filter. It replaces the value of pixel by the minimum intensity level of the neighborhood of that pixel. This filter finds darkest points in an image. It removes salt noise from an image containing salt and pepper noise due to its high intensity value [19]. The min filter can be represented by the following equation:
$$f^\wedge(x,y)=min\{g(s,t)\} \ where \ (s,t) \in S_{xy} \quad (15)$$

3.1.2.4 Max Filter:

Max filter is also known as 100th percentile filter. It replaces the value of pixel by the maximum intensity level of the neighborhood of that pixel. This filter finds brightest points in an image. It removes pepper noise from an image containing salt and pepper noise due to its very low intensity value [19].
$$f^\wedge(x,y)=max\{g(s,t)\} \ where \ (s,t) \in S_{xy} \quad (16)$$

3.1.3 Adaptive Filters:

These filters work accordingly the statistical characteristics of image inside the filter region defined by the m x n rectangular window. They are more complex and give better performance than existing spatial filters. The most commonly used spatial filter is adaptive median filter which is discussed below:

3.1.3.1 Adaptive Median Filter:

It performs well on images containing high density salt & pepper noise. It preserves the details of an image while smoothing non impulse noise. It changes its windows size during its operation depending on the certain conditions [19]. It works in two stages. First it calculates the minimum, maximum and median values of sub image window of the corrupted image. In stage one, it checks whether the calculated median itself is a salt or pepper noise or not. If the median is salt or pepper noise, then it increase the size of sub image window and recalculates the minimum, maximum and median values otherwise it proceeds to stage two. In stage two, it checks whether the selected pixel is a salt or pepper noise or not. If it is salt or pepper noise, then it replaces the selected pixel with previously calculated median otherwise the pixel remains unchanged.

4. IMPLEMENTATION AND RESULTS

Experiments were carried out on various standard grayscale images of size 256 x 256 which are of jpeg format. Simulation is performed using Matlab R2013a software. The input images are corrupted by a simulated Gaussian white noise (mean=0, variance=0.01), Salt & Pepper noise (noise density= 0.05), Speckle noise (mean=0, variance=0.04), Poisson noise, Uniform noise (interval [0, 1]), Rayleigh noise (parameters 0,1), Erlang noise (parameters 2,5). For denoising process, various spatial linear filters which are Gaussian filter (3x3), average filter (3x3) and spatial nonlinear filters which are median filter (3x3), min filter (3x3), max filter (3x3) and adaptive filters which are adaptive median filter (3x3), have been used.

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5. CONCLUSION

In this paper, various noise models and filtering techniques like linear, nonlinear filtering and adaptive filtering have been discussed. The seven different types of noises which includes Gaussian noise, Salt & Pepper noise, Speckle noise, Poisson noise, Uniform noise, Rayleigh noise and Erlang noise, were simulated. Then six different spatial filters which includes Average filter, Gaussian filter, Min filter, Max filter, Median filter & Adaptive Median filter, were applied on different noisy images. The performance of the filters was evaluated using PSNR parameter. The comparison results show that Average filter shows better performance in removing Gaussian and Speckle noise while Gaussian filter removes Poisson noise efficiently. The adaptive median filters performed well in removing Salt & Pepper, Uniform, Rayleigh and Erlang noise.

6. FUTURE SCOPE

This comparative study can be further extended by including more noise types like Exponential noise, Anisotropic noise, Film grain etc and/or by using multiple types of noise in different types of images. One can include more spatial filters using various means filters like Arithmetic mean filter, Geometric mean filter, Harmonic mean filter, Contra harmonic mean filter and order statistics filters like Midpoint filter, Alpha trimmed filter and Adaptive filters like Adaptive local noise reduction filter for comparison. One can also use hybrid filtering approach which involves two or more filters. Some other parameters like Entropy, Structure Similarity Index and Image Quality can also be considered for measuring the performance of different filters.

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