A Quantum Study on Digital Image Noises and their In-Depth Clusterization

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I. *Abstract*—

In this paper, we represented a detailed survey of various types of Noise and its applications. Image processing is a field of study and research where we process raw images with the help of various functions or the input can be any parameter of the picture that we need to process. Noise as we all know as Unwanted Signal is responsible for Degradation of pictures in terms of Quality and Detailing. The primary source of Noise can be when we capture a picture, due to slow Shutter Speed, Temperature. Some noises are beneficial for us like noise is used in Posterization, Sharpness and in Dither. So, implementing an efficient noise removal technique is the utmost need today to harness each and every required detail. Nowadays we have effective Algorithms and Codes that can harness noise to enhance the image quality at any integral level of our choice. Every Image Processing Technique has its own advantages and disadvantages. We have to identify which kind of Algorithm will help us in getting the desired result. In this paper, we represented the survey of various kinds of Noise in Digital Image and we presented their effects in a particular Image.

***Keywords*—Salt and Pepper Noise; Gaussian Noise; Image Processing; Shot Noise; White Noise; Fractal Noise; Grey Noise; Red Noise; Periodic Noise; Quantization Noise; Speckle Noise;**

I. INTRODUCTION TO IMAGE PROCESSING

A digital image is a 2-dimensional (2D) array of several pinpoints each of which is associated with a specific value. The arrangement can be represented by a function $f(x, y)$ where (x,y) are spatial coordinates of a point within the image and the function denotes the value of the specified point. The point is referred to as a pixel and the value is the intensity level of the pixel i.e. a measure of how bright the point is.

An image can also be represented by a grid of square blocks, where each block represents one pixel. Each pixel contains a specific value (V) and location (L). The pixel value is normally represented by an integer or a floating point number. A pixel physically represents the brightness or color of the image at that point. The location L is represented as a pair of coordinates measured with respect to an origin O located at the top left corner, X-axis from left to right and Y axis from top to bottom. [1][5][8][13][16][19]

An image can be classified into three categories: 1. Binary image 2. Grayscale Image 3. Color Image. A pixel in a binary image can be represented by either 0 or 1. A pixel in a Gray Scale image can be represented by the numbers within the range 0 to 255. A color image can be represented by 3 different matrices – red, green and blue, where each pixel has a unique red, green and blue value. Each pixel value is within the range of 0 to 255. Every specific image or picture can be represented in Binary Matrix (Fig. 1). During image processing or image compression, we work with this property of a particular image. The 0-bit represents "White" and 1-bit represents "Black". Since the binary form can have a maximum of two colors, therefore sometimes this type of images are termed as "Bi-tonal".[4]

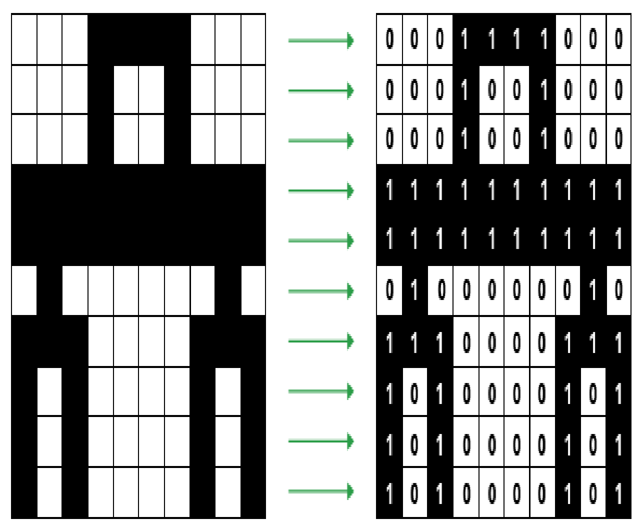

Figure 1: Representation of Image in Binary Form

In image processing technique where we process different types of images using mathematical operations. It also refers to form of signal processing where an image or a series of images, or a video, such as a photograph or a video frame is given as input. After applying this technique as an output a new enhanced or restored or compressed image is generated or a set of characteristics or parameters related to the image is generated. Image processing can be classified into three categories: 1. Analog Image Processing 2. Optical Image Processing and 3.Digital Image Processing. An Analog image processing is a process of image processing which is applied to two-dimensional analog signals and it is based on analog data. Optical Image Processing is a task of processing image generated by optical devices such as telescopes and microscopes in conjunction with cameras. in this image processing technique, images are generated through light-sensitive media such as film or electronic sensors etc. Digital Image Processing is a type of digital signal processing. This requires the image to be represented in a digital way to be processed by the computers, thus is the digital image. A digital image is given as input to the computer and a processed image is given as the output by the computer. Digital image processing is advantageous over analog image processing, as it not only allows easy implementation of complex algorithms and methods to the digital image data but also allows a wide range of algorithms to be applied to the image data. [13][14]

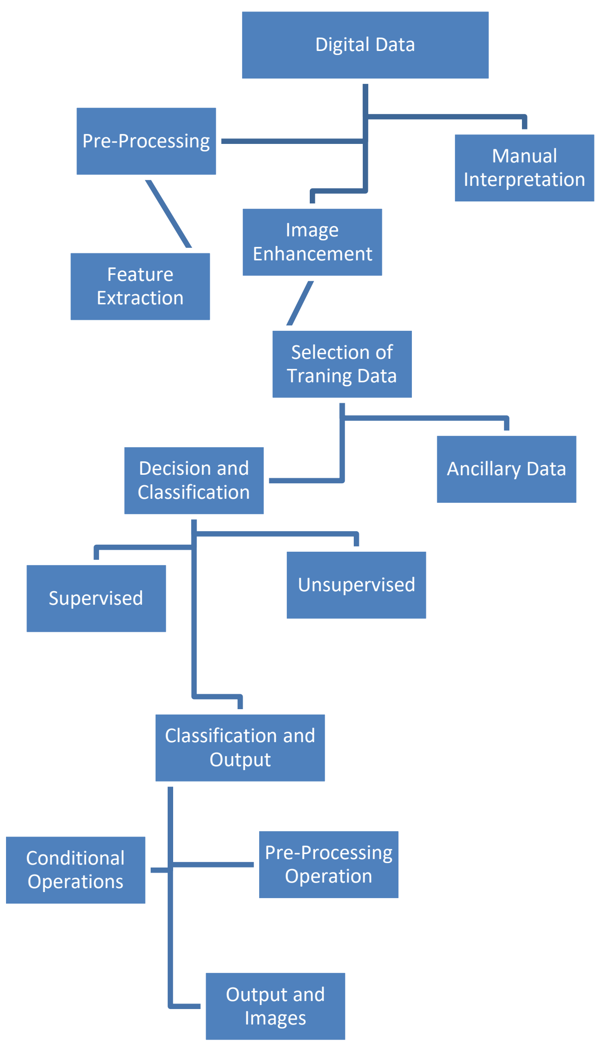

Figure 2: (Flowchart of Image Processing Model)

Now we can formally define Noise. Noise is the unwanted distortion in an Image or a Picture. Sometimes noise distorts the original image to a certain level that it becomes very difficult to understand the fine details present in the image. Since we can treat Images as functions; we can operate on Images as we operate on functions like addition and multiplication. Here we can define a *Noise;* a noise is just another function $n(x, y)$ which when added to our Image function $I(x, y)$outputs another Image function $I'(x, y)$.

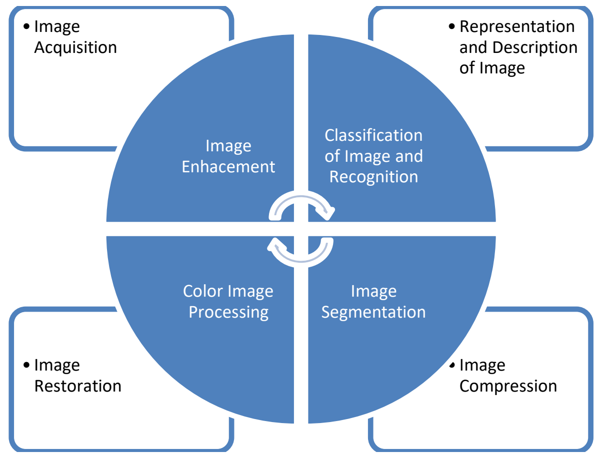

Figure 3: (Design of the steps in Image Processing)

II. VARIOUS TYPES OF MODELS IN NOISE

Noise is present in two forms they are:-

- Additive Noise Model
- Multiplicative Noise Model

ADDITIVE NOISE MODEL

When noise gets added to the original signal which corrupts the original signal to create a noisy signal and if it can be represented using a model then it is known as Additive noise model. Additive noise model can be represented using the following equation: [23][34][24][12][11]

$$A(b,c)=O(b,c)+N(b,c) \quad (1)$$

Where,

Let (b.c) be a particular pixel location where we focus.

O(b,c) is the original image intensity, N(b,c) be the noise intensity implemented in the original image, A(b,c) is the resultant and corrupted signal.

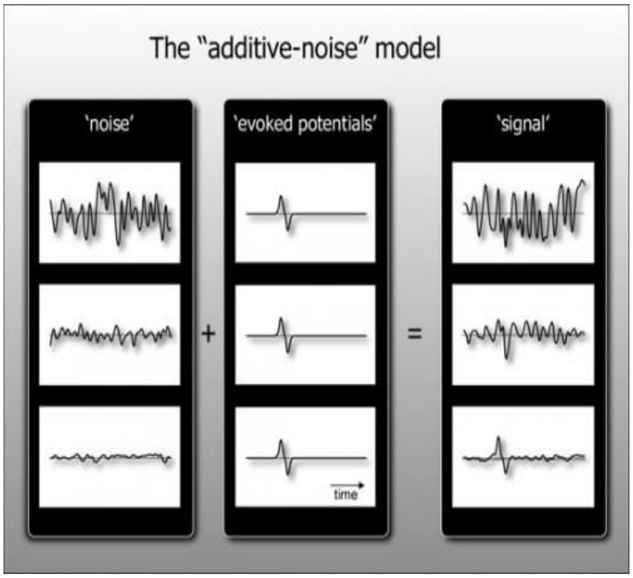

Figure 4: (Representation of Additive Noise Model)

MULTIPLICATIVE NOISE MODEL

When noise gets multiplied to the original signal which corrupts the original signal to create a noisy signal and if it can be represented using a model then it is known as Multiplicative noise model. Multiplicative noise model can be represented using the following equation:

$$A(b,c)=O(b,c)*N(b,c) \tag{2}$$

Where, [1][23][34]

Let (b.c) be a particular pixel location where we focus.

O(b,c) is the original image intensity, N(b,c) be the noise intensity implemented in the original image, A(b,c) is the resultant and corrupted signal.

Figure 5: (Multiplicative Noisy Image)

III. The Different Types of Noise in an Image

GAUSSIAN NOISE

Gaussian noise is also called Amplifier noise or additive noise. It is additive in nature. Gaussian noise is statistical noise. The probability density function (PDF) of Gaussian noise is equal to the normal distribution, which is also known as the Gaussian distribution. [5][7][1][8][10][13][24]

Gaussian noise can be inserted in digital images while capturing or storing an image. It occurs due to:

1. Poor illumination.
2. High temperature.
3. While transmitting an image from one to another medium.

The probability density function p of a Gaussian random variable z is given by:

$$p(z) = (1/(\sigma\sqrt{2\pi}))\ e^{\wedge}(-((z-\mu)^{\wedge}2/(2\sigma^{\wedge}2))) \tag{3}$$

Where,

Let, z means gray level, μ is the mean value, and σ the standard deviation.

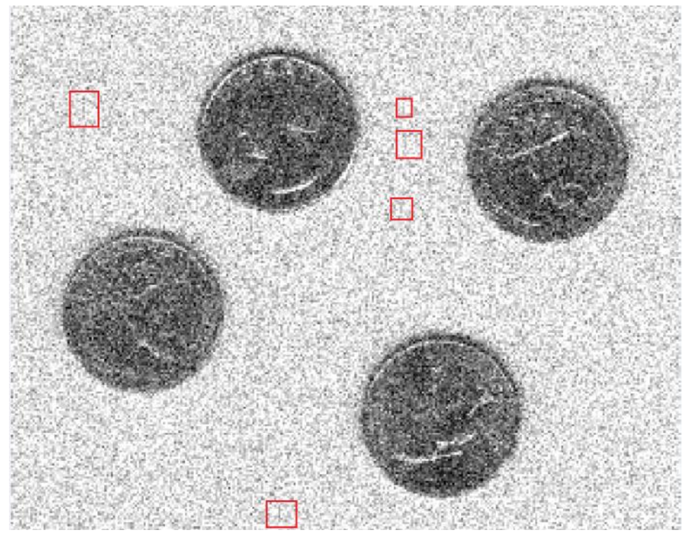

Figure 6: (Gaussian Noise Implication in an Image)

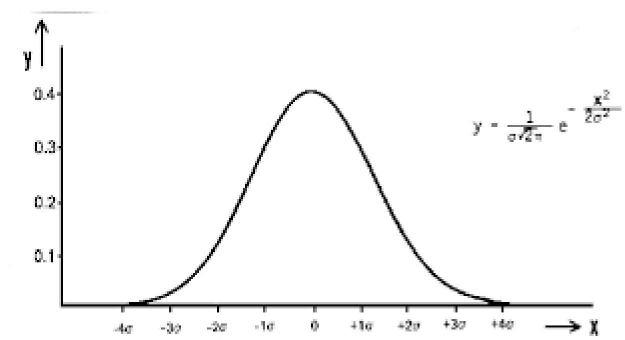

Figure 7: (Graphical Representation of Gaussian Noise)

FRACTAL NOISE

Fractal noise can be referred as fractional noise, colored noise, pink noise, flicker noise or 1/f noise. In this noise signal, each octave carries an equal amount of noise energy. If we represent this noise signal by means of light then a pink appearance can be visible. So, this type of noise is also known as pink noise.[25][26][2][23]

Fractal noise can be inserted in digital images due to the following reasons:

1. Fluctuations in the tide and river heights.

2. Quasar light emissions.
3. Heart beat.
4. Firings of single neurons.
5. Resistivity in solid state devices.

In this noise, the power spectral density is inversely proportional to the frequency of the signal. Fractal noise can be represented using the following equation:

$$S(f) = 1/f^\alpha \tag{4}$$

Where S(f) is a power spectral density function; f is the frequency of the noise signal; α is a constant which in the following range: $0 < \alpha < 2$.

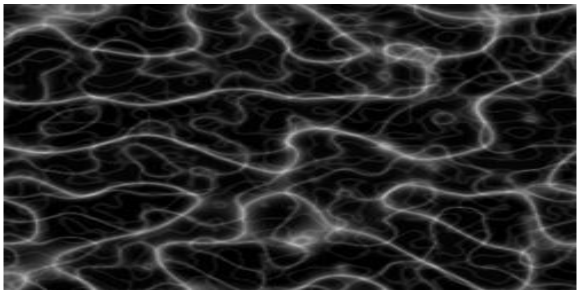

Figure 8: (Image with Fractional Noise)

WHITE NOISE

White noise is a random signal with a constant power spectral density. White noise refers to a statistical model for signals and signal sources, rather than to any specific signal. White noise is a discrete signal whose samples are regarded as a sequence of serially uncorrelated random variables with zero mean and finite variance. In digital image processing, the pixels of a white noise image are typically arranged in a rectangular grid and are assumed to be independent random variables with a uniform probability distribution over some interval.[31][22][27][17][13][15][19]

Principle reasons of white noise are as follows:
1. White noise may be generated digitally with a digital signal processor.
2. White noise may be generated digitally by a microprocessor.
3. White noise may be generated digitally with a microcontroller.

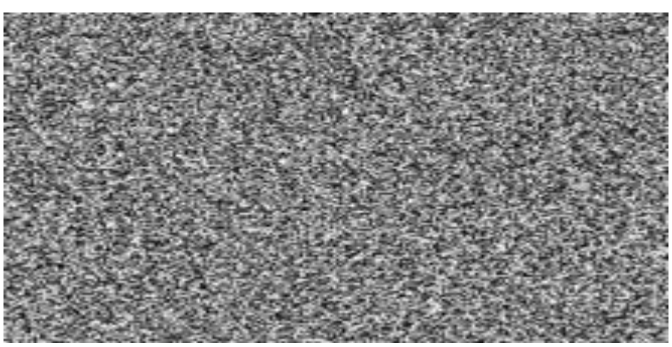

Figure 9: (White Noise in an Image)

BROWNIAN NOISE OR RED NOISE

Brownian noise is also known as Brown noise or red noise.
Brownian noise can be productive due to the following reasons: [6][8][9][13]
1. Brown noise can be produced by integrating white noise.
2. Brownian noise caused by Brownian motion. Brownian motion may be seen due to the random movement of suspended particles in fluid

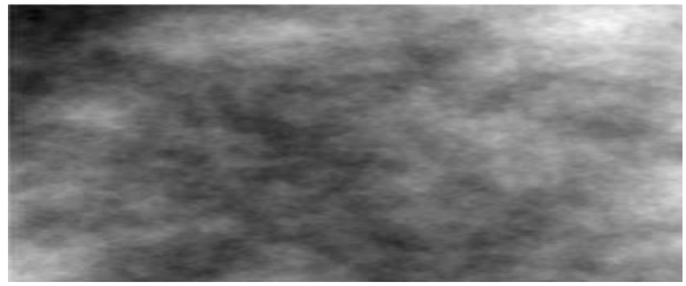

Figure 10: (Image with Red Noise in it)

SALT AND PEPPER NOISE

It is the type of impulse noise. When some black and white dots appear on the image it is known as salt and pepper noise. This noise actually occurs due to the fact that some of the pixels drop its value to 0 it gives rise to white spot and when the original pixel value drops to 1 it gives rise to a dark black spot on the image. This is how salt and pepper noise is created in an original image. This noise is also known as Impulse Valued Noise. [9][8][12][17][32][31]

The Salt and Pepper noise is generally caused by,
1. Malfunctioning of pixel elements in the camera sensors.
2. Faulty memory locations.
3. Timing errors in the digitization process.

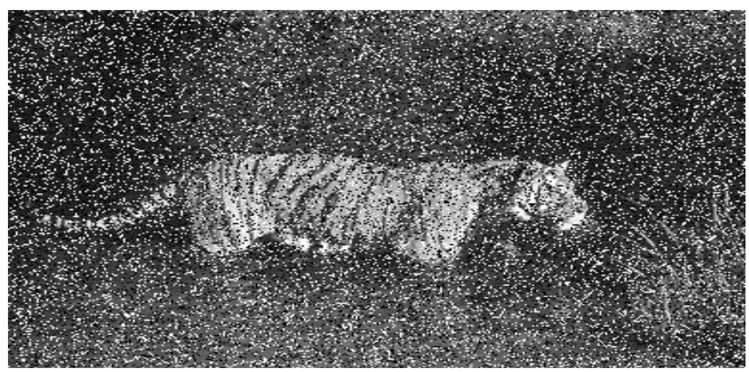

Figure 11: (Image with Salt and Pepper Noise)

PERIODIC NOISE

It is sinusoidal in nature. When the image gets distorted the bands or stripes or dots are formed at regular intervals on the image this is the periodic noise. [17][14][32][35][33]

Principle sources of periodic noise are:
1. During image capturing when electronic signal interferes then the image gets distorted to give rise to the periodic noise.
2. Power signal fluctuation during image acquisition.

Also there is a special kind of Periodic Noise called Asy-Periodic Noise which is counter-interference of the Periodic Noise.

Figure 12: (Representation of Periodic Noise in an Image)

QUANTIZATION NOISE

This noise which is caused by the quantization of the pixel of a sensed image to a number of discreet levels is known as quantization noise. It occurs only for amplitude quantization process. It occurs when analog data is converted to digital data. [14][17][18][29]
The SNR is given by:

$$\delta = (20log\_10\ (p\_max - p\_(min\ )))/\sigma\_n \qquad (5)$$

Where $\sigma_n$the standard deviation of noise, δ is the signal to noise ratio,p_max and p_min is the maximum and minimum pixel value. In this model SNR is limited by maximum and minimum pixel value. [11][18][27].

While there is a special kind of noise which is a type of Q-noise, but such do not specify the properties of Quantization Noise.
The generic formula for such noises is:

$$\delta = (20log\_10\ (p_{max} * - p\_ * (min\ )))/\sigma_n \qquad (5*)$$

Where * values denote the unmatched expression in the special Q-noise.

Figure 13: Image with Quantization Noise Embedded within it)

SHOT NOISE OR POISSON NOISE

Shot noise is also called Poisson noise or Photon noise. This is a kind of electric noise which can be modeled by a Poisson method. [35][32][33][17][19]
Shot noise appears due to particle nature of light i.e., the movement of discrete particles in the light and electric current. It depends on the photons per unit time on the image. When the number of photons increases or decreases per pixel this noise is created.[21][22][26]
The Poisson distribution which it obeys is:-

$$p(x = k) = (\lambda^\wedge k\ i^\wedge(e^\wedge(-\lambda)))/k! \qquad (6)$$

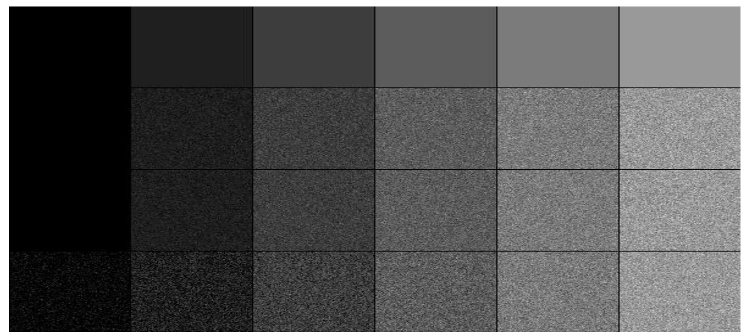

Figure 14: (Picture with Shot Noise inserted)

SPECKLE NOISE

This is an example of the multiplicative noise model. [23][20][10][12][13] This is a granular noise which degrades the quality of radar, synthetic aperture radar, medical ultrasound and optical coherence tomography image. And it follows gamma distribution as given below:

$$F(g) = (g^\wedge(\alpha - 1)\ e^\wedge(-g/a))/((\alpha - 1)!\ a^\wedge\alpha) \qquad (7)$$

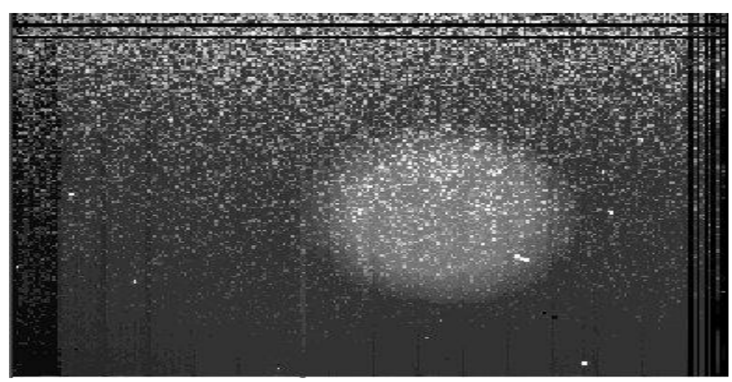

Figure 15: (Insertion of Speckle-Noise)

STRUCTURED NOISE

Structured noise is periodic, stationary or non-stationary and aperiodic in nature. If this noise is stationary, it has fixed

amplitude, frequency, and phase. Structured noise is also called low-rank noise. Noise presents in the communication channel are in two parts, unstructured noise (u) and structured noise (s). The principle reason for the structural noise is interferences among electronic components.[23][5][7][9]
Mathematical equation to represent structural noise is given below:

$$y(x) = \mathrm{n(r, c)} + \sum_{i=0}^{\infty} \mathrm{x(r, c)} \qquad (8)$$

Where, r = rows, c = columns, y = received image, x= density function, n= noise function. [29][31][33][21]

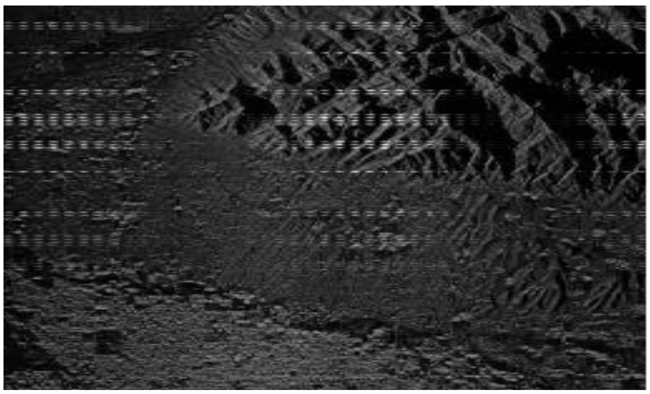

Figure 16: (Picture with Structured Noise)

GAMMA NOISE

Gamma noise is generally seen in the laser-based images. [2][3][16] This noise obeys the gamma distribution. The PDF of gamma noise is given below:

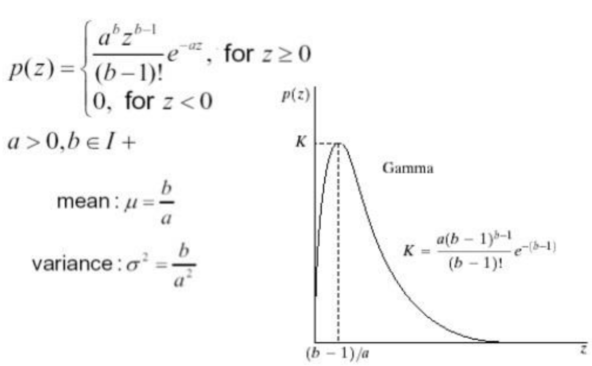

Figure 17: (Graphical Representation of Gamma Noise)

IV. CONCLUSION

In this paper, we built a detailed survey of the various models of Noise and the study of different types of Noise that can be incorporated in a picture. Noise, as we studied, can be both useful and sometimes can degrade our image. So, Image processing is the Domain to look for in the future. We described the features and applications of different noise and made a detailed survey.

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