International Journal of Emerging Technologies in Engineering Research (IJETER)
Volume 5, Issue 10, October (2017) www.ijeter.everscience.org

A Brief Study on the Various Noise Models in Digital Image Processing

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Abstract – In image processing, the noise reduction and restoration techniques are used for improving the qualitative analysis as well as the performance criteria of the quantitative analysis techniques of the image. Digital images are prone to a variety of noises which affects the quality. The primary goal of de-noising the image is to re-establish the details of the original image as much as possible. The criterion for the noise removal problem depends on the type of noise by which the image has been corrupted. In the field of image processing, there are several types of linear and non-linear filtering techniques available for eliminating noise from the images. Different methods for noise reduction and image enhancement is considered with their strength and limitations.

Index Terms – Digital Image Processing, Images Types, Noise Models, Filters, Performance Parameters.

1. INTRODUCTION

Digital Image Processing is a part of digital signal processing. The area of digital image processing is concerned with processing of a digital image with the help of a computer system. Digital image processing has a number of advantages over analog image processing: it permits an impressively more extensive collection of algorithms to be applied to input data and can avoid issues like noise build-up and deformation of signals during processing. Digital Image Processing involves the reconstruction of digital information for enhancing the quality of the image with the help of a computer. The processing helps in boosting the clarity, sharpness of image, and draw out the details of interest for feature extraction and further study. Digital image processing is an extremely wide subject and it usually includes mathematically complex mechanisms, however the main intension behind digital image processing is straightforward. The digital image is given as input into a computer which is programmed to modify these data with the help of an equation, or a number of equations and then store the estimations of the calculation for every pixel or picture element.

The resultant is a new digital image that maybe displayed or saved in a format specified for images or might also be further modified using additional techniques. To improve certain elements and to eliminate noise, the digital images are put through different image processing operations.

Image processing involves modifying the quality of an image so as to:

- Enhance the pictorial data for human interpretation.
- Rendering the image ought to be more appropriate for independent machine learning.

Image processing techniques maybe grouped into three main categories:

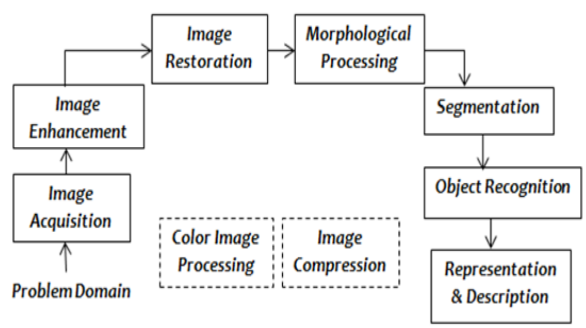

Figure1: Steps in Digital Image Processing

Image Restoration- eradicate noise, data errors, and the geometric distortions that is developed during the recording, scanning, and the playback operations.

- Restores periodic line dropouts.
- Restores periodic line striping.
- Effective for random noise.
- Boost geometric distortion.

Image Enhancement- produce a processed image that is suitable for a given application. For example, sharpening or de-blurring ill-defined images, highlighting the edges of an image, boosting image contrast or increasing the brightness level of an image, removing the noise from noisy images.

- Used for Contrast Enhancement.
- Intensity, saturation and hue transformations.
- Improving the edges.
- Generating synthetic stereo images.

Image Analysis- making a quantitative measurement from an image so as to produce the description of it. Image analysis techniques extract certain features of an image that helps in the recognition of an object. This feature allows the description and classification of the image.

- Produces principal component images.
- Produce ratio images.
- Used for Multi-spectral classification.
- Produce change detection images.

2. IMAGE AND ITS TYPES

An image maybe thought of as a two-dimensional function F(a,b), where a and b are spatial (plane) coordinate, and the magnitude of F at any pair of coordinates (a,b) is called the intensity or gray level of the image at that point. When a, b and the magnitude values are predetermined, we call the image as digital image. A digital image is a collection of finite number of elements, in which each element has a particular value and location. These elements are known as Picture elements or pixels.

2.1 Types of Digital images

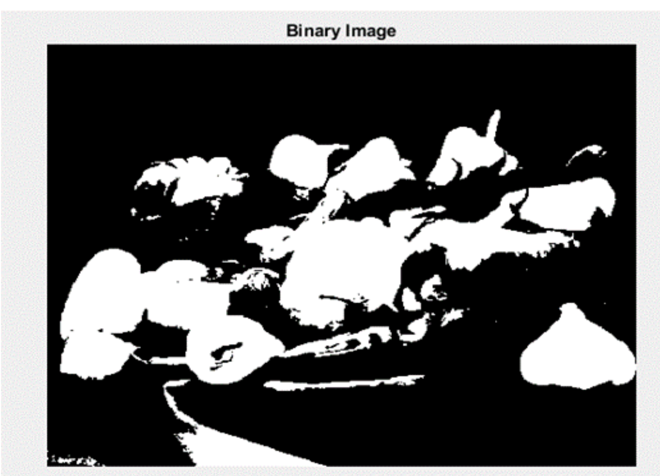

Figure1.2: An Example of Binary Image

Binary image: In binary images, the value of each pixel is either black or white. There only two possible values for each pixel either 0 or 1, one bit per pixel is required.

Grayscale image: In grayscale image, each pixel is shade of gray whose value normally ranges from 0 [black] to 255 [white]. This implies that every pixel in this image can be shown by eight bits, i.e., exactly one byte. Other grayscale ranges can be utilized, but usually they are a power of 2.

Figure1.3: An example of Grayscale Image

True Color or **RGB image**: Each pixel in an RGB image has a specific color and it is described by the amount of red, green and blue values in the image. If each of the components has a range from 0–255, this implies that a total of different color 255^3 = 16, 777, 216 values are possible. Such an image is represented as a ‘stack’ of three matrices; which represent the red, green and blue values in the image for each pixel. That means for every pixel there corresponds three values.

Figure1.4: An Example of an RGB image

Indexed image: Mostly the color images only have a small subset of the more than sixteen million possible colors. For convenient file handling and storage, the image has a corresponding color map (i.e., a color palette) which is basically a list of all the colors used in that image. Each pixel has a corresponding value which does not give its color as in an RGB image, but an index to the color in map. It is convenient for an image having 256 colors or less, for then the index values will only require a single byte each to store. Some image file formats such as GIF allows only 256 colors or less, for this reason.

2.1. Digital Image File Types

BMP-

BMP stands for Bitmap. Every picture in a computer appears to be a BMP. In Windows XP, the Paint program automatically saves its images in the bitmap format. However, in Windows Vista images now are saved in the JPEG format. Bitmap is the foundation for many other file types.

Strength: Great quality image; Easy to change and edit; Lossless image processing

Limitation: Difficulty while displaying on the internet; large file sizes.

JPEG-

JPEG is an acronym for Joint Photographic Experts Group. Jpeg format is predominantly used for color photographs. It is poor with sharp edges and it tends to blur the image a bit. This format became popular with the innovation of the digital camera. Digital cameras mostly download images to our computer in Jpeg format. Digital camera manufacturers clearly see the value in high quality images that ultimately takes up less space.

Strength: Small file size; format is compatible and it is displayed correctly in any browsers; suitable for full-color realistic images with a lot of color and contrast transitions.

Limitation: Every next step of compressing the image degrades its quality; less suitable for working with text or monochrome graphics with clear boundaries; does not support transparency.

GIF-

The acronym GIF stands for Graphics Interchange Format and is an 8-Bit format. This format is more appropriate for text, drawing line screen shots, animations and cartoons. Gif format is restricted to a total of 256 colors or less. GIF images have a small file size and they tend to load quickly. So it is used for making banner and logo for different webpages. Various animated pictures are saved in GIF format. For example, the flashing banner will be saved as a Gif file.

Strength: supported mostly by all web browsers; very small file size; Easy to load; Transparency is supported; Good for saving crisp, clean line art; Good for saving images with lots of flat, solid colors; Animation is supported.

Limitation: only basic colors can be used; Complex pictures look unpleasant; details of images are not allowed.

PNG-

PNG stands for Portable Network Graphics. This is one of the best image formats, still it was not generally appropriate with all web programs and image programming. This is the best image format to use on the internet. Logos and screen shots are also saved in this format.

Strength: minimum compression loss; When you re-save image, quality is not lost; supports a large number of colors; supports multilevel of transparency; small file sizes.

Limitation: does not support animation; ill-suited for working with full-color images; cannot store multiple images in one file.

TIFF-

TIFF is the acronym for Tagged Image File Format. This format is now owned by Adobe. It stores an image and data (tag) as a single file. This file format is generally used for scanning the data, faxing, word processing etc. It is not a common format that can be used with digital images.

Strength: High definition images, Lossless compression.

Limitation: File transfer is difficult due to its massive size; not viewable on the internet; requires specialized program to view it.

3. NOISE MODELS

The fundamental source of noise in digital images arises during image acquisition (digitization) or during image transmission. The performance of image sensor is influenced by a variety of reasons such as environmental condition during image acquisition or quality of the sensing element used.

For instance, while acquiring images using a CCD camera, temperature of the sensor and availability of light are the major factors that influence the amount of noise in the image captured. The main reason of noise during image transmission is due to the interference in the channel which is used for the transmission. A noisy image is modeled as follows:

$$C(x, y) = A(x, y) + B(x, y)$$

where, A(x,y) is the pixel value of the original image; B(x,y) is the noise in the image; and C(x,y) is the resulting noise image.

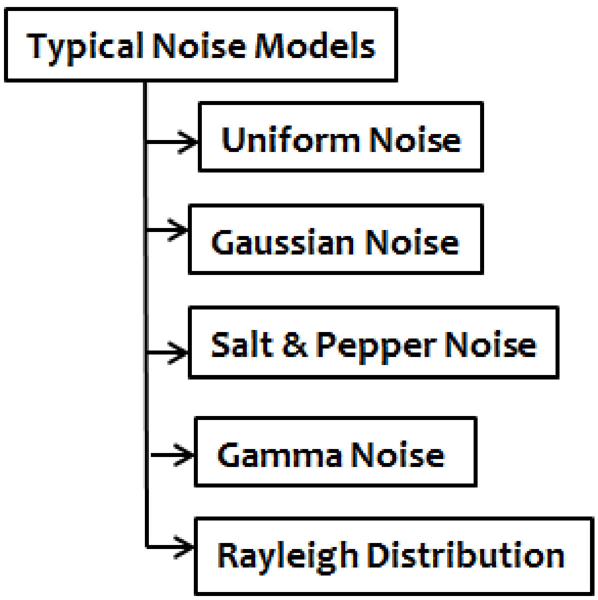

Figure 2: Various Noise Models

Uniform Noise

The noise caused by the quantization of pixels of the image to a number of distinct levels is known as quantization noise. It almost has a uniform distribution. In the uniform noise, the gray level values of the noise are evenly distributed across a specified range. Uniform noise can be used to generate different type of noise distributions. It is often used to break down images for the evaluation of restoration algorithms. This noise produces the most neutral or unbiased noise.

The Probability Distribution Function, Mean and Variance of Uniform Noise are:

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

where, $\mu=(a+b)/2$; $\sigma^2 = (b-a)^2/12$

Gaussian Noise or Amplifier Noise

The Gaussian noise has a probability density function (pdf) of the normal distribution and is also known as Gaussian distribution. It is a major part of the "read noise" of an image sensor, that is, of the constant noise level in dark areas of the image.

The Probability Distribution Function of Gaussian noise is:

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

Salt & pepper noise

The salt and pepper noise is also known as shot noise, impulse noise or spike noise. It is usually caused by inaccurate memory locations, flaw of pixel elements in the camera sensors or timing errors during the digitization process. In this noise only two possible values exists a and b, and their probability is < 0.2 each. If the values go greater than this, then the noise will overwhelm the image. For an 8-bit image the typical value for the salt and pepper noise is 0.

Causes of Salt and Pepper Noise are:

- memory cell failure.
- faulty sensor cells of the camera.
- synchronization errors during image digitization or transmission.

The Probability Distribution Function of Salt and Pepper noise is

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

Rayleigh Noise

Radar Images and Velocity images are the typical examples of Rayleigh Noise. These can be modeled by Rayleigh distribution which is given as follows:

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

$$\sigma^2 = \frac{b(4-\mu)}{4}; \ \mu = a + \sqrt{\pi b/4}$$

Gamma Noise

Gamma noise is normally seen in laser based images. It obeys the Gamma distribution.

The Probability Distribution Function, Mean and Variance of Gamma noise is:

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

$$\mu = \frac{b}{a}; \qquad \sigma^2 = b/a^2$$

4. IMAGE FILTERS

Filtering in an image processing is a basic function that is used for achieving various tasks such as noise reduction, interpolation, and re-sampling. Filtering the image data is a typical process utilized in almost all the image processing systems. The choice of filter is determined by the nature of the task performed by the filter, and the type and behavior of the data being examined. Filters are used to remove noise from digital image while preserving the details of the image and this is most important in any image processing system. Filtering can be done in three ways: (a) Filtering without Detection, (b) Detection followed by Filtering, (c) Hybrid Filtering

Filtering without Detection:

In this way of filtering there is a window mask which is moved across an observed image. The size of this mask is usually (2*N*+1)/2, where *N* is any positive integer. In this the middle element is the pixel of concern. When the mask starts moving from the top left corner to the bottom right corner of the image, it performs some arithmetic operations without discriminating any of its pixels.

Detection Followed by Filtering:

This filtering involves two steps. In the first step it identifies the noisy pixels in the image and in second step it filters those pixels. In this type of filtering too there is a mask which is moved across the image which performs some arithmetic operations to detect the noisy pixels of the image. Then, the filtering operations are carried out only on those pixels which are found to be noisy, keeping the non-noisy pixels untouched.

Hybrid Filtering:

In hybrid filtering method, two or more filters are used to filter the corrupted pixels of a noisy image. The choice of a particular filter is based on the noise level of the image at the test location and the performance of the filter which is used on the filtering mask.

Filter Description:

where, g(x, y) = Corrupted image, and f(x ,y) = Filtered image

4.1 Filtering Techniques

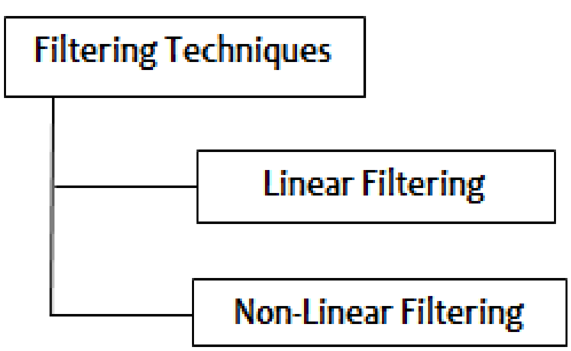

Figure 3: Types of filtering

Linear Filters-

Linear filters are filters whose output values are linear combinations of the pixels in the original image. Gaussian or Averaging filters are the examples of linear filters. These filters also tend to blur the edges, and destroy the fine details of the image, and perform poorly in the presence of signal dependent noise.

Non-Linear Filters-

Over recent years, a variety of non-linear median type filters such as rank conditioned, weighted median & weighted mean, relaxed median, rank selection have been developed to overcome the drawbacks of linear filters.

4.2 Different Types of Linear and Non-Linear Filters:

Mean Filter:-

The mean filter is a simple spatial filter and it is also known as a sliding-window filter that replaces the center value in the window with the average mean of all the pixel values in the kernel or window. The window is typically square yet it can be of any shape.

Let the Unfiltered values be

8	4	7
2	1	9
5	3	6

Table 1: an example of a 3x3 kernel with values

The mean value is 8+4+7+2+1+9+5+3+6 = 45/9 = 5.

After applying mean filter:

*	*	*
*	5	*
*	*	*

Table 2: In this the value of the element in the center which was previously 1 in the unfiltered value is replaced by the mean value 5.

Advantage:

- Easy implementation.
- Used for removing the impulse noise.

Disadvantage:

- It does not preserve the details of the image. Some details of the image are removed with the use of mean filter.

Median Filter:-

This Filter is a simple and powerful non-linear filter, which is based on the order statistics. It is an easy method to implement smoothing of images. Median filters are used for decreasing the amount of intensity variations between two pixels. In this filter, the pixel value of the image is not replaced with the mean value of its neighboring pixels' values, it is instead replaced with the median value of the neighboring pixels. The median is calculated by first sorting all the pixel values in the ascending order, and then the value in the center is called the median value, which is then is reassigned as the pixel value of the middle element. If the number of all the neighboring pixel values of the image which is to be considered is an even number, then the average of the two middle pixel values is used for reassigning. The median filter gives the best result when the percentage of the impulse noise is less than 0.1. When the amount of impulse noise is increased, then the median filter does not produce good result.

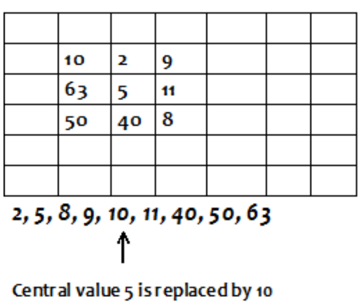

Figure 4: An example of Median Filter

Algorithm of Median Filter:

The algorithm for the median filter is as follows:-

Step 1: Select a two dimensional window W of size 3x3. Assume that the pixel being processed is Cx,y.

Step 2: Determine Wmed, the median of the pixel values in W.

Step 3: Replace Cx,y by Wmed.

Step 4: Repeat steps 1 to 3 until all the pixels in the image are processed.

Advantage:

- Ease of implementation.
- It is used for de-noising various noise types.

Disadvantage:

- Median Filter tends to remove minute details of the image such as thin lines and corners during the filtering process.
- The performance of the median filter is not satisfactory in case of signal dependent noise. To eliminate these difficulties, different variations of the median filters have been developed.

Wiener Filter:-

The major goal of the Wiener filter is to filter out the noise that has corrupted a signal. This filter depends on a statistical approach. Normally, all the filters are designed for a desired frequency response. But, the Wiener filter deals with the filtering of an image from a different aspect. The objective of wiener filter is to reduce the Mean Square Error [MSE] as much as possible. It is capable of decreasing the noise and degrading the function. One method is to assume that we have knowledge of the spectral property of the noise and the original signal. We use the Linear Time Invariant filter which, to an extent, produces the output similar to that of the original signal.

Wiener Filters are outlined by the following:

- Assumption: signal and (additive) noise are stationary linear stochastic processes with known spectral characteristics or known auto-correlations and cross-correlations.
- Requirement: the filter must be physically realizable, i.e. causal (this requirement can be dropped, resulting in a non-causal solution).
- Performance criteria: minimum Mean-Square Error.

The Fourier domain of the Wiener filter is given as:

$$G(u,v) = \frac{H^{*}(u,v)}{|H(u,v)|^{2} P_{s}(u,v) + P_{n}(u,v)}$$

where, $H^*(u, v)$ is the Complex conjugate of degradation function; $Pn(u, v)$ is the Power Spectral Density of Noise; $P_s(u, v)$ is the Power Spectral Density of non-degraded image; $H(u, v)$ is the Degradation function.

5. PERFORMANCE PARAMETERS

For the comparison of the original image and the uncompressed image, we calculate the following:

i. Mean Square Error (MSE): It is the cumulative square error between the encoded and the original image. It is defined by:

$$MSE = \frac{1}{mn} \sum_{0}^{m-1} \sum_{0}^{n-1} ||f(i,j) - g(i,j)||^{2}$$

where, f is the original image; and g is the uncompressed image. The dimensions of the images is m x n. Thus, MSE must be as low as possible for effective compression.

ii. Root Mean Square Error: It is the square root value of the Mean Square Error.

$$\mathrm{RMSE} = \sqrt{\mathrm{MSE}}$$

iii. Peak signal to Noise ratio (PSNR): It is the ratio between the maximum possible power of a signal and the power of distorting noise which affects the quality of its characterization. It is defined by:

$$\mathrm{PSNR} = 20\log_{10}\left(\frac{\mathrm{MAX_f}}{\sqrt{\mathrm{MSE}}}\right)$$

where, $\mathrm{MAX_f}$ is the maximum signal value that exists in the original "known to be good" image.

iv. Bit Per Pixel (BPP): BPP is defined as the number of bits required to compress each pixel in an image. It should be very low in order to reduce the storage requirement.

v. Signal to Noise Ratio: This is defined as the power ratio between a signal and the background noise.

$$\mathrm{SNR} = \frac{\mathrm{P_{signal}}}{\mathrm{P_{noise}}}$$

Where, P is the average power. Both noise and power should be measured at the same point in a system, and within the system with the same bandwidth.

6. CONCLUSION

Improvement of a noisy image is a vital task in digital image processing. Filters are utilized best to remove noise from the images. In this paper we depict the different types of noise models and the filtering techniques. Filtering procedures are divided into two segments- Linear techniques and Non-Linear techniques. After studying the linear and non-linear filters, we understand that each has their own limitations and advantages. In Hybrid Filtering method, there are at least two or more filters that are prescribed to filter a corrupted location. The choice to apply a specific filter depends on the noise levels at different test pixel area or the performance quality of the filtering technique on a filtering mask.

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