3.1 A Model of Image Degradation/Restoration Process

Image Degradation process operates on a degradation function that operates on an input image with an additive noise term to produce degraded image. The image degradation model is shown below.

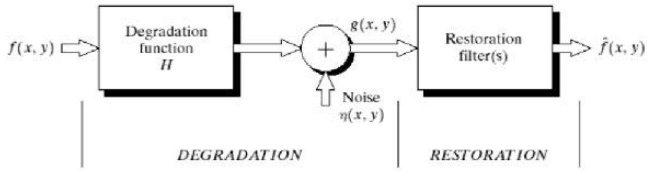


Fig: A Model of Image Degradation/Restoration Process

Let $f(x, y)$ is an input image and $g(x, y)$ is the degraded image with some knowledge about the degradation function H and some knowledge about the additive noise term $\eta(x, y)$. The objective of the restoration is to obtain an estimate $\hat{f}(x, y)$ of the original image. If H is a linear, position-invariant process, then the degraded image is given in the spatial domain by

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

Where $h(x, y)$ is the spatial representation of the degraded function. The degrade image in frequency domain is represented as

$$G(u,v)=F(u,v)H(u,v)+N(u,v)$$

The terms in the capital letters are the Fourier Transform of the corresponding terms in the spatial domain.

3.2 Noise Models

The principle sources of noise in digital image are due to image acquisition and transmission.

- During image acquisition, the performance of image sensors gets affected by a variety of factors such as environmental conditions and the quality of sensing elements.
- During image transmission, the images are corrupted due to the interference introduced in the channel used for transmission.

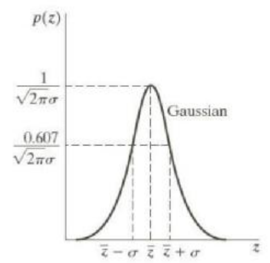
The Noise components are considered as random variables, characterized by a probability density function. The most common PDFs found in digital image processing applications are given below.

Gaussian Noise

Gaussian noise is also known as 'normal' noise. The Probability density function of a Gaussian random variable z is given by

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

Where z represents intensity, $\bar{z}$ is the mean and σ is its standard deviation and its square (σ^2) is called the variance of z. The values of Gaussian noise is approximately 70% will be in the range $[(\bar{z}-\sigma), (\bar{z}+\sigma)]$ and 95% will be in the range $[(\bar{z}-2\sigma), (\bar{z}+2\sigma)]$.



Rayleigh Noise

The PDF of Rayleigh Noise is given by

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

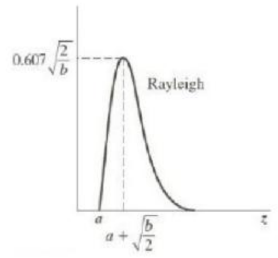
$b(4-\pi)$

Rayleigh Noise

The PDF of Rayleigh Noise is given by

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

Mean: $\bar{z} = a + \sqrt{\pi b/4}$ Variance: $\sigma^2 = \dfrac{b(4-\pi)}{4}$



Applications:

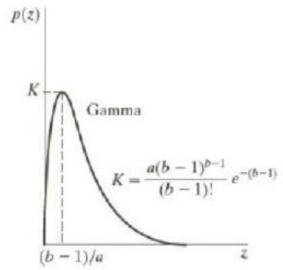
- It is used for characterizing noise phenomenon in range imaging.
- It describes the error in the measurement instrument.
- It describes the noise affected in radar.
- It determines the noise occurred when the signal is passed through the band pass filter.

Erlang (gamma) Noise

The probability density function of Erlang noise is given by

$$p(z) = \begin{cases} \frac{a^b z^{b-1}}{(b-1)!}e^{-az} & \text{for } z \geq 0 \\ 0 & \text{for } z < 0 \end{cases} \qquad a > 0, \ \text{b positive integer}$$

Mean: $\bar{z} = \dfrac{b}{a}$ Variance: $\sigma^2 = \dfrac{b}{a^2}$



Exponential Noise

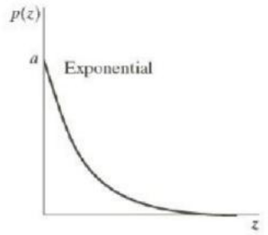
The probability density function of Exponential noise is given by

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

p(z) is maximum at z=0

Mean: $z = \frac{1}{a}$ Variance: $\sigma^2 = \frac{1}{a^2}$

$p(z)$



Applications:

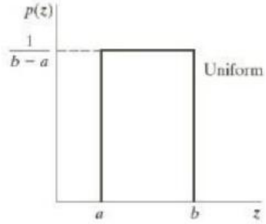
- It is used to describe the size of the raindrop.
- It is used to describe the fluctuations in received power reflected from certain targets
- It finds application in Laser imaging.

Uniform Noise

The probability density function of Uniform noise is given by

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

$$\text{Mean: } \bar{z} = \frac{a+b}{2} \qquad \text{Variance: } \sigma^2 = \frac{(b-a)^2}{12}$$

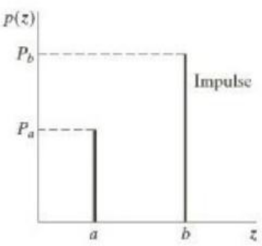


Salt and Pepper Noise (Impulse Noise)

The probability density function of Salt and Impulse noise is given by

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

$$P_a = P_b \Rightarrow \textit{unipolar} \text{ noise}$$



If b>a, gray level b will appear as a light dot in image. Level a will appear like a dark dot. The salt and pepper noise is also called as bi-polar impulse noise or Data-drop-out and spike noise.

Periodic Noise

Periodic noise in an image occurred from electrical or elecrtomechnaical interference during image acquisition. This is the only type of spatially dependent noise and the parameters are estimated by the Fourier spectrum of the image. Periodic noise tends to produce frequency spikes that often can be detected even by visual analysis. The mean and variance are defined as

$$\bar{z} = \sum_{i=0}^{L-1} z_i p_S(z_i)$$

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$$\sigma^2 = \sum_{i=0}^{L-1} (z_i - \bar{z})^2 p_S(z_i)$$

3.3 Restoration in the Presence of Noise only-Spatial Filtering

When the only degradation present in an image is noise,

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

and

$$G(u, v) = F(u, v) + N(u, v)$$

The noise terms are unknown so subtracting them from g(x, y) or G (u, v) is not a realistic approach. In the case of periodic noise it is possible to estimate N (u, v) from the spectrum G (u, v). So N (u, v) can be subtracted from G (u, v) to obtain an estimate of original image. Spatial filtering can be done when only additive noise is present.

Mean Filters

Arithmetic Mean Filter:

It is the simplest mean filter. Let S_{xy} represents the set of coordinates in the sub image of size m*n centered at point (x, y). The arithmetic mean filter computes the average value of the corrupted image g(x, y) in the area defined by S_{xy}. The value of the restored image f at any point (x, y) is the arithmetic mean computed using the pixels in the region defined by S_{xy}.

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

This operation can be using a convolution mask in which all coefficients have value 1/mn. A mean filter smoothes local variations in image Noise is reduced as a result of blurring.

Geometric Mean Filter:

An image restored using a geometric mean filter is given by the expression

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

Here, each restored pixel is given by the product of the pixel in the sub-image window, raised to the power 1/mn. A Geometric means filter achieves smoothing comparable to the arithmetic mean filter, but it tends to lose image details in the process.

Harmonic Mean Filter:

The harmonic mean filtering operation is given by the expression

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

The harmonic mean filter works well for salt noise but fails for pepper noise. It does

The harmonic mean filter works well for salt noise but fails for pepper noise. It does well also with other types of noise.

Contra harmonic Mean Filter:

The contra harmonic mean filter yields a restored image based on the expression

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

Where Q is called the order of the filter and this filter is well suited for reducing the effects of salt and pepper noise. For positive values of Q the filter eliminates pepper noise. For negative values of Q it eliminates salt noise. It cannot do both simultaneously. The contra harmonic filter reduces to arithmetic mean filter if Q=0 and to the harmonic filter if Q= -1.

Order-Static Filters

Order statistics filters are spatial filters whose response is based on ordering the pixel contained in the image area encompassed by the filter. The response of the filter at any point is determined by the ranking result.

Median Filter:

It is the best known order statistic filter. It replaces the value of a pixel by the median of gray levels in the Neighborhood of the pixel.

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

The value of the pixel at *(x, y)* is included in the computation of the median. Median filters are quite popular because for certain types of random noise, they provide excellent noise reduction capabilities with considerably less blurring than smoothing filters of similar size. These are effective for bipolar and unipolar impulse noise.

Max and Min Filters:

The median filter represents the 50th percentile of a ranked set of numbers. If using the 100th percentile results is called "Max Filter". It can be defined as

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

This filter is used for finding the brightest point in an image. Pepper noise in the image has very low values, it is reduced by max filter using the max selection process in the sublimated area S_{XY}.

The 0th percentile filter is min filter

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

This filter is useful for flinging the darkest point in image. Also, it reduces salt noise as a result of the min operation.

Midpoint Filter:

The midpoint filter simply computes the midpoint between the maximum and minimum values in the area encompassed by the filter.

$$\hat{f}(x, y) = \frac{1}{2}\left[\max_{(s,t)\in S_{xy}}\{g(s,t)\} + \min_{(s,t)\in S_{xy}}\{g(s,t)\}\right].$$

It combines the order statistics and averaging .This filter works best for randomly distributed noise like Gaussian or uniform noise.

Alpha-trimmed mean Filter:

If we delete the d/2 lowest and the d/2 highest intensity values of *g(s, t)* in the neighborhood S_{XY}. Let $g_r(s, t)$ represents the remaining *mn-d* pixels. A filter formed by averaging the reaming pixels is called alpha-trimmed mean filter.

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

The value of d can range from 0 to *mn*-1. If d=0 this filter reduces to arithmetic mean

The value of d can range from 0 to mn-1. If d=0 this filter reduces to arithmetic mean filter. If d=mn-1, the filter becomes a median filter. For the other values of d the alpha-trimmed median filter is useful for multiple types of noise, such as combination of salt-and-pepper and Gaussian noise.

3.4 Adaptive Filters

Adaptive filter whose behavior changes based on the statistical characteristics of the image inside the filter region S_{xy}.

Adaptive, local noise reduction filter

The simplest statistical measures of a random variable are its mean and variance. The mean gives a measure of average intensity in the region over which the mean is computed and the variance gives a measure of contrast in that region.

Let the filter is operate on a local region S_{XY}. The response of the filter at any point (x, y) is based on four quantities: (a) $g(x, y)$, the value of noisy image at (x, y); (b) σ_η^2 the variance of the noise corrupting $f(x, y)$ to form $g(x, y)$; (c) m_L, the local mean of the pixels in S_{XY}; and (d) σ_L^2, the local variance of the pixels in S_{XY}. Hence the behavior of the filter is,

- If σ_η^2 is zero, the filter should return simply the value of $g(x, y)$.
- If the local variance is high relative to σ_η^2 that means ($\sigma_L^2 > \sigma_\eta^2$), the filter should return a value close to $g(x, y)$.
- If the two variances are equal, the filter returns the arithmetic mean value of the pixel in S_{XY}.

An adaptive filter for obtaining the restored image is

$$\hat{f}(x, y) = g(x, y) - \frac{\sigma_\eta^2}{\sigma_L^2}\left[g(x, y) - m_L\right]$$

The only quantity that needs to be known or estimated is the variance of the overall noise is σ_η^2. The other parameters are computed from the pixels in S_{XY}.

Adaptive median filter

Adaptive median filters are used to preserve the details while smoothing non impulse. However it changes the size of S_{XY} during the filtering operation, depending on certain conditions. The output of the filter is a single value used to replace the value of pixel at (x, y). Let us consider the following parameters,

z_{min} = minimum intensity value in S_{XY}
z_{max} = maximum intensity value in S_{XY}
z_{med} = median of intensity values in S_{XY}
z_{xy} = intensity value at co-ordinates (x, y)
S_{max} = maximum allowed size of S_{XY}

The adaptive median filtering algorithm works in two stages, denoted as stage A and stage B as follows:

Stage A: $A1 = z_{med} - z_{min}$
$A2 = z_{med} - z_{max}$
If A1>0 AND A2<0, go to stage B
Else increase the window size
If window size ≤ S_{max} repeat stage A
Else output z_{med}

Stage B: $B1 = z_{xy} - z_{min}$
$B2 = z_{xy} - z_{max}$

Else output z_{med}

Stage B: $B1 = z_{xy} - z_{min}$

$B2 = z_{xy} - z_{max}$

If B1>0 AND B2<0, output z_{xy}.

Else output z_{med}

3.5 Periodic Noise Reduction by Frequency Domain Filtering

Periodic noise in images are appears as concentrated bursts of energy in the Fourier transform at locations corresponding to the frequencies of the periodic interference. This can be removed by using selective filters.

Band Reject Filter:

The Band Reject Filter transfer function is defined as

Ideal	Butterworth	Gaussian
$H(u,v) = \begin{cases} 0 & \text{if } D_0 - \frac{W}{2} \le D \le D_0 + \frac{W}{2} \\ 1 & \text{otherwise} \end{cases}$	$H(u,v) = \dfrac{1}{1 + \left[\dfrac{DW}{D^2 - D_0^2}\right]^{2n}}$	$H(u,v) = 1 - e^{-\left[\frac{D^2 - D_0^2}{DW}\right]^2}$

Where 'W' is the width of the band, D is the distance $D\,(u,\ v)$ from the centre of the filter, D_o is the cutoff frequency and n is the order of the Butterworth filter. The band reject filters are very effective in removing periodic noise and the ringing effect normally small. The perspective plots of these filters are

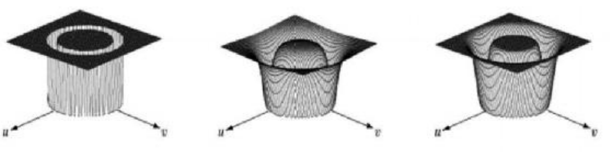

Fig: Perspective plots of (a) Ideal (b) Butterworth and (c) Gaussian Band Reject Filters

Band Pass Filter:

A *band pass* filter performs the opposite operation of a band reject filter. A Band pass filter is obtained from the band reject filter as

$$H_{BP}(u,v) = 1 - H_{BR}(u,v)$$

Notch Filters:

A Notch filter Reject (or pass) frequencies in a predefined neighborhood about the centre of the frequency rectangle. It is constructed as products of high pass filters whose centers have been translated to the centers of the notches. The general form is defined as

$$H_{NR}(u,v) = \prod_{k=1}^{Q} \underbrace{H_k(u,v)}_{\substack{\text{centre at} \\ (u_k,\, v_k)}} \underbrace{H_{-k}(u,v)}_{\substack{\text{centre at} \\ (-u_k,\, -v_k)}}$$

Where $H_k(u,v)$ and $H_{-k}(u,v)$ are high pass filters whose centers are at (u_k, v_k) and ($-u_k$, $-v_k$) respectively. These centers are specified with respect to the center of the frequency rectangle (M/2, N/2).

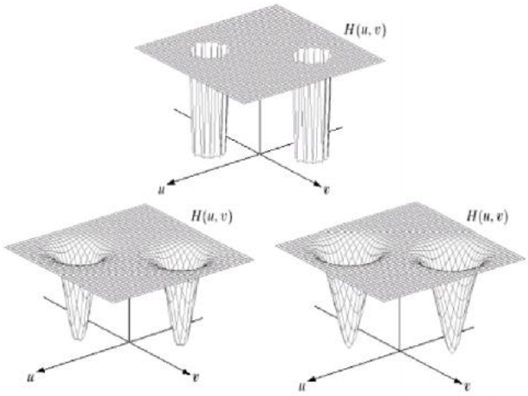

Fig: Perspective plots of (a) Ideal (b) Butterworth and (c) Gaussian Notch Reject Filters