Intensity Transformation and Spatial Filtering – I.

Intensity Transformation and Image noise.

* What is the spatial Domain?
  - The spatial domain refers to the actual pixels of an image.
  - Each pixel has an intensity (brightness) value and a specific location (x, y)

* There are 3 common Domain.
  1. spatial Domain
  2. Frequency Domain
  3. Energy Domain

* Mathematical Representation

$$G(x,y) = T[f(x,y)]$$

$f(x,y)$: Input image (original image)
T : A transformation (or filter) applied to modify pixel values.
$G(x,y)$: output image (processed image).

- Examples of spatial domain techniques include
  1. Intensity Transformations
     e.g. contrast stretching, log transformation
  2. Smoothing filters
     e.g. mean filter, Gaussian filter.
  3. Edge Detection
     e.g. Sobel, Prewitt, Canny.

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- What is Image Enhancement?

Image enhancement is the process of modifying an image to make it more useful for a specific application.

- Why Are Enhancement Techniques Problem-Oriented?

Different applications need different enhancements.

- Medical imaging: Enhancing X-rays or MRI scans to detect diseases.
- Satellite images:
- Security cameras: Reducing noise for clear video footage.

Intensity Transformation

- What is Intensity Transformation?

Intensity transformation modifies the brightness and contrast of an image by changing pixel values.

$s = T(r)$

- s: New pixel value
- T: Transformation function
- r: original pixel value

Types of Gray Level Transformations.

1. Linear Transformation (Direct Adjustments)
   - → contrast stretching
   - → Negative Transformation. $S = L - 1 - r$
2. Logarithmic Transformation (Enhancing Dark Details)
3. Power-Law (Gamma) Transformation (Adjusting Brightness) $S = cr^{\gamma}$

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Linear Transformation

→ Identity Transformation.
- No change in pixel values.
- $g(x,y) = f(x,y)$
- output same as input
- Used stored, analyzed without alteration.

→ Image Negatives - This transformation inverts the pixel values
$s = (L-1) - r$

Log Transformation

- what is Log Transformation?
  - Log transformation enhances dark regions while compressing bright regions.
  - It is useful when an image has many dark pixels with hidden details.

- Types of Log Transformation
  1. Log Transformation (Enhancing Dark Details)
  2. Inverse Log Transformation (Enhancing Bright Details)

→ $s = c \log(1+r)$ $\quad r >= 0$

r = input pixel intensity
s = Output pixel intensity
c = Scaling constant (adjusts intensity range

- Why Use Log Transformations?
  Medical Imaging - Enhancing X-ray scans.
  Satellite Images -
  Low-light photography -

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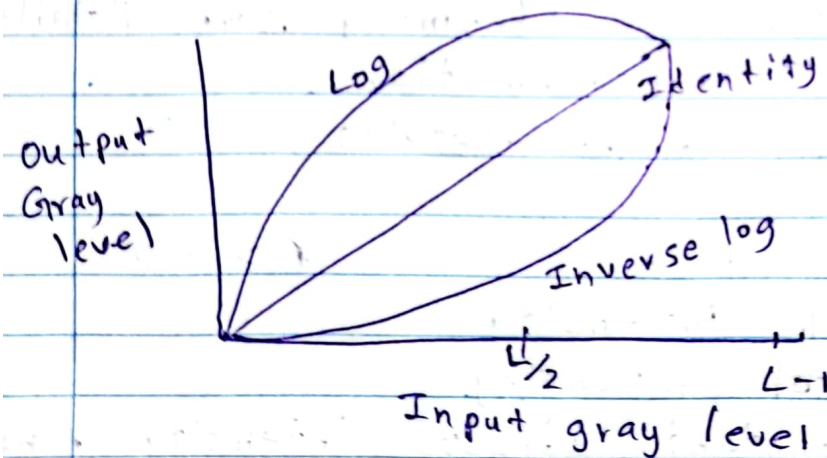
• Power-Law (Gamma) Transformation

- What is Power-Law (Gamma) Transformation?
  - The power-law transformation (~~also called~~ gamma correction) is used to adjust the contrast of an image.
  - It maps input pixel values to output values based on a power function.

$$S = c \cdot r^2$$

S = Output pixel value
r = Input pixel value
c = Constant scaling factor (Controls the overall brightness)
γ = Exponent that controls the nonlinear relationship between the input and output values.

• Intensity Transformation All in One



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* Contrast Stretching.

- What is Contrast Stretching ?

  Contrast stretching is a technique used to increase the contrast in images, especially in low contrast images.

- Low contrast images can occur due to:
  - poor illumination (insufficient light during capture)
  - Limited dynamic range in the camera or sensor.
  - Incorrect lens settings (e.g. wrong aperture)

- Gray Level Slicing
  - purpose : Highlights specific intensity ranges in an image.

- Histogram Processing.

  A histogram in image processing is a graphical way to show how pixel intensities are distributed in an image.

- Understanding the Histogram.
  - In a grayscale image, each pixel has an intensity ranging from 0 (black) to 255 (white)
  - A histogram counts how many pixels exist for each intensity level.
  - It helps in analyzing the brightness, contrast, and exposure of an image.

Normalization of Histogram

- This is done by dividing each histogram value by the total number of pixels.

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- Why use Histogram Processing?
  - Enhances contrast
  - Equalizes brightness
  - Improves image quality.

- Histogram Equalization:

(PDF) probability distribution function:

$$P(r_k) = h(r_k) / N$$

(CDF) cumulative distribution function:

$$CDF(r_k) = \sum_{i=0}^{k} p(r_k)$$

$$S_k = ((L-1) \cdot CDF(r_k))$$

gray Levels	0	1	2	3	4	5	6	7
No. of pixels	0	100	400	50	200	50	200	0

$$h = \sum n_k = 0 + 100 + 400 + 50 + 200 + 50 + 200 + 0 = 1000$$

Gray level	0	1	2	3	4	5	6	7
nk	0	100	400	50	200	50	200	0
$pf = \frac{nk}{h}$	$\frac{0}{1000} = 0$	$\frac{100}{1000} = 0.1$	0.4	0.05	0.2	0.05	0.2	0
CDF(S_k)	0	0+0.1 = 0.1	0.1+0.4 = 0.5	0.5+0.05 = 0.55	0.55+0.2 = 0.75	0.75+0.05 = 0.80	0.80+0.20 = 1.00	1
$(L-1) * S_k$ $8-1=7$	0	7×0.1 = 0.7	7×0.5 = 3.5	7×0.55 = 3.85	7×0.75 = 5.25	7×0.80 = 5.6	7×1 = 7	7×1 = 7
Rounding	0	1	4	4	5	6	7	7

x old Gray levels	0	1	2	3	4	5	6	7
y No. of pixel	0	100	400	50	200	50	200	0
New Gray Level	0	1	4	4	5	6	7	7

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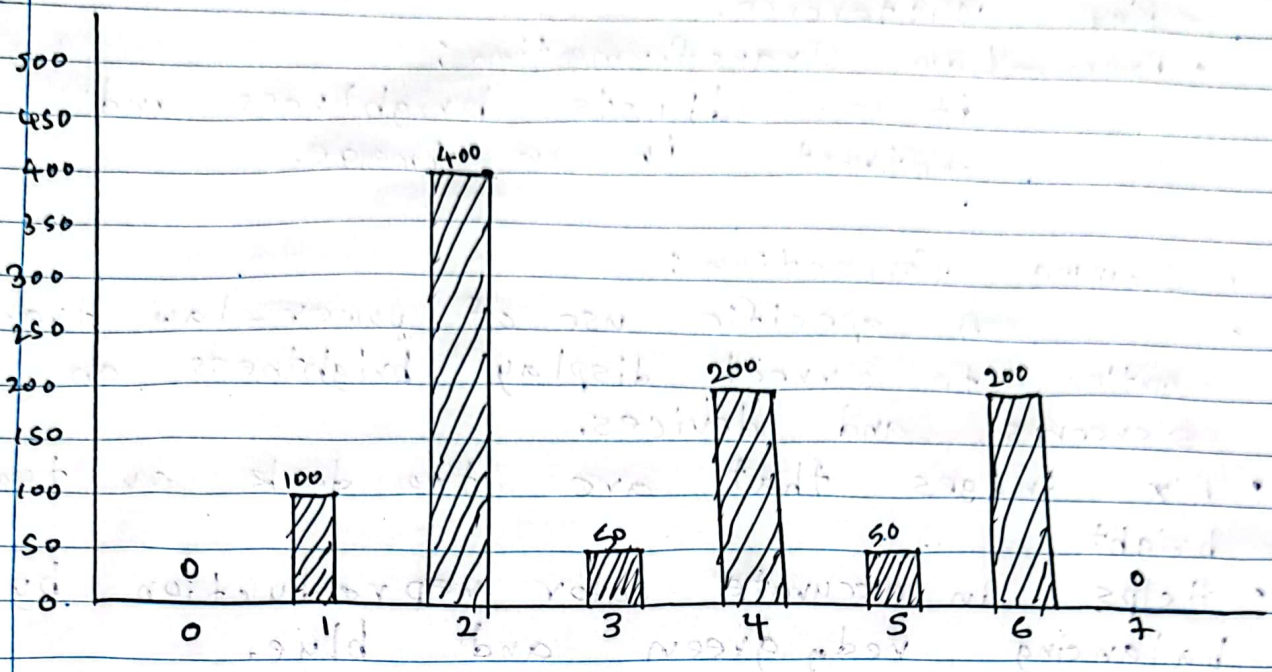
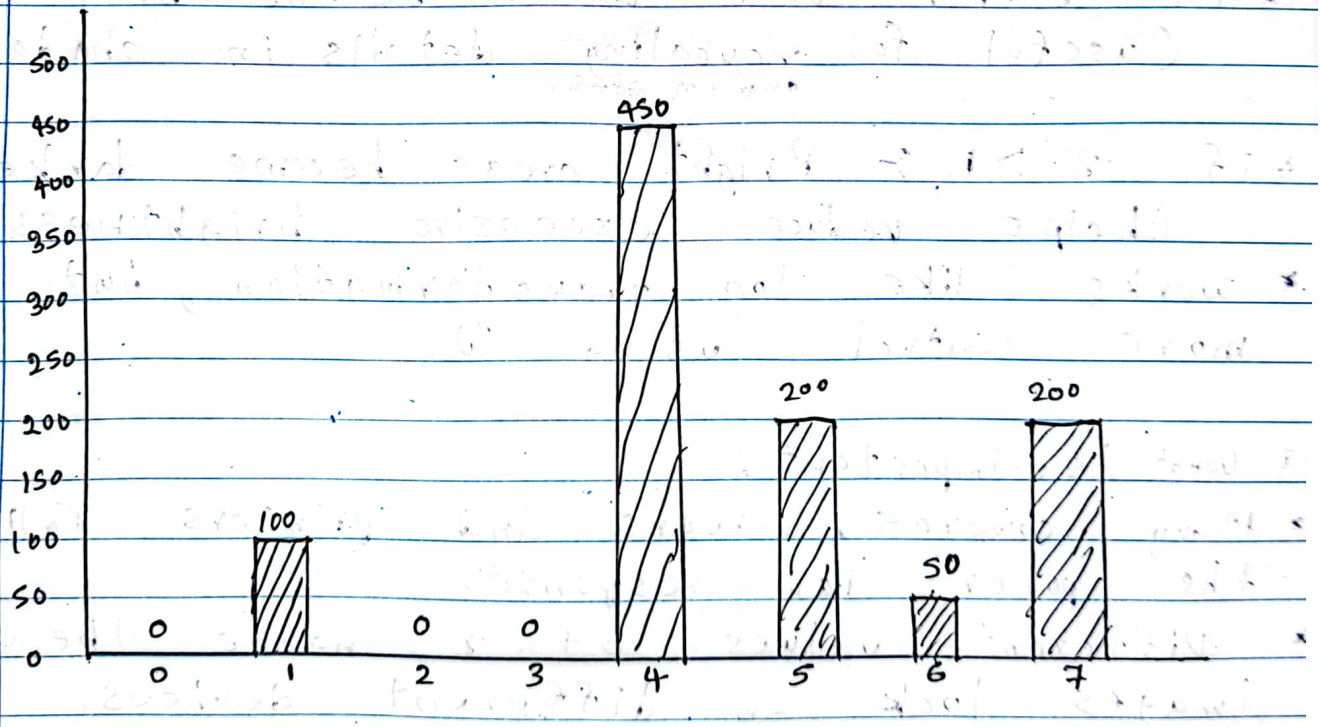
Original Histogram



Equilized Histogram



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* Power-Law (Gamma) Transformation.

Key Difference:

- **Power-Law Transformation:**
  It is adjusts brightness and contrast in an image.

- **Gamma Correction:**
- A specific use of power-law transformation to correct display brightness on screens and devices.
- Fix images that are too dark or too bright
- Helps in accurate color reproduction by balancing red, green and blue.

→ How it works (Power-Law Transformation)

* if $\gamma < 1$:- Dark areas become brighter (useful for revealing details in shadows)

* if $\gamma > 1$:- Bright areas become darker (helps reduce excessive brightness)
* Works like log transformation, but gives more control using γ

→ What is important?

* Many cameras, screens and printers follow the power law response.
* Different values of γ change the way images look on different devices.

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Image Noice

* Noice is a visual distrotion in digital image.
* It causes visual degradations in digital images :
  Noice reduce image quality, making it look grainy, blurry, or speckled.
* Even though noice is unvoidable. noice is always present, but if the main image data (signal) is strong enough, the noice become too small to noice.

* SNR (signal to Noice Ratio) compares the amount of useful image data (signal) to unwanted noise. A high SNR means clear image with little noise, while low SNR means noisier, degraded image.

* In digital imaging, A Noisy image can be mathematically represented as,

$$g(x,y) = f(x,y) + n(x,y)$$

$f(x,y)$ → original image pixel
$n(x,y)$ → noise in the image
$g(x,y)$ → final pixel value with noise

* **Source of Image Noise.**

— Error occurs in image signal :
noise happens when an image sent electronically from one place to another, data gets lost or mixed up.

ISO Factor [illegible]

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- Exposure time :

If the camera's shutter open for a long time, static or unwanted signal maybe introduced, leading to noice.

- ISO Factor :

ISO setting on camera controls its sensitivity to light. Higher ISO setting can brighten images but also increase noise.

- size of the sensor :

smaller sensors have a reduced capacity to gather light, which can lead to increase noise.

- Pixel Density :

Higher pixel density means more pixel are packed into a small area, which can reduce light per pixel and increase noice

- shadows :

In dark areas, camera has trouble capturing details, causing noise

Types of Noise :

* The distribution of noise is based on probability. So this discribed probability Density function (PDF).
* PDF helps to understand the distribution of noise values.

* Noise types are,

1) Gaussian Noise :
   - This is a common type of noise.
   - Gaussian noise happens in images because of things like electronic circuits and sensor issues in cameras, especially when there's poor lighting or high temperatures.
   - It has a random distribution, meaning the noise values are normally distributed over time.

2) Rayleigh noise -
   - Typically appears in images taken by devices that measure distance, like radar or sonar.

3) Gamma (Erlang) Noise and Exponential noise:
   - This can be found in laser imaging.

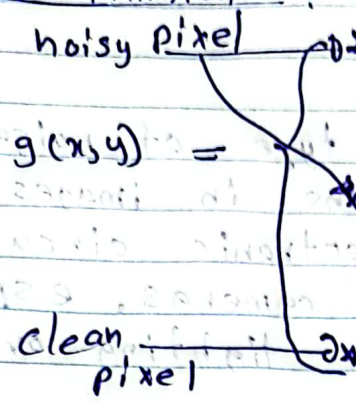
4) Uniform Noise : This noise rave in real world images.

5) Impulse Noise -
   - Common type of noise found in digital images.
   - Impulse noise doesn't affect every pixel in an image.
   - only some pixel are corrupted.

There are two main types :

1. Salt noise - This appears as white spots and has the brightest brightness level.
2. Pepper noise - This appears as black spots and has the darkest brightness level.

Definition



* In some applications, noisy pixel have not simply black or white, which makes the impulse noise removal problem more difficult.

Image Restoration

* The main goal of restoration technique is to improve an image by reversing the damage.
* Unlike image enhacement, which makes image look better for a specific purpose, restoration tries to get the image back to its original state.

Common ways to restore an image:

* Deblurring;
* Inverse filtering;

Periodic Noise

* depends spatial coordinates.
* can reduced through frequency domain filtering.