قســـم الانظمة الطبية الذكية

المرحلة الثالثة

Subject : Medical image processing

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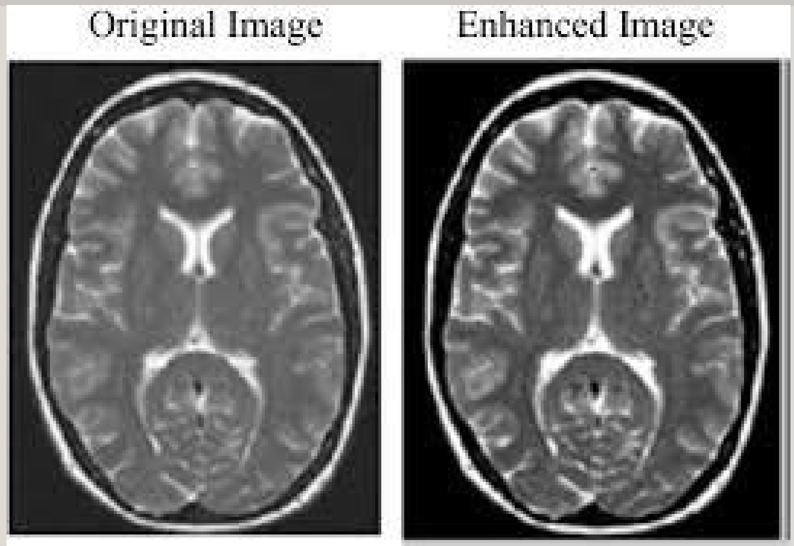
Class 5: Medical image preprocessing algorithms

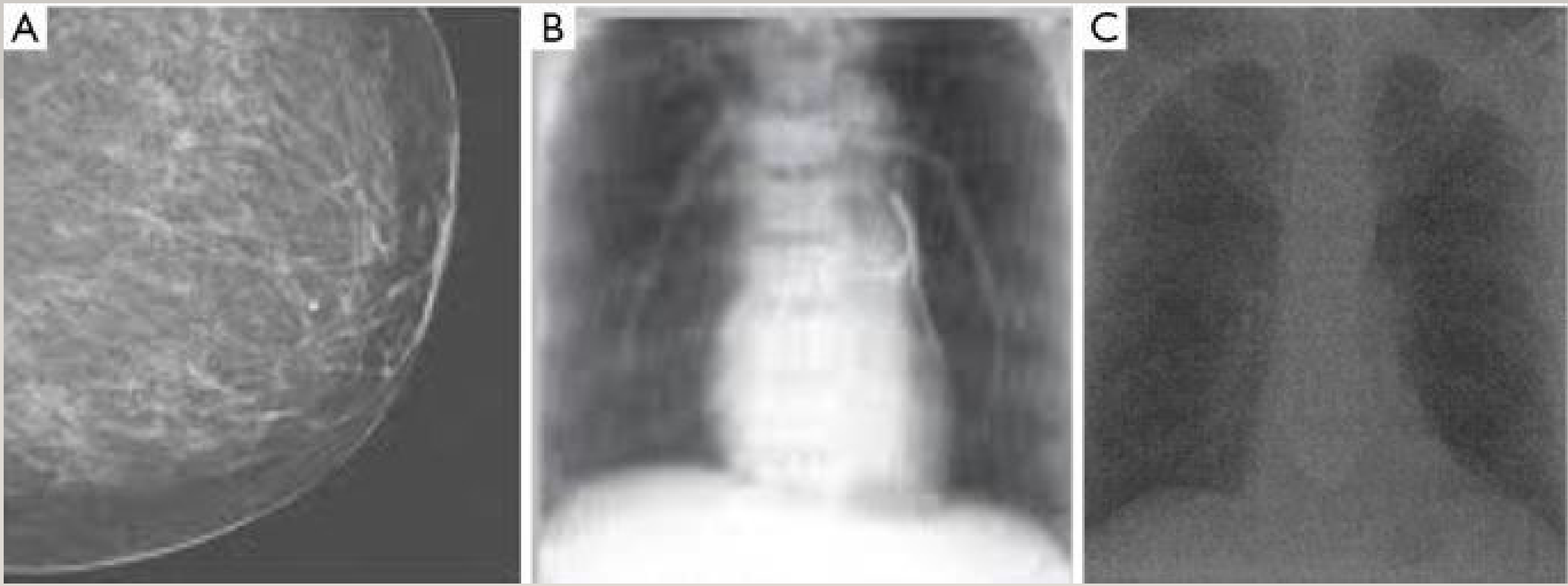
MEDICAL IMAGE PREPROCESSING ALGORITHMS

- **Image enhancement** involves improving the visual quality of an image, so it is easier to analyze, interpret, or make more visually appealing. The process can target various aspects such as contrast, sharpness, noise reduction, color balance, or fine details.

Other words

- **Image enhancement is a process where the produced image is made more suitable for subsequent processing or viewing than the original image**





Low-quality medical images

IMAGE ENHANCEMENT TECHNIQUES

- Spatial Domain Techniques: These techniques operate directly on the image , processing is generally represented by the following symbol:

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

The function *T* is called the intensity transformation function or mapping function

1. Brightness Adjustment (Point Processing , Power-Law (Gamma) Transformations)
2. Quantization
3. Contrast Enhancement
4. Edge Enhancement (Laplacian Filtering, Unsharp Masking)

- 2. **Frequency Domain Techniques:** These techniques process images using Fourier Transform. Frequency domain techniques manipulate an image by transforming it into the frequency space (via the **Fourier Transform**) and then applying various filters to enhance specific features.

(In image processing, transforming an image into the frequency space means converting it from the spatial domain (where pixel values represent brightness or color) to the frequency domain, where the image is represented as a sum of sinusoidal (Sin) waves (frequencies))

- **) High-Pass Filtering**
- Enhances edges and fine details by removing low-frequency components.
- **b) Low-Pass Filtering**
- Smoothens the image by reducing noise and blurring details.
- **c) Band-Pass Filtering**
- Retains mid-frequency components to balance smoothness and details.

3. Noise Reduction Techniques:

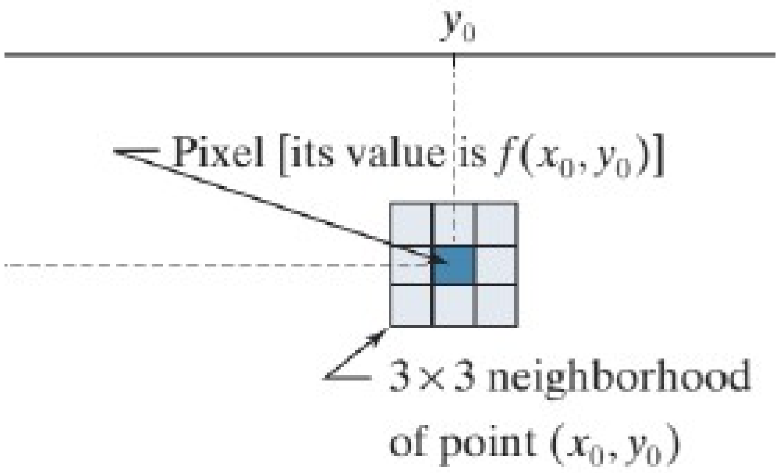
- Gaussian Filtering: Reduces noise while preserving edges.
- Median Filtering: Effective for removing salt-and-pepper noise.
- Bilateral Filtering: Preserves edges while reducing noise

1- Point processing in image processing refers to the manipulation of pixel values in an image, where each pixel is modified independently of its neighbors based on a specific transformation or function. It is one of the simplest and most fundamental image processing techniques

•**Pixel Independence:** Each pixel is processed without considering surrounding pixels. Point processing is the simplest form of neighborhood processing, where the window size is 1×1,In this case, $g(x,y)$ only depends on the value of f at point (x,y)

•**Transformation Function:** A mathematical function maps input pixel values to output pixel values. (The function T is called the intensity transformation function or mapping function

•**Efficiency:** It's computationally efficient because it involves direct per-pixel calculations.



- **Input Image**: A grayscale photo of a bright scene.
- **Output Image**: The same photo, but bright areas
- become dark and dark areas become bright.

Image f

Image negation inverts the pixel intensities of an image, transforming bright areas into dark area: and vice versa.

Formula:

For an 8-bit grayscale image:

$$g(x, y) = 255 - f(x, y)$$

Where:

- $g(x, y)$: Output pixel value.
- $f(x, y)$: Input pixel value.
- 255: Maximum pixel intensity for an 8-bit image.

Example:

Original Grayscale Image (3x3 pixels):

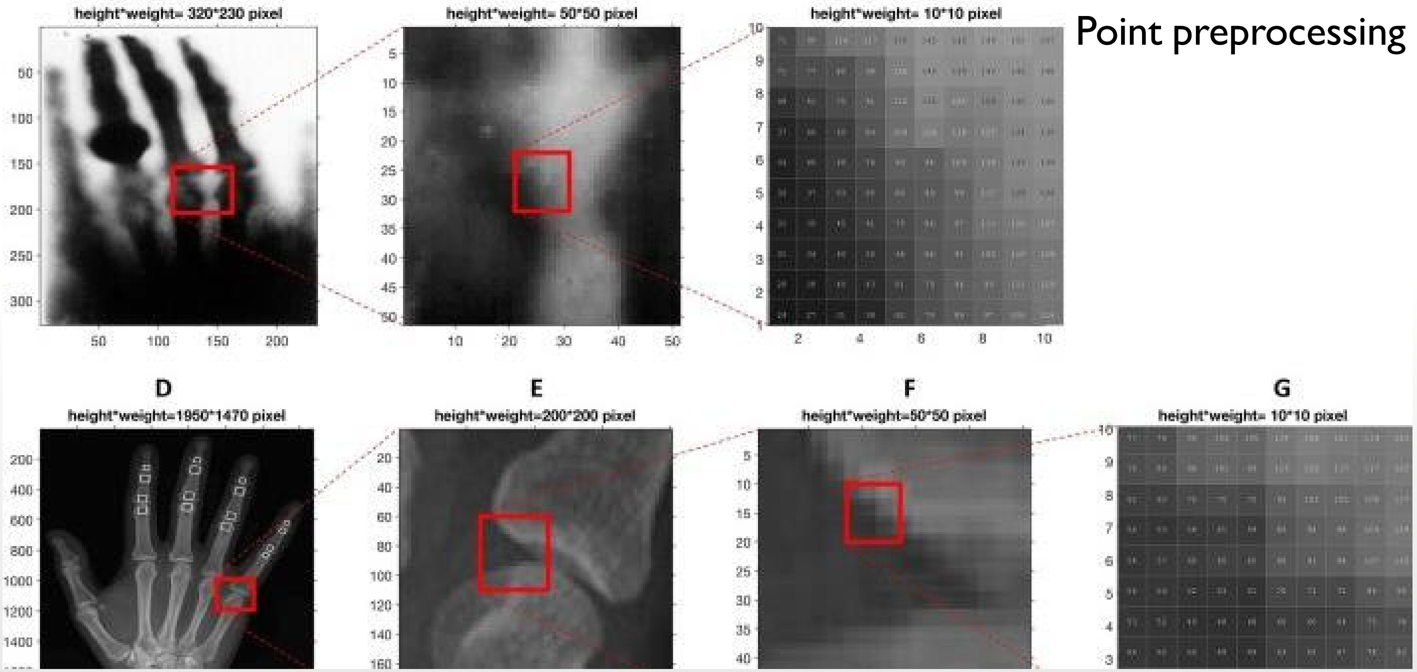
$$f(x, y) = \begin{bmatrix} 50 & 100 & 150 \\ 200 & 50 & 100 \\ 150 & 200 & 250 \end{bmatrix}$$

Negated Image:

$$g(x, y) = 255 - f(x, y)$$

$$\begin{bmatrix} 205 & 155 & 105 \end{bmatrix}$$

Point preprocessing



2- Power-Law (Gamma) Transformations are used in image processing to adjust the brightness and contrast of an image. This transformation is based on the formula

$$g(x, y) = c \cdot [f(x, y)]^{\gamma}$$

Where:

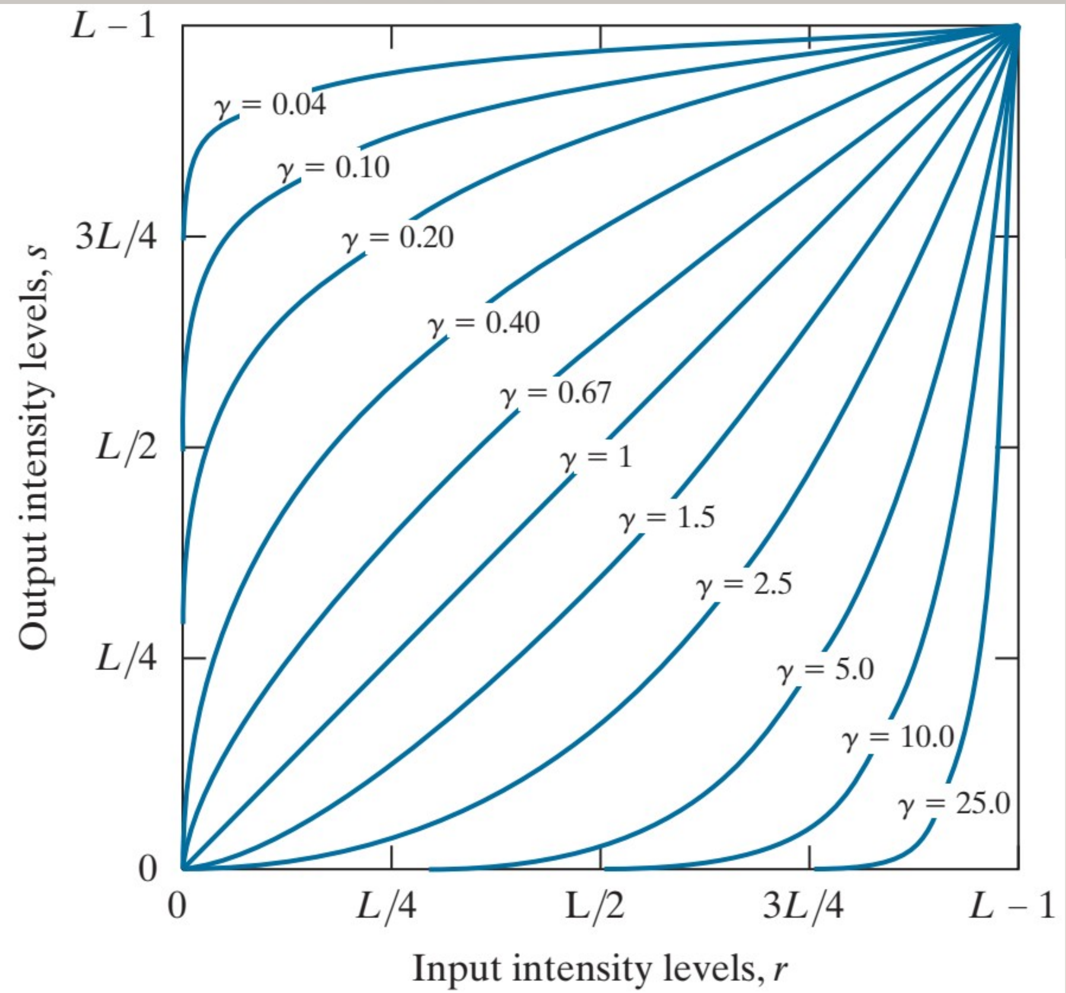
- $g(x, y)$: Output pixel intensity.
- $f(x, y)$: Input pixel intensity (normalized to [0, 1]).
- c: A scaling constant (often set to 1 for simplicity).
- γ: The gamma value, which determines the transformation's effect.

1.Gamma < 1:

1. Brightens the image. 2- Enhances details in darker regions.

2.Gamma = 1:

1. No change (identity transformation).
2. **Gamma > 1:** Darkens the image. Enhances details in brighter regions.



Example

Let :

- Pixel intensity **r=0.5** (normalized)
- Gamma **γ=2.0**
- Scaling constant **c=1**

Using the formula:

$s=1* \ 0.5^{2.0} \ = 1*0.25$

transformed pixel intensity g= 0.25

Quiz:

- **r=0.8r**
- **γ=0.5\gamma**

3- Quantization refers to the process of reducing the range of intensity or color values in an image, typically for the purpose of simplifying analysis, reducing storage requirements, or standardizing data for comparison. In medical imaging, quantization is often applied to modalities like CT, MRI, or PET images, where pixel or voxel intensities represent specific physical properties (e.g., tissue density or contrast agent concentration). Quantization helps in **compression, noise reduction, and feature extraction** for analysis.

Key Aspects of Quantization in Medical Imaging:

1.Gray-Level Reduction:

1. Most medical images have a high dynamic range. For instance, a CT scan may have values ranging from -1000 HU (Hounsfield units) to over +3000 HU. Quantization reduces these continuous or wide-ranging intensity values into a smaller set of discrete levels (e.g., 256, 64, or even fewer gray levels).
2. This can make it easier to identify regions of interest (ROIs), compare images from different devices, or reduce the complexity of subsequent image processing steps.

In grayscale images quantization:

Quantization reduces the number of possible pixel intensity values from 2^n(e.g., 256 for an 8-bit image) to a smaller set of values. This is useful in medical imaging to optimize storage and processing. Mathematically, quantization is expressed as:

$$\boxed{Q = \left\lfloor \frac{255}{L-1} \right\rfloor}$$

$$Q(I) = \left[\frac{\mathrm{I}}{\mathrm{Q}} \right] \times \mathrm{Q}$$

Where

I= pixel intensity (0-255 for 8 bits)

L is the number of quantization levels

Q(I) = quantized intensity

Common Levels in Grayscale Quantization:

Bits (b)	Levels (L)	Example Values
8-bit	256	0, 1, 2, ..., 255
4-bit	16	0, 17, 34, ..., 255
3-bit	8	0, 36, 73, ..., 255
2-bit	4	0, 85, 170, 255
1-bit	2 (Binary)	0, 255 (Black & White)

Example: Quantizing a Medical Image (CT/X-ray)
Let's reduce an 8-bit grayscale image (256 levels) to 4 levels (L=4).

$$I=\begin{bmatrix} 30 & 200 \\ 120 & 255 \end{bmatrix}$$

Sol/
1- Compute step size

$$Q = \left\lfloor \frac{255}{4-1} \right\rfloor$$

2-Apply quantization to pixel values:

Original Pixel Value (I)	Q(I)
30	$\lfloor 30/85 \rfloor \times 85 = 0$
120	$\lfloor 120/85 \rfloor \times 85 = 85$
200	$\lfloor 200/85 \rfloor \times 85 = 170$
255	$\lfloor 255/85 \rfloor \times 85 = 255$

$$Q(I) = \begin{matrix} 0 & 170 \\ 85 & 255 \end{matrix}$$

Home work:

Quantizing an 8-Bit Medical Image (8 Levels)

Take 5x5 grayscale image with the following pixel intensity values:

$$M = \begin{bmatrix} 34 & 78 & 120 & 200 \\ 60 & 90 & 140 & 220 \\ 30 & 85 & 130 & 210 \\ 45 & 75 & 125 & 195 \end{bmatrix}$$

and quantize it to **8 levels (L=8)**. This means that the pixel values will be reduced from 256 possible intensity levels (0-255) to just 8 levels.

2-Region-Specific Quantization: focuses on applying different quantization levels to specific parts or regions of an image rather than treating the entire image uniformly. The idea is to tailor the quantization process based on the distinct characteristics of various regions, enhancing the clarity and usability of the data for targeted analysis.

- Bone and air regions might be assigned distinct, easily recognizable levels in a CT scan.
- Different tissue types in an MRI (e.g., white matter, gray matter, cerebrospinal fluid) may be quantized into distinct intensity ranges.

Mathematical Concept of Region-Specific Quantization

Suppose we have a medical image and apply region-specific quantization. The idea is to divide the image into different regions (e.g., foreground, background, or regions of interest), and quantize each region with a different number of levels.

The general idea of region-specific quantization is:

$$Q(I) = \left\lfloor \frac{I - I_{\text{min}}}{\Delta_{\text{region}}} \right\rfloor \times \Delta_{\text{region}} + I_{\text{min}}$$

Where:

•I = pixel intensity

•I_{min} = minimum pixel intensity in the region

•Δregion = step size specific to that region = L-1

•Q(I) = quantized value for that region

Let's assume the following:

1. **Tumor Region** (Region 1): Requires higher precision (16 levels).
2. **Surrounding Tissue** (Region 2): Requires moderate precision (8 levels).
3. **Background Region** (Region 3): Can be coarsely quantized (4 levels).

Sol:

1- calculate Tumor Region (16 Levels) :

$Q(I) = [\frac{255}{16-1}]$ =17

And Apply quantization formula to the tumor region.

2. Surrounding Tissue (8 Levels)

$Q(I) = [\frac{255}{8-1}]$ =36

Apply quantization formula to the tissue region.

3. Background Region (4 Levels)

$Q(I) = [\frac{255}{4-1}]$ =85

Homework

Let use 4×4 matrix of intensity values.

$$\begin{bmatrix} 10 & 20 & 30 & 40 \\ 50 & 60 & 70 & 80 \\ 90 & 100 & 110 & 120 \\ 130 & 140 & 150 & 160 \end{bmatrix}$$

Use previse level and apply region-specific quantization by assigning different quantization levels to different parts of this matrix. For instance, l treat the top half of the matrix (Region 1) differently from the bottom half (Region 2).

4. **Contrast Enhancement:**

Image contrast enhancement is the process of increasing the contrast quality of the intensity variations in the considered image. One of the most useful applications of the image contrast enhancement is its usage in medical imaging. There are different types of medical image contrast enhancement

1. Linear Contrast Stretching
2. Gamma correction for the contrast enhancement
3. Histogram equalization (HEs)
4. Adaptive Histogram Equalization:
5. Contrast Limited Adaptive Histogram Equalization (CLAHE)

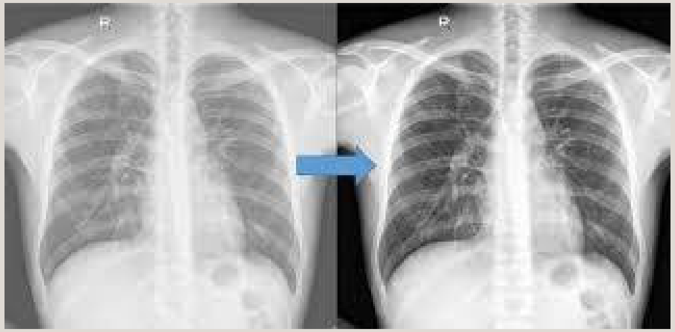
1- Linear Contrast Stretching

Contrast stretching is used to increase the dynamic range of the gray levels in the image. For example, in an 8-bit system the image display can show a maximum of 256 gray levels. If the number of gray levels in the recorded image spread over a lesser range, the images can be enhanced by expanding the number of gray levels to a wider range. This process is called contrast stretching. The resulting image displays enhanced contrast between the features of interests

Another words

Process Maps the original intensity range to a wider range, often from the minimum and maximum pixel values in the image to the full dynamic range (e.g., 0–255 for an 8-bit image).

Darker pixels become closer to black, and lighter pixels become closer to white, enhancing contrast.



When the values in the original image are expanded uniformly to fill the total range of the output device, the transformation is called linear contrast stretching

Example: Linear Contrast Stretching

This is a simple contrast enhancement technique that increases the dynamic range of pixel intensities in an image.

Steps for Linear Contrast Stretching

1.Identify the Intensity Range:

1. Find the minimum and maximum intensity values (I_{min}, I_{max})in the image

2. Apply a linear transformation to stretch the intensity values to cover the full range.

For each pixel intensity I(x,y) apply the following formula:

$$I_{\text{new}}(x, y) = \frac{(I(x, y) - I_{\text{min}})}{(I_{\text{max}} - I_{\text{min}})} \times (L - 1)$$

where L is the desired intensity range (e.g., 256 for an 8-bit image).

3.Update Pixel Intensities: Replace the original intensity values with the stretched values.

Assume an 8-bit image with:

- $I_{\min} = 50$,
- $I_{\max} = 180$,
- Desired range: $[0, 255]$.

For a pixel with intensity $I(x, y) = 100$:

Apply Linear Transformation:

$$I_{\text{norm}}(x, y) = \frac{100 - 50}{180 - 50} = \frac{50}{130} \approx 0.3846$$

$$I_{\text{new}}(x, y) = 0.3846 \cdot 255 \approx 98$$

2. Gamma Correction:

-Adjusts the image brightness using a gamma curve, suitable for correcting underexposed or overexposed images. Gamma correction controls the overall brightness of an image. Trying to enhance the image requires knowledge of gamma. A proper estimation of gamma value enhances the contrast of the image.

-Gamma value less than 1 makes dark regions brighter, while a gamma value greater than 1 darkens bright regions.

Benefit : Enhanced contrast in either dark or bright regions without drastically changing the overall brightness.

The following mathematical formula:

$$I_{\text{out}} = \left(\frac{I_{\text{in}}}{I_{\text{max}}} \right)^{\gamma} \cdot I_{\text{max}}$$

Where:

•I_{in}: Input pixel intensity (original value).

• I_{out} : Output pixel intensity after gamma correction.

•I_{max} : Maximum possible intensity value (e.g., 255 for 8-bit images).

•γ : Gamma value (a positive real number).

Important Points:

1.If γ=1:

1. The output intensities remain unchanged.
2. The formula simplifies to $I_{out} = I_{in}$

3. If γ<1:

1. The result is a “gamma expansion.”
2. The image becomes brighter as lower intensities are stretched upward more than higher intensities.

3. If γ>1 :

1. The result is a “gamma compression.”
2. The image becomes darker as higher intensities are compressed downward more than lower intensities.

Example : Let's have an 8-bit grayscale image with pixel intensities ranging from 0 to 255

I_{max} =255

Suppose γ=2.2

For an input intensity I_{in} =128

$$I_{ou} = \frac{I_{in}}{I_{max}}^{\gamma} \times I_{max} = \frac{128}{255}^{2.2} \times 255 = 55$$

So after gamma correction, the input intensity of 128 is mapped to an output intensity of approximately 55.

Quiz : apply two methods of contrast enhancement: stretching and Gamma to the image with matrix:

$$\begin{bmatrix} 12 & 45 & 130 & 200 & 255 \\ 75 & 85 & 160 & 210 & 250 \\ 30 & 70 & 125 & 180 & 230 \\ 15 & 95 & 140 & 190 & 240 \\ 60 & 100 & 155 & 205 & 245 \end{bmatrix}$$