Image Processing Theory Part-3

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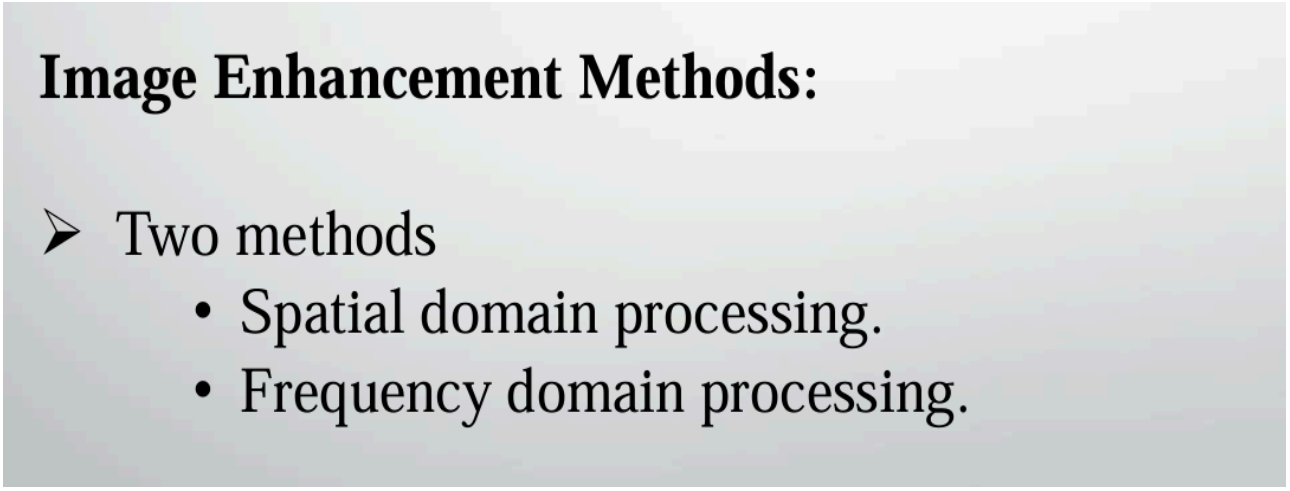
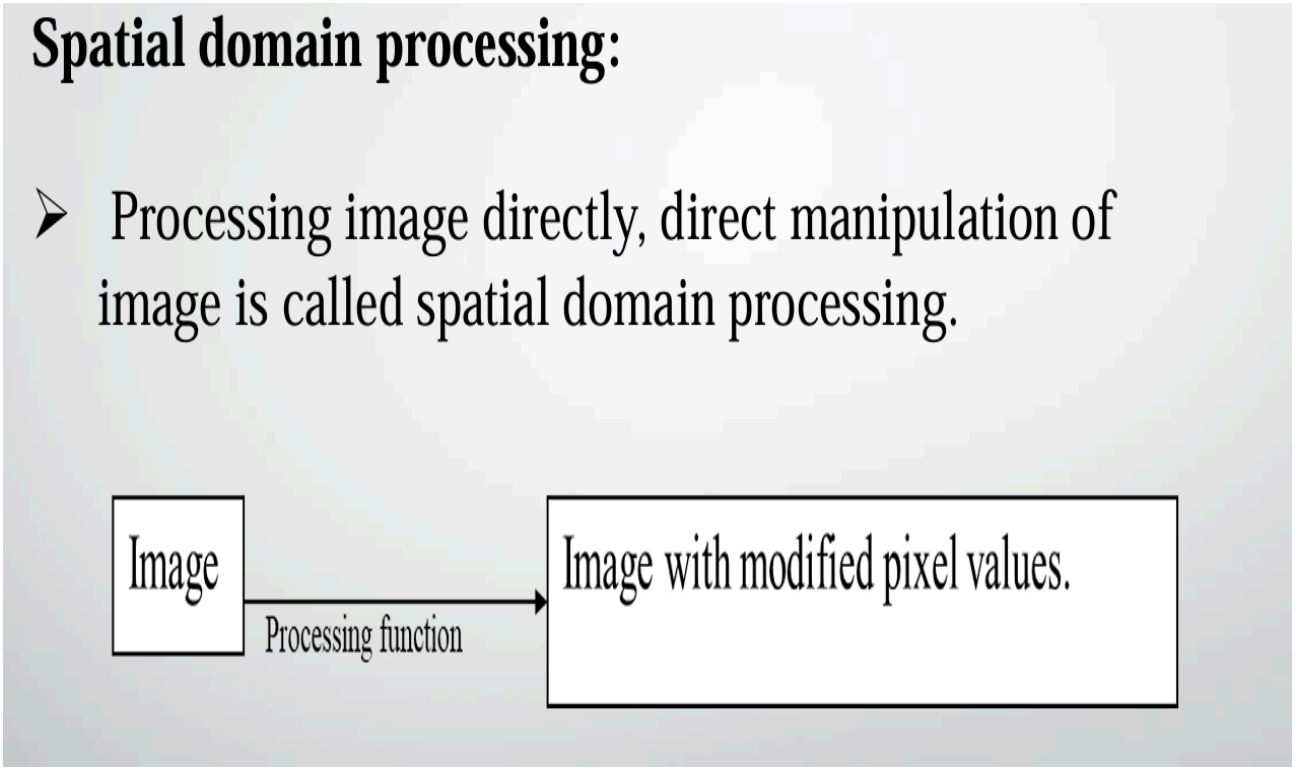
Image enhancement

Image enhancement is the process an image to make the result more suitable.It is used to improve the quality of an image by increasing contrast, brightness, sharpness, and reducing noise.

ইমেজ এনহ্যান্সমেন্ট হল একটি চিত্র প্রক্রিয়াকরণের প্রক্রিয়া যা ছবিটিকে আরও উপযোগী করে তুলতে ব্যবহৃত হয়। এটি কনট্রাস্ট, উজ্জ্বলতা, শার্পনেস বৃদ্ধি এবং নয়েজ কমানোর মাধ্যমে ছবির গুণগত মান উন্নত করতে সহায়তা করে।





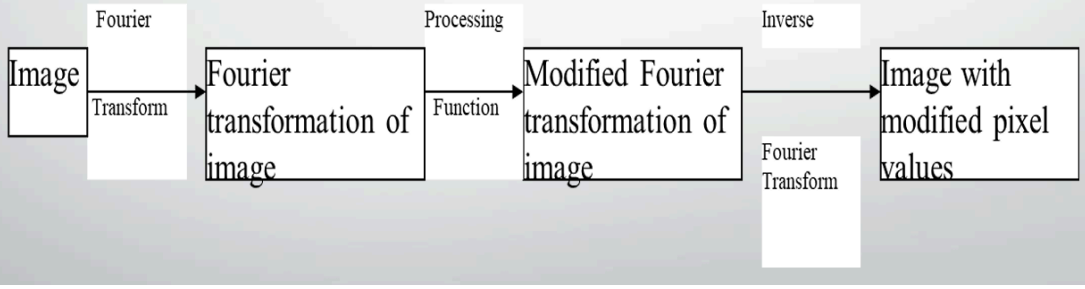
- **Spatial domain methods:**

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

where, g(x, y)= Processed image (output image)
f(x, y)= Original image (input image)
T= Operation on f.

Frequency domain processing:

➢Does not change directly
➢Processing the image based on modifying Fourier transform



Feature	Spatial Domain Processing	Frequency Domain Processing
Definition	Directly manipulates pixel values in an image.	Modifies the image by transforming it into the frequency domain.
Operation Method	Works by applying functions like addition, subtraction, filtering, etc., to pixel values.	Uses mathematical transformations (e.g., Fourier Transform) to process image frequencies.
Processing Basis	Works on intensity values of individual pixels.	Works on frequency components of the image.
Common Techniques	Histogram Equalization, Smoothing, Sharpening, Edge Detection.	Low-pass filtering, High-pass filtering, Fourier Transform, Wavelet Transform.
Speed & Complexity	Generally simpler and faster for basic image enhancements.	More computationally complex but effective for certain applications.
Use Cases	Used for direct image enhancements like brightness adjustment and noise reduction.	Used for image compression, denoising, and feature extraction.
Example	Blurring an image by averaging neighboring pixels.	Removing noise by filtering out high-frequency components.

Types of Image Enhancement Operations

- **Point/Pixel operations:** the output value at a specific coordinate (x,y) is dependent only on the input value at that same coordinate (x,y)
- **Local operations:** the output value at a specific coordinate (x,y) is dependent on the input values in the *neighborhood* of that same coordinate (x,y)
- **Global operations:** the output value at a specific coordinate is dependent on all the values in the input image.

- Another 5 types of processing:
  - Point Processing.
  - Spatial Filtering.
  - Temporal Processing.
  - Geometric Processing.
  - Morphological Processing.

Point Processing

- Monadic operation
- Threshold
- Contrast stretching
- Gray level slicing
- Image histogram
- Histogram equalization
- Other spatial functions

Threshold

Operation to convert an image into two levels

Single Threshold (Global Thresholding)

$$T(x,y) = \begin{cases} 255 & \text{if } I(x,y) > T \\ 0 & \text{if } I(x,y) \leq T \end{cases}$$

Where:

- T is the threshold value, and;
- (x,y) are the coordinates of a pixel in the image.

Dual threshold:

- Uses **two threshold values** (T1 and T2).

$$I'(x,y) = \begin{cases} 255, & \text{if } I(x,y) > T2 \\ I(x,y), & \text{if } T1 \leq I(x,y) \leq T2 \\ 0, & \text{if } I(x,y) < T1 \end{cases}$$

Grayscale Thresholding

- Instead of binary (black and white), thresholding **retains grayscale values**.
- Pixels **below T** are set to 0, but others keep their original values

$$I'(x,y) = \begin{cases} I(x,y), & \text{if } I(x,y) > T \\ 0, & \text{if } I(x,y) \leq T \end{cases}$$

Contrast stretching

- is a simple image enhancement technique used to improve the contrast of an image by stretching the range of intensity values
- contrast refers to the amount of color or grayscale differentiation that exists between various image features in both analog and digital images
- maps the original pixel values of an image to a wider range of pixel values, thus making the dark areas darker and the light areas lighter

Gray level slicing

Highlighting a specific range of gray levels in an image.
Two approaches:

$$g(x,y) = \begin{cases} 0 \\ p \\ 0 \end{cases}$$

[if f(x,y) <A and if A<=f(x,y) <=B and if f(x,y) > B]
A, B = threshold value

$$g(x,y) = \begin{cases} f(x,y) \\ p \\ f(x,y) \end{cases}$$

[if f(x,y) <A and if A<=f(x,y) <=B and if f(x,y) > B]

Temporal processing

- **Processing involving more than one image (frame).**
- **If 2 frame---- dyadic processing.**
- **Addition: g(x,y)= (f1(x,y) + f2(x,y)).k**
- **Subtraction : g(x,y)= f1(x,y) - f2(x,y)**
- **Signal Averaging: g(x,y)= 1/n(f1(x,y) + f2(x,y) + ……..+ fn(x,y))**
- **Multiplication: g(x,y)= f1(x,y) * f2(x,y)**
- **OR : g(x,y)= f1(x,y) OR f2(x,y)**
- **AND : g(x,y)= f1(x,y) AND f2(x,y)**
- **XOR : g(x,y)= f1(x,y) XOR f2(x,y)**

Geometric Processing

Transpose/Rotation:

```
for i = 1 : 512
        for j = 1 : 512
                B(j; i) = A(i; j); OR >> B = Ao;
        end
end
```

- **Flip:** The vertical flipped image B (N x M) of A (N x M) can be obtained as B(i,M+1-j) = A(i,j) (i = 1....N and j = 1....M).

```
for i = 1 : 512
        for j = 1 : 512
                B(i, 512 + 1 - j) = A(i, j);
        end
end
```

- **Crop:**
- The cropped image B (N1xN2) of A(NxM), starting from (n1; n2), can
- be obtained as B(k; l) = A(n1+k; n2+l) (k = 0;.....N1-1; l = 0.....N2-1).

Kernel (Filter): A small matrix (e.g., 3x3, 5x5) that is applied to each pixel in the image. It represents the shape and size of the neighborhood that will be sampled when calculating the pixel values to be modified.

Padding: When applying a filter near the edges, padding is often added to the image so that every pixel can be processed. Padding can involve filling with zeros, replicating the nearest edge pixel, or other methods.

SMOOTHING (LOWPASS) SPATIAL FILTERS

- Smoothing (also called averaging) spatial filters are used to reduce sharp transitions in intensity
- random noise typically consists of sharp
- obvious application of smoothing is noise reduction
- Smoothing is used to reduce irrelevant detail in an image
- Smoothing filters are used in combination with other techniques for image enhancement, such as the histogram processing techniques
- linear spatial filtering consists of convolving an image with a filter kernel

Adaptive Histogram Equalization (AHE)

Adaptive Histogram Equalization (AHE) is an image processing technique that enhances contrast by adjusting different regions of an image separately. This method improves **local contrast**, making edges and details more visible, especially in images with varying lighting conditions.

অ্যাডাপটিভ হিস্টোগ্রাম ইকুয়ালাইজেশন (AHE) একটি ইমেজ প্রসেসিং প্রযুক্তি যা ছবির বিভিন্ন অঞ্চলের কনট্রাস্ট আলাদাভাবে সামঞ্জস্য করে। এই পদ্ধতিটি **স্থানীয় কনট্রাস্ট বৃদ্ধি** করে, ফলে ছবির প্রান্ত ও সূক্ষ্ম বিবরণ আরও স্পষ্ট হয়, বিশেষ করে যখন ছবির আলোর মাত্রা বিভিন্ন হয়।

Local Histogram:

Local Histogram refers to the histogram computed over a small region or neighborhood of an image rather than the entire image. It is used in **local contrast enhancement** techniques, such as Adaptive Histogram Equalization, to improve details and visibility in different areas of an image.

স্থানীয় হিস্টোগ্রাম (Local Histogram) হল একটি চিত্রের ছোট অঞ্চল বা নির্দিষ্ট অংশের জন্য গণনা করা হিস্টোগ্রাম, সম্পূর্ণ চিত্রের পরিবর্তে। এটি **স্থানীয় কনট্রাস্ট বৃদ্ধি** করার জন্য ব্যবহৃত হয়, যেমন **অ্যাডাপটিভ হিস্টোগ্রাম ইকুয়ালাইজেশন (AHE)**, যা বিভিন্ন অঞ্চলে চিত্রের বিস্তারিত ও দৃশ্যমানতা উন্নত করে।

Explain spatial filtering in image enhancement. Explain different types of thresholding operations in short.

Spatial Filtering is an image enhancement technique where a filter or mask is applied to an image to modify pixel values based on neighboring pixels. It is used for **edge sharpening, noise reduction, and smoothing** by moving a kernel over the image and computing new pixel values.

Types of Spatial Filtering in Image Enhancement

✅ **Smoothing Filters** – Reduce noise and blur by averaging pixel values.
➡️ Examples: **Gaussian filter, Mean filter**

✅ **Sharpening Filters** – Enhance edges and fine details by increasing intensity variations.
➡️ Examples: **Laplacian filter, Sobel filter**

✅ **Edge Detection Filters** – Detect rapid intensity changes to highlight edges and boundaries.
➡️ Examples: **Prewitt filter, Roberts filter**

✅ **Noise Reduction Filters** – Remove noise like salt-and-pepper noise.
➡️ Example: **Median filter**

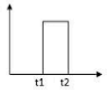
Thresholding operations in image processing involve dividing an image into regions based on pixel intensity values and assigning them to different classes or categories. Different types of thresholding operations include:

Threshold

Operation to convert an image into two levels.t, t= threshold value
Single:

$g(x,y) = \begin{cases} 0 \\ M \end{cases}$ [if f(x,y) <t and if f(x,y) >=t and usually M= 2l-1]

Dual Threshold: t2t1t1, t2 = threshold value



$g(x,y) = \begin{cases} 0 \\ M \\ 0 \end{cases}$ [if f(x,y) <t1 and if t1<=f(x,y) <=t2 and if f(x,y) > t2 usually M= 2l-1

Gray scale threshold:t2t1t1, t2 = threshold value

$g(x,y) = \begin{cases} 0 \\ f(x,y) \\ 0 \end{cases}$ [if f(x,y) <t1 and if t1<=f(x,y) <=t2 and if f(x,y) > t2 usually M= 2l-1

"The performance of Median filtering is better than low pass filtering for removing noise" - Why? মিডিয়ান ফিল্টারিং (Median Filtering) লো-পাস ফিল্টারিং (Low Pass Filtering) এর তুলনায় বেশি কার্যকর কেন?

Median filtering is better than low-pass filtering for noise removal because it **preserves edges** while effectively reducing impulsive noise like **salt-and-pepper noise**. Low-pass filtering can blur the image, while median filtering replaces a pixel with the **median of its neighbors**, making it more **robust against outliers** and better for noise reduction **without losing important details**.

মিডিয়ান ফিল্টারিং লো-পাস ফিল্টারিংয়ের চেয়ে ভালো কারণ এটি **প্রান্ত (edge) সংরক্ষণ করে** এবং **salt-and-pepper নোইজ** দূর করতে কার্যকর। লো-পাস ফিল্টারিং ছবিকে ঝাপসা করতে পারে, কিন্তু মিডিয়ান ফিল্টার **প্রতিটি পিক্সেলকে তার প্রতিবেশী পিক্সেলগুলোর মিডিয়ান মান দিয়ে পরিবর্তন করে**, যা **আউটলাইয়ার (outlier) দূর করতে বেশি কার্যকর** এবং **ছবির গুরুত্বপূর্ণ বিবরণ সংরক্ষণ করে**।

Justify the statement, "Applying Low-pass filter on an image result in a blurrier Image". Explain with proper example.

"লো-পাস ফিল্টার প্রয়োগ করলে ছবিটি আরও ঝাপসা হয়ে যায়"

A **low-pass filter** removes high-frequency components (sharp edges, fine details) and retains low-frequency components (smooth regions). This results in a **blurry image** by reducing sharpness.

লো-পাস ফিল্টার উচ্চ-ফ্রিকোয়েন্সি উপাদান (তীক্ষ্ণ প্রান্ত, সূক্ষ্ম বিবরণ) অপসারণ করে এবং নিম্ন-ফ্রিকোয়েন্সি উপাদান (মসৃণ অঞ্চল) সংরক্ষণ করে। ফলে চিত্রটি **ঝাপসা বা অস্পষ্ট** হয়ে যায়।

🔷 **Reason:**

- **Edges & details** → Represent high-frequency information.
- **Low-pass filtering** → Suppresses high-frequency details, making edges smoother.
- **Effect** → Image loses sharpness and clarity.

🔷 **কারণ:**

- **প্রান্ত ও সূক্ষ্ম বিবরণ** → উচ্চ-ফ্রিকোয়েন্সি তথ্য বহন করে।
- **লো-পাস ফিল্টার** → উচ্চ-ফ্রিকোয়েন্সি উপাদান দমন করে, ফলে প্রান্ত মসৃণ হয়ে যায়।
- **প্রভাব** → চিত্রের তীক্ষ্ণতা ও স্বচ্ছতা কমে যায়।

🔷 **Example:**
Applying a **Gaussian filter** or **Mean filter** on a text image will blur the letters, making them less readable. Similarly, edges in a high-detail image will appear softened.

🔷 **উদাহরণ:**
যদি **গাউসিয়ান ফিল্টার** বা **মিন ফিল্টার** কোনো লেখা বা উচ্চ-সংজ্ঞাযুক্ত ছবিতে প্রয়োগ করা হয়, তাহলে লেখার ধারা অস্পষ্ট হয়ে যাবে এবং চিত্রের প্রান্ত ঝাপসা দেখাবে।

Low-pass filters **smooth images but reduce clarity**, leading to a blurrier appearance.

লো-পাস ফিল্টার **চিত্র মসৃণ করে কিন্তু স্পষ্টতা কমিয়ে দেয়**, যার ফলে চিত্রটি ঝাপসা হয়ে যায়।

Justify the statement, "Blurring of Images can significantly reduce noise". Explain with proper example.

"চিত্র ঝাপসা করলে শব্দ উল্লেখযোগ্যভাবে কমে যায়"

The statement "Blurring of images can significantly reduce noise" can be justified based on the principle of noise reduction through spatial averaging.বক্তব্যটি **"চিত্র ব্লার করলে নয়েজ উল্লেখযোগ্যভাবে কমে যায়"** স্প্যাটিয়াল অ্যাভারেজিং প্রক্রিয়ার মাধ্যমে ব্যাখ্যা করা যায়।

Blurring helps reduce noise by averaging pixel values over a region, smoothing out random variations. This process, called **spatial averaging**, minimizes the effect of noisy pixels.

ব্লারিং একটি নির্দিষ্ট অঞ্চলের পিক্সেল মান গড়ে নিয়ে নয়েজ কমায় এবং এলোমেলো পরিবর্তনগুলো মসৃণ করে। **স্প্যাটিয়াল অ্যাভারেজিং** প্রক্রিয়ার ফলে নয়েজযুক্ত পিক্সেলের প্রভাব কমে যায়।

Example: In a low-light image with grainy noise, applying a **Gaussian blur filter** smooths pixel values, reducing noise and making the image cleare

উদাহরণ: কম আলোতে তোলা ছবিতে দানাদার নয়েজ দেখা যায়। যদি **Gaussian Blur Filter** প্রয়োগ করা হয়, তবে পিক্সেল মানগুলো মসৃণ হয়, নয়েজ কমে গিয়ে ছবি আরও পরিষ্কার দেখায়।

Define spatial quantization, amplitude quantization.

Spatial Quantization: Spatial quantization refers to the process of discretizing the spatial domain of an image by dividing it into discrete units or pixels.

Amplitude Quantization: Amplitude quantization involves the process of discretizing the intensity or amplitude values of an image, typically in the context of converting analog signals to digital signals.

Define gray level, dpi, ppi, resolution, aspect ratio.

Gray Level: Gray level refers to the intensity or brightness of a pixel in a grayscale digital image.

DPI (Dots Per Inch): DPI is a measure of the printing resolution, indicating the number of dots (pixels) per inch in a printed image or document.

PPI (Pixels Per Inch): PPI is a measure of the pixel density in a digital image or display. It represents the number of pixels per inch.

Resolution: Resolution refers to the level of detail that can be captured, displayed, or printed in an image.

Aspect Ratio: Aspect ratio is the ratio of the width to the height of an image or display. It is expressed as two numbers separated by a colon, where the first number represents the width, and the second number represents the height.

Thresholding 👍

Thresholding is the simplest method of image segmentation. From a grayscale image, thresholding can be used to create binary images.

What is noise? Write down the types of noise.

Noise means, the pixels in the image show different intensity values instead of true pixel values.

The common types of noise that arises in the image are 👍

a) Impulse noise
b) Additive noise
c) Multiplicative noise.

Function of Grey Level Slicing:

Grey level slicing is a technique used to highlight specific intensity ranges in an image while suppressing or ignoring others.

- 🔷 It works like a **band-pass filter** in the spatial domain.
- 🔷 It can either **enhance** a particular range of intensities and reduce the rest.
- 🔷 Or, it can **highlight** certain grey levels while keeping the rest unchanged.

This helps in detecting specific features in an image, like medical imaging or object detection.

Median Filtering Technique:

Median filtering is a **nonlinear** method used to remove noise from images.

- 🔷 It **replaces each pixel** with the **median** value of its neighboring pixels.
- 🔷 Helps in **reducing noise** while keeping edges sharp.
- 🔷 Commonly used as a **pre-processing step** before tasks like **edge detection**.

Example: Used to remove **salt-and-pepper noise** from images while preserving details.

Linear Spatial Filtering:

Linear spatial filtering **modifies an image** by replacing each pixel's value with a **weighted sum** of its neighboring pixels.

- 🔷 It applies a **fixed mathematical rule** (linear function) to all pixels.
- 🔷 The filtering process is **independent** of the pixel's position.
- 🔷 The image is treated as a **matrix (m × n)** where calculations happen for each pixel.

Example: Blurring and **sharpening** images using filters like **Gaussian or Sobel filters**.