Image Processing.

Unit - 01

Intro:- Image Processing systems and its ~~dependencies~~ Applications.
Basic image file formats, ~~Image~~
Image formation:- Geometric and photometric models,
Digitization - sampling, quantization; Image definition
and its representation, neighborhood metrics.

Image Processing systems.

An Image Processing System is designed to ~~capture~~
capture, process, analyze, and manipulate digital
Images using various algorithms. The system transforms
input images into a desired output, which may
be an enhanced image or a set of useful data
for further processing.

A basic image processing system consists of the
following components:-

Image Sensor :- captures the original image using devices
like cameras or scanners.

Digitizer (ADC) :- Converts analog images into digital
form using Analog-to-Digital Converters.

Processing Unit :- Performs various operations like filtering, enhancement, compression, etc.

Storage :- Stores the input, intermediate, and output images.

Display :- Shows the processed image for interpretation or further use.

Software :- Include algorithms for image analysis, transformation, and visualization.

Image Sensor →	Digitizer (ADC) →	Processing Unit →	Storage →	Display

Applications :-

Image processing has numerous practical applications accross various domains :-

Medical Imaging :- MRI, CT scan, enhancement, tumor detection

Remote Sensing :- Satellite image analysis for agriculture, weather, and land use.

Industrial :- Quality inspection, defect detection in manufacturing.

Security & Surveillance :- face recognition, motion detection, license plate reading.

Robotics & Automation :- Object recognition and navigation systems.

Document Processing :- OCR (optical character recognition), barcode scanning.

Photography & media :- Image enhancement, noise removal, artistic filters.

Autonomous Vehicles :- lane detection, pedestrian recognition, traffic sign detection.

Basic Image file formats.

Image file formats define how image data is stored, compressed, and rendered. Each format has its own structure, quality handling, compression technique, and use case. Understanding common image file formats is essential in image processing, especially for tasks like storage, transmission, and editing.

→ Common Image file formats

BMP (Bitmap) → uncompressed → stores pixel data without compression. large file size, high quality. used in Windows OS.

JPEG (Joint Photographic Experts Group) → lossy compression
→ popular for photographs and web images. Supports 24-bit color smaller file size but quality loss.

PNG (Portable Network Graphics) → lossless compression.
→ supports transparency, Good for logos, web graphics, and images needing high quality and sharp edges.

GIF :- (Graphics Interchange Format) → lossless (8-bit),
→ Supports animation. Limited to 256 colors, suitable for simple graphics and icons.

TIFF :- (Tagged Image File Format) → lossless or uncompressed
→ high quality format used in printing, medical imaging and proffesional photography ~~for~~ ~~soft processing.~~

RAW :- → uncompressed sensor data
→ Captures all data from camera sensor. Used in Proffessional photography for post processing.

WEBP : (Web Picture Format) → lossy/lossless.
→ Developed by Google. Provides better compression for web use while maintaining quality.

HEIF/HEIC : (High-Efficiency Image Format) → lossy. (advanced compression).
→ Used by Apple devices. Smaller size, better quality than JPEG. Supports image sequences.

Image Formation.

Geometric models.

Geometric models in image processing describe how ~~a 3D~~ a 3D scene is projected into a 2D image through a camera or imaging system. The process is governed by geometry and optics, particularly the pinhole camera model.

These models help in understanding how objects are captured in images, and are crucial for tasks like object recognition, image reconstruction, and camera calibration.

Geometric transformations types.

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~~Image formation.~~

Translation :- shifts the position of an image (moves pixels).

Scaling :- Enlarges or shrinks the image dimensions.

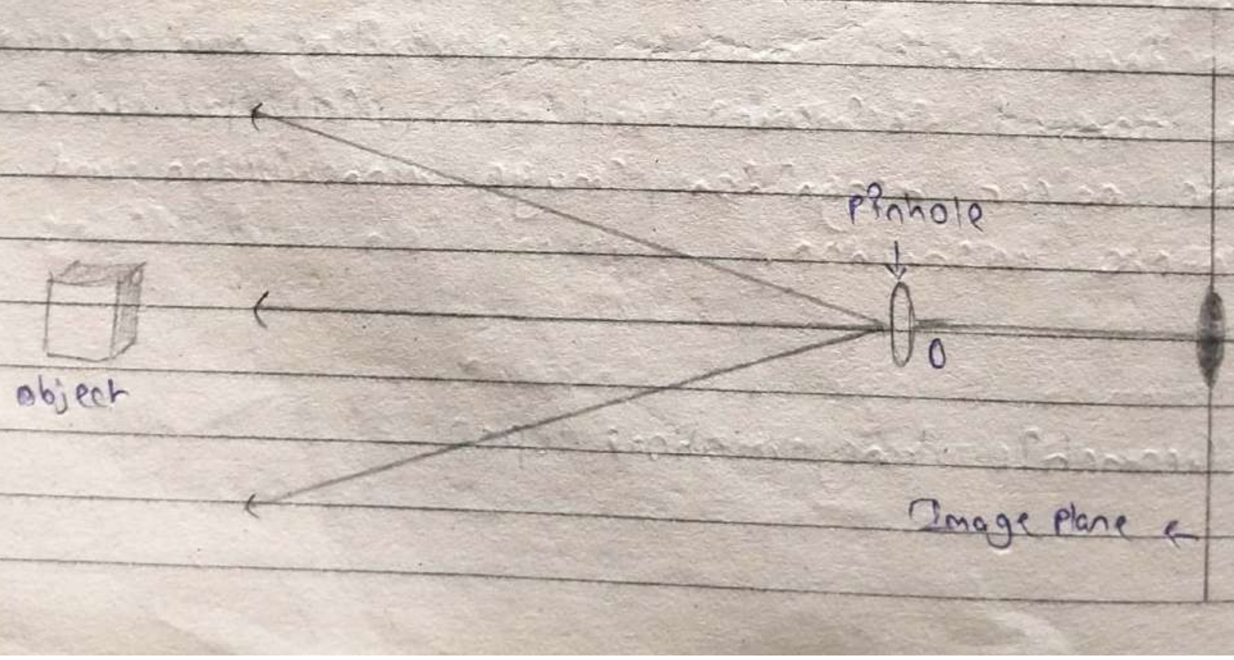
Rotation :- Rotates the image around a point or axis.

Shearing :- Slants the image shape in x or y direction

Affine Transformation :- Combines linear transformations and translations (Preserves lines and parallelism)

Projective (Perspective) Transformation :- Models how a camera sees a scene with depth; lines converge at vanishing points.

Ex: Pinhole Camera model.



3D object → Projected through a pinhole → 2D Image Plane

Labels:-

- O = center of projection (pinhole)
- Rays = light path from object to image plane
- Show inverted image forming on the image plane

Photometric models.

Photometric models describe how light interacts with surfaces and how ~~it~~ this interaction affects the intensity (brightness) values captured in an image. These models are essential for understanding shading, illumination, and reflectance, which play a key role in image analysis, enhancement, and 3D reconstruction.

In simple terms, they help in determine how bright or dark a pixel appears based on the lighting conditions and surface properties.

Components of photometric models.

Illumination :- The amount of light falling on the surface (also called incident light).

Reflectance :- The ~~portion~~ proportion of light that a surface reflects (depends on material).

Surface orientation :- Angle between the light source and the surface affects brightness.

Camera Angle/view :- Changes how the reflected light enters the sensor.

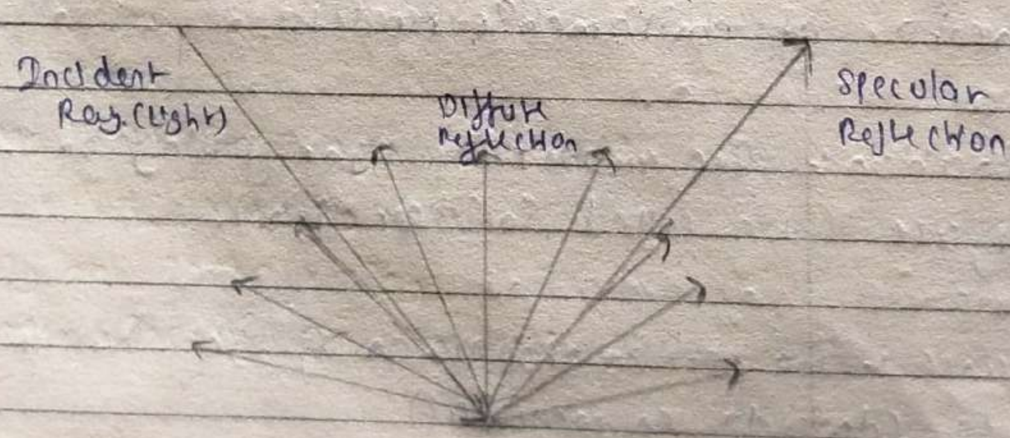
3. Common photometric Models :-

Lambertian model :- Assumes surface reflects light equally in all directions (ideal diffuse reflection). Brightness ∝ cosine of the angle between light direction and surface normal.

Specular Reflection :- Models mirror-like surfaces where light is reflected in a preferred direction (e.g. shiny metal, water).

Combined Models :- Real-world surfaces are modeled using both diffuse and specular reflection component.

Ex :- Lambertian model



Digitization.

~~Sampling~~:- Digitization is the process of converting a continuous image into a digital form so it can be processed by a computer.

It involves two main steps:-

Sampling:- Converting spatial coordinates into discrete points.
Quantization:- Converting intensity values into discrete levels.

Sampling

Sampling is the process of measuring the intensity of the image at regularly spaced points (pixels) in the spatial domain.

The spacing between these points is called the sampling interval.
The number of samples per unit distance is called the sampling rate (or spatial resolution)

Key points:-

High sampling Rate:- Captures more detail, large file size

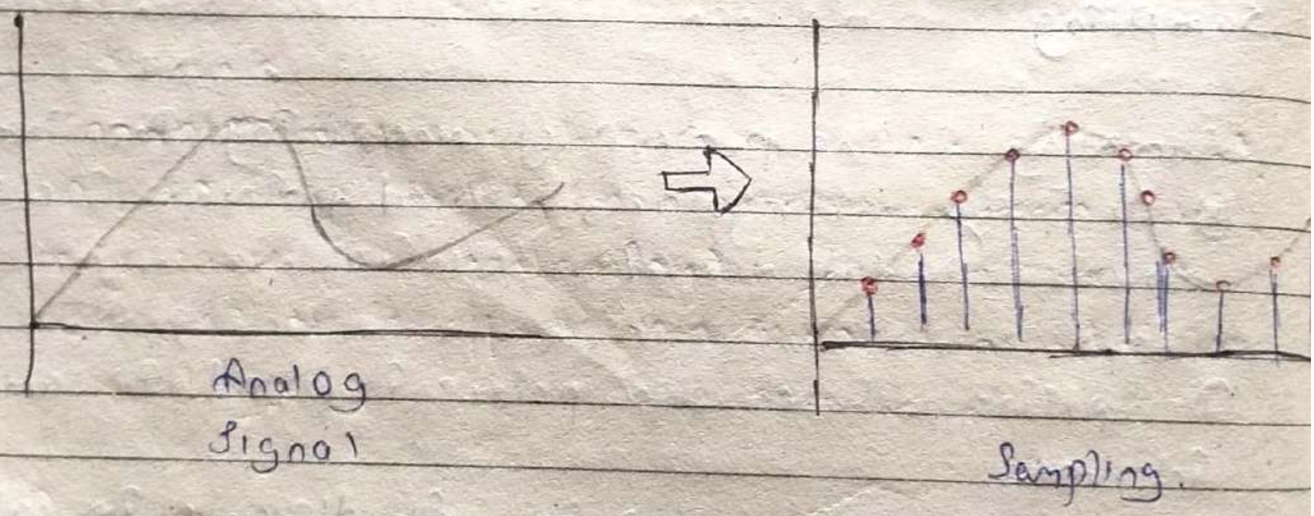
Low sampling Rate :- loss of details, aliasing effect.

Nyquist sampling Theorem :- The sampling rate must be at least twice the highest frequency present in the image to avoid aliasing.

Factors Affecting Sampling Quality.

Resolution :- No. of pixels in the image.
Field of view :- Physical area being captured.
Sensor Quality :- Precision of light capture.

Diagram.



Application :-
Medical Imaging (MRI, CT scan)
Satellite Imagery
Digital photography
Machine vision systems.

Quantization.

Quantization in image processing is the process of mapping a large set of possible intensity values into a smaller, finite set of discrete levels. After an image is sampled (spatial discretization), quantization is applied to limit the number of gray levels (intensity values) that each pixel can take.

It is an essential step because digital systems can only store and process finite values, not infinite continuous ranges.

Process of Quantization

- The continuous gray levels (eg. 0-255) are partitioned into intervals.
- Each interval is represented by a single discrete value (usually the midpoint of the interval).
- When a pixel intensity falls into an interval, it is replaced by that representative value.

Mathematically:-

$$Q(f(x,y)) = q_i \quad \text{if} \quad f(x,y) \in [t_i, t_{i+1})$$

Where Q = Quantization operator, q_i = representative value, and $[t_i, t_{i+1})$ = interval.

Types of Quantization

a) uniform Quantization
- Divides the range of values into equal intervals.
- simple and widely used.
- Example : ~~reading~~ reducing 256 gray levels to 16 by dividing into 16 equal parts.

(b) Non-uniform Quantization
- Uses unequal intervals, giving more precision to frequently occuring intensity ranges.
- more efficient for images with skewed histograms. (e.g. medical images).

Importance
- Controls image size (fewer gray levels = less memory).
- Affects image quality (more quantization = less detail, may cause false contouring).
- Balances trade-off between compression and visual quality.

Diagram.

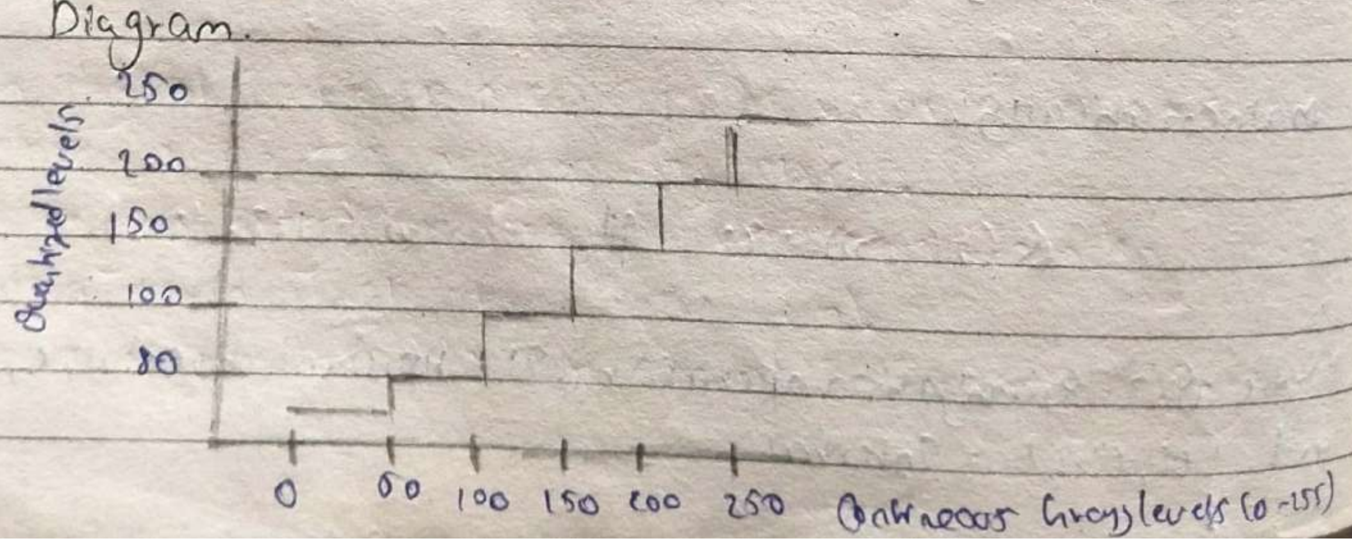


Image definition & its representation

An image is a two-dimensional function $f(x,y)$, where :-
- $x,y \rightarrow$ spatial (coordinate system) positions.
- $f(x,y) \rightarrow$ intensity (gray level or color value) at ~~point~~ that point.

In ~~image~~ digital image processing, the contineous image is sampled and quantized to form a digital image.
A digital image consists of a finite set of elements called pixels (picture elements).

Representation of Images

Digital images can be represented in various forms depending on the application:

1. Intensity / Gray-scale Image representation
- Each pixel has a value between 0 and L-1 (commonly 0-255).
- 0 → black, 255 → white.

2. Binary Image Representation
- Pixels are either 0 or 1
- Used in document scanning, text recognition, and masks.

3. Color Image Representation
- Each pixel represented by three components: Red (R), Green (G), Blue (B).

stored as three matrices (R, G, B) channels.

4. Multi-spectral / Hyper-spectral Representation.
- Images captured in many spectral bands (beyond visible light).
- used in satellite imaging, medical imaging, and remote sensing.

Mathematical Representation.

- An image of size $M \times N$ can be represented as a matrix:

$$\text{Image} = \begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-1) \\ \vdots & \vdots & \ddots & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{bmatrix}$$

where, $f(i,j)$ is the pixel intensity at position (i,j).

Neighborhood metrices.

In digital image processing, the value of a pixel often depends on its neighbouring pixels.
A neighbourhood matrix defines the surrounding pixels of a given pixel at location (x,y).
These neighbourhoods are crucial in image filtering,

edge detection, noise reduction, and morphological operation.

Types of neighborhoods.

1. 4-neighbourhood (N_4)
- considers immediate horizontal and vertical neighbors of pixel (x, y).
- positions: $(x-1, y), (x+1, y), (x, y-1), (x, y+1)$.

$$\begin{array}{ccc} & (x-1, y) & \\ (x, y-1) & (x, y) & (x, y+1) \\ & (x+1, y) & \end{array}$$

2. Diagonal Neighbourhood (N_D)
- considers diagonal neighbours.
- Positions: $(x-1, y-1), (x-1, y+1), (x+1, y-1), (x+1, y+1)$.

$$\begin{array}{ccc} (x-1, y-1) & & (x-1, y+1) \\ & (x, y) & \\ (x+1, y-1) & & (x+1, y+1) \end{array}$$

3. 8-neighbourhood (N_8)
- combines 4-neighbours + diagonal neighbours.
- Positions: $(x-1, y-1), (x-1, y)$ $(x-1, y+1)$, ~~$(x+1, y)$~~
$(x, y-1), (x, y), (x, y+1), (x+1, y-1), (x+1, y), (x+1, y+1)$

(x-1, y-1) (x-1, y) (x-1, y+1)
(x, y-1) (x, y) (x, y+1)
(x+1, y-1) (x+1, y) (x+1, y+1)

Applications:-

- 4-neighbourhood : for connectivity analysis (objects connected via edges).
- 8-neighbourhood : for connectivity include diagonals
- Neighbourhood matrices in filtering: Used in convolution masks (e.g. 3x3 kernel for smoothing or edge detection).