1) A pair of 3×3 convolution kernels of Sobel operator (G_x and G_y) as shown in the below figures:

-1	0	1
-1	0	1
-1	0	1

G_x

-1	-1	-1
0	0	0
1	0	1

G_y

Perform the edge detected output image using G_x and G_y on the input image given below:

12	10	13
14	12	13
15	14	11

Solution:

Sobel Kernels –

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \qquad G_y = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

Input Image:

$$I = \begin{bmatrix} 12 & 10 & 13 \\ 14 & 12 & 13 \\ 15 & 14 & 11 \end{bmatrix}$$

Convolution with G_x:

$$G_x(I) = (-1 \times 12) + (0 \times 10) + (1 \times 13) + (-1 \times 14) + (0 \times 12) + (1 \times 13) + (-1 \times 15) + (0 \times 14) + (1 \times 11)$$

$$= -12 + 0 + 13 - 14 + 0 + 13 - 15 + 0 + 11$$

$$= 9$$

Convolution with G_y:

$$G_y(I) = (-1 \times 12) + (-1 \times 10) + (-1 \times 13) + (0 \times 14) + (0 \times 12) + (0 \times 13) + (1 \times 15) + (1 \times 14) + (1 \times 11)$$

$$= -12 - 10 - 13 + 15 + 14 + 11$$

$$= 5$$

Gradient Magnitude,

$$G = \sqrt{(G_x)^2 + (G_y)^2}$$

$$\Rightarrow G = \sqrt{9^2 + 5^2} = \sqrt{81 + 25} = \sqrt{106} \simeq 10.3$$

The edge-detected intensity at this location is approximately 10.3

2) Explain the Region-Based Approach for image segmentation with proper example.

Solution:

The Region-Based Approach for image segmentation divides an image into meaningful regions based on predefined criteria such as intensity, color, texture, or connectivity. This approach groups similar pixels together and separates dissimilar ones to extract objects or areas of interest from an image.

Key Techniques in Region-Based Segmentation –

(i) Region Growing:

This technique starts with a seed pixel and expands the region by adding neighboring pixels that have similar properties (e.g., intensity or color).

Example:

Image –

$$\begin{bmatrix} 5 & 6 & 8 & 100 & 102 & 101 \\ 7 & 8 & 9 & 98 & 101 & 99 \\ 6 & 7 & 9 & 97 & 100 & 98 \\ 5 & 6 & 8 & 96 & 99 & 97 \end{bmatrix}$$

Step 1: Select an initial seed pixel based on a criterion (e.g., intensity)

→ Select seed pixel (e.g., top-left pixel with intensity 5).

Step 2: Compare the seed pixel with its neighbors.

→ Grow the region by adding pixels with similar intensity (values near 5-9)

Step 3: If the neighboring pixel meets the similar criterion, add it to the region.

→ Ignore higher-intensity pixels (96–102) since they belong to another region.

Step 4: Repeat the process until no more pixels meet the condition.

→ The output is two segmented regions: dark background and bright object.

(ii) Region Splitting and Merging:

This technique recursively splits the image into smaller regions until each region is homogeneous. If neighboring regions are similar, they are merged.

Example:

If an image has different intensity areas:

Step 1: Start with the entire image as one region. If the region is not uniform, split it into four quadrants.

→ The top-left region has intensities (5–9).

The top-right region has intensities (96–102)

Step 2: Repeat the process until all regions are uniform.

→ The algorithm splits these into smaller regions until they are homogeneous.

Step 3: Merge adjacent similar regions.

→ Similar regions are then merged back together.

(iii) Watershed Algorithm :

This technique is based on topographical interpretation. It treats an image as a 3D surface where pixel intensities represent heights.

Example :

Step 1 : Compute the gradient magnitude of the image (edges appear as ridges).

Step 2 : Treat low-intensity areas as basins and high-intensity areas as ridges.

Step 3 : Simulate water flooding the image and filling the basins.

Step 4 : Watershed lines are drawn where different water regions meet.

→ If an image has objects with distinct edges :
The watershed algorithm finds the edges and assigns different labels to separate them.

3) Compare and contrast global and local registration techniques in detail.

Solution:

Image registration is the process of aligning two or more images of the same scene taken at different times, from different viewpoints, or using different sensors. The two main types of registration techniques are Global Registration and Local Registration.

Global Registration:

Global registration aligns the entire image using a single transformation model that applies uniformly across the whole image.

Characteristics —

(i) Uses a single transformation function for the whole image.

(ii) Suitable for images with minor distortions.

(iii) Works well when images have similar structures and global changes like translation, rotation, scaling, or affine transformations.

(iv) Computationally efficient

Local Registration:

Local registration aligns specific regions or features within an image using different transformations for different areas.

Characteristics —

(i) Uses multiple localized transformations instead of a single global one.

(ii) Handles non-uniform distortions like warping and local misalignment.
(iii) Works well for images with varying changes in different regions.
(iv) Computationally complex.

Comparison:

Feature	Global Registration	Local Registration
Transformation Type	Single transformation for the whole image.	Multiple localized transformations
Handling Distortions	Handles uniform distortions (translation, rotation, scaling)	Handles local deformations (warping, stretching)
Computational Complexity	Low	High
Accuracy	Lower for non-rigid changes	Higher for complex local variations.
Methods Used	Affine, Homography, Fourier-based	Feature-based, TPS warping, Optical Flow
Use Cases	Remote sensing, MRI alignment, Panoramic images	Facial recognition, Medical tissue alignment, Object tracking

4) Explain Dilation and Erosion techniques to perform the Morphological Operations with proper example.

Solution:

Morphological operations are fundamental image processing techniques used for shape analysis, noise removal, and object enhancement. Two primary morphological operations are:

(a) Dilation –

Dilation expands the boundaries of objects in an image. It adds pixels to the objects' edges, making it thicker.

Working Process –

(i) A structuring element (a small matrix or kernel) is placed over the image.

(ii) If at least one pixel under the structuring element is white (1), the corresponding output pixel is set to white.

(iii) The operation is repeated over the entire image.

Example –

Input Binary Image (3 × 3)

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

Structuring Element (3 × 3)

$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

After Dilation :

$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

The object grows in size as white pixels spread.

(b) Erosion —

Erosion shrinks the boundaries of objects by removing pixels from the edges.

Working Process —

(i) The structuring element is placed over the image.

(ii) If all pixels under the structuring element are white (1), the output pixel remains white; otherwise, it is set to black (0).

(iii) The operation is repeated over the entire image.

Example —

Input Binary Image (5 × 5)

$$\begin{bmatrix} 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 0 \end{bmatrix}$$

Structuring Element (3 × 3)

$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

After Erosion :

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The object shrinks in size as edge pixels are removed.

5) What is sharpening of an Image and how it is done. Explain Sharpening spatial filter for both 1^{st} and 2^{nd} order derivative filters.

Solution:

Image sharpening is a technique used in image processing to enhance edges and fine details in an image. It helps improve the clarity and visibility of important structures by increasing the contrast along edges.

How is Image Sharpening Done?

Sharpening is typically done using spatial filtering, which involves convolving the image with a filter (kernel) that enhances edges. It can be achieved using:

(i) 1st order derivative filters (Gradient-based sharpening) —

These filters compute the gradient of an image, which measures the rate of intensity change. The most commonly used 1st order derivative filters are:

(a) Sobel Operator
(b) Prewitt Operator
(c) Roberts Operator

The gradient of an image $f(x,y)$ is calculated as:

$$\text{Gradient} = \nabla f = \left(\frac{df}{dx}, \frac{df}{dy}\right)$$

where:

$\frac{df}{dx}$ detects vertical edges

$\frac{df}{dy}$ detects horizontal edges

Sobel Operator (Example)

The sobel filter uses the following kernels:

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad G_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

Procedure:

- These filters detect changes in intensity and highlight edges.
- The magnitude of the gradient is calculated as:

$$G = \sqrt{G_x^2 + G_y^2}$$

- This enhances edges, making the image appear sharper.

(ii) 2nd order derivative filters (Laplacian-based sharpening)-

These filters measure how intensity changes at a faster rate than 1st order filters. They detect both thin and thick edges and highlight sharper features.

The most common 2nd order filter is the Laplacian operator.

Laplacian Operator (Example)

The Laplacian filter is defined as:

$$\nabla^2 f = \frac{d^2 f}{dx^2} + \frac{d^2 f}{dy^2}$$

A common Laplacian kernel is:

$$L = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \quad \text{or} \quad L = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Procedure:

- Detects rapid intensity changes (edges).
- Produces both positive and negative values, so sharpening is usually done by adding the Laplacian-filtered image to the original image:

Sharpened Image = Original Image − α (Laplacian)

where α controls the sharpening effect.

6) Explain four primary steps involved in the image registration process.

Solution:

Image registration is the process of aligning two or more images of the same scene taken at different times, from different viewpoints, or using different sensors. The goal is to find a geometric transformation that maps one image (moving / floating image) onto another (fixed / reference image).

(i) Feature Detection:

Identify key features (points, edges, corners, or regions) in the images that can be used for alignment.

Common Feature Detectors —

ⓐ Corner Detectors: Harris Corner, FAST

ⓑ Edge Detectors: Canny, Sobel

ⓒ Blob Detectors: SIFT (Scale-Invariant Feature Transform), SURF (Speeded-Up Robust Features), ORB

Example —

In satellite imagery, feature detection can identify roads, buildings, or landmarks for alignment.

(ii) Feature Matching:

Establish correspondence between detected features in the reference and moving images.

Common Feature Matching Techniques —

ⓐ Descriptor-Based Matching:

→ SIFT & SURF Matching — Uses feature descriptors to find the best matching keypoints.

→ ORB Matching – Faster alternative for real-time applications.

(b) Intensity-Based Matching:

→ Normalized Cross-Correlation (NCC) – Measures similarity between patches of images.

→ Mutual Information – Used in medical imaging and multimodal registration.

Example –

In medical imaging, matching brain structures across MRI scans from different machines.

(iii) Transformation Estimation:

Compute the transformation function that maps the moving image onto the reference image based on matched features.

Types of Transformations –

(a) Rigid Transformation – Rotation, translation

(b) Affine Transformation – Scaling, shearing

(c) Projective Transformation – Used for all perspectives

(d) Non-Rigid Transformation – Warping techniques for deformable objects

Common Estimation Methods –

(a) Least Squares Method: Minimizes error in feature matching

(b) RANSAC (Random Sample Consensus): Filters out incorrect matches and finds the best transformation.

Example—

Aligning images for panoramic stitching by estimating a homography transformation.

(iv) Image Resampling and Transformation:

Apply the estimated transformation to wrap the moving image so that it aligns with the reference image.

Common Resampling Methods—

ⓐ Nearest Neighbour: Fast but may cause pixelation.

ⓑ Bilinear Interpolation: Smoothens the transformation by averaging nearby pixels.

ⓒ Bicubic Interpolation: Provides better quality by considering 16 pixels around a point

Example—

Registering multi-temporal satellite images to monitor environmental changes.

7) What is the significance of the structuring element in morphological operations.

Solution:

A structuring element (SE) is a small matrix (kernel) used in morphological operations to probe and modify the shape of objects in an image. It determines how pixels in the input image are processed and affects the results of operations like dilation, erosion, opening and closing.

Importance:

(i) Defines the shape of Morphological Changes—

- The structuring element controls how an operation is applied to objects in an image.
- Different shapes of SE lead to different transformations of the image.

Example: A cross-shaped SE enhances vertical and horizontal edges, while a circular SE preserves round objects.

(ii) Affects the Size and Strength of Operations—

- A large SE increases the effect of dilation and erosion, making objects grow or shrink more significantly.
- A smaller SE applies finer modifications.

Example: In noise removal, a small SE removes minor noise, while a larger SE eliminates larger unwanted regions.

(iii) Controls Connectivity of Objects —

- The choice of SE determines which pixels remain connected after morphological operations.

Example: A rectangular SE connects adjacent pixels better in text processing, while a diamond-shaped SE may break connections.

(iv) Customizes Morphological Filtering —

- Different SE shapes are used for specific applications:
  - Line SE for detecting or enhancing linear features.
  - Circular SE for preserving round objects.
  - Elliptical SE for smoothing boundaries.

8) Explain the hit and miss transformation techniques with proper example.

Solution:

The Hit or Miss transformation is a morphological operation used to detect specific patterns or shapes in a binary image.

For a given binary image I, the Hit or Miss transformation is defined as -

$$I \circ S = (I \ominus S_1) \cap (\text{complement}(I) \ominus S_2)$$

where:

S_1 is the foreground structuring element

S_2 is the background structuring element

$\ominus$ represents erosion

The transformation is performed by:

(i) Eroding the image using the foreground structuring element (S_1).

(ii) Eroding the complement of the image using the background structuring element (S_2).

(iii) Taking the intersection of both results.

Procedure -

(i) If the shape in the structuring element exactly matches part of the image, that region is kept.

(ii) If the shape does not match anywhere, the result is empty (no detection).

Example -

Consider an input binary image:

$$I = \begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$

Add a structuring element (SE):

$$S_1 = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix} \qquad S_2 = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 1 \end{bmatrix}$$

Applying the Hit or Miss transformation will detect places in the image where this exact pattern appears.

9) Describe three common techniques used for image segmentation. Explain how each technique works and provide a real-life application for each.

Solution:

Image segmentation is the process of dividing an image into meaningful regions to analyze objects separately. It is widely used in computer vision, medical imaging, and autonomous driving. Below are three common image segmentation techniques:

(i) Threshold-Based Segmentation —

Procedure:

(a) Divides the image into foreground and background based on pixel intensity.

(b) A threshold value T is chosen, and pixels are classified as:

$$I(x, y) = \begin{cases} 1, & \text{if } f(x, y) > T \text{ (object)} \\ 0, & \text{if } f(x, y) \leq T \text{ (background)} \end{cases}$$

(c) Otsu's method automatically finds the best threshold by minimizing intra-class variance.

Real-Life Application:

Document Binarization (OCR) – Used to extract text from scanned documents by segmenting text from the background.

(ii) Edge-Based Segmentation —

Procedure:

ⓐ Detects edges where pixel intensity changes significantly.

ⓑ Uses edge detection operators like:

- Sobel (detects horizontal and vertical edges).
- Canny (detects edges with noise filtering and hysteresis thresholding).
- Forms object boundaries by connecting detected edges.

Real-Life Application:

Autonomous Vehicles — Used for lane detection in self-driving cars by identifying road boundaries.

(iii) Region-Based Segmentation —

Procedure:

ⓐ Groups pixels based on similarity in color, texture, or intensity.

ⓑ Two popular approaches:

- Region Growing — Starts from a seed pixel and expands to neighboring pixels with similar properties.
- Watershed Algorithm — Treats pixel intensity as topography and floods basins to separate regions.

Real-Life Application:

Medical Imaging — Used for tumor detection in MRI scans by segmenting different tissue regions.

10) Explain transform and similarity measures in details for registration with proper example.

Solution:

Image registration is the process of aligning two or more images of the same scene taken at different times, from different viewpoints, or using different sensors. It involves two key concepts:

(i) Transformation Models in Image Registration

A transformation model defines the mathematical function that maps points from the moving image to the reference image. Different transformation types vary in complexity and application.

Types of Transformations:

1.1 Rigid Transformation

a) Preserves shape and angles but allows movement.

b) Includes rotation and translation only.

c) Mathematical Model:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \end{bmatrix}$$

Example: Aligning satellite images taken at different times.

1.2 Affine Transformation

a) Preserves parallelism but allows scaling, shearing, rotation, and translation.

b) Mathematical Model:
$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \end{bmatrix}$$

c) Example: Registering aerial images from different angles.

1.3 Projective Transformation

a) Preserves straight lines but allows for perspective changes.

b) Used when images are taken from different viewpoints.

Mathematical Model:

$$\begin{bmatrix} x' \\ y' \\ w' \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

c) Example: Stitching images in panorama creation.

1.4 Non-Rigid Transformation

a) Allows local deformations, useful for medical image registration.

b) Example: Aligning MRI and CT scans of human organs.

(ii) Similarity Measures in Image Registration —

After applying a transformation, a similarity measure evaluates how well the transformed image matches the reference image.

Types of Similarity Measures:

2.1 Mean Squared Error (MSE)

a) Measures the average squared difference between pixel values.

b) Formula:

$$MSE = \frac{1}{N} \Sigma \left(I_{ref}(x, y) - I_{trans}(x, y)\right)^2$$

c) Best For: Images with same intensity distribution (e.g. X-ray to X-ray)

2.2 Cross-Correlation (CC)

a) Measures the similarity of intensity patterns between images.

b) Formula:

$$CC = \Sigma\, I_{ref}(x, y) \cdot I_{trans}(x, y)$$

c) Best For: Same modality images (e.g. satellite images)

2.3 Mutual Information (MI)

a) Measures the statistical dependency between images.

b) Formula:

$$MI = H(I_{ref}) + H(I_{trans}) - H(I_{ref}, I_{trans})$$

c) Best For: Multi-modal images (e.g. MRI to CT)

2.4 Structural Similarity Index (SSIM)

a) Considers luminance, contrast, and structure.

b) Formula:

$$SSIM = \frac{(2\mu_x \mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)}$$

c) Best For: Perceptual image similarity (e.g. medical imaging)

11) Explain how the mono-modal and multimodal image registration techniques performs image restoration. Show with proper example.

Solution:

Image registration is the process of aligning two or more images of the same scene taken at different times, from different viewpoints, or using different sensors. It plays a crucial role in image restoration, especially when images are degraded due to noise, motion blur, or sensor variations.

There are two main types of image registration techniques used in image restoration:

(i) Mono-Modal Image Registration

Mono-modal registration is used when images come from the same sensor and have similar intensity distributions but may have slight variations due to motion blur, lighting changes, or noise.

Procedure :-

Step 1 : Feature Extraction : Identifies key points in the image (e.g. edges, corners)

Step 2 : Transformation Estimation : Finds the best transformation (e.g. affine, rigid) to align images.

Step 3 : Optimization : Uses similarity measures like Mean Squared Error (MSE) or Cross-Correlation (CC) to refine alignment.

Step 4 : Restoration : Once registered, noise and distortions can be removed using image fusion, filtering, or deblurring techniques.

Example:

Restoring a blurry medical X-ray image

(a) A motion-blurred X-ray image is aligned with a sharp reference X-ray.

(b) Registration corrects misalignment, making deblurring more effective.

(c) Filtered image reconstruction removes remaining noise.

(ii) Multi-Modal Image Registration

Multi-modal registration is used when images come from different sensors or modalities (e.g. MRI vs. CT, visible vs infrared). It helps combine information from different sources to restore missing details.

Procedure:—

Step 1: Feature-Based Registration: Uses key features (e.g. SIFT, ORB) to align images.

Step 2: Mutual Information (MI): A similarity measure that helps match images with different intensity distributions.

Step 3: Transformation and Warping: Adjusts images to a common coordinate system.

Step 4: Image Fusion: Combines useful information from different modalities to reconstruct a more detailed image.

Example:

Restoring a night-time infrared image using visible light details

(i) A thermal infrared image lacks texture but shows heat variations.

(ii) A visible light image has textures but poor visibility at night.

(iii) Multi-modal registration aligns and fuses both images to enhance scene visibility.

12) A pair of 3×3 convolution kernels of Sobel operator (G_x and G_y) as shown in the below figures:

-1	0	+1
-2	0	+2
-1	0	+1

G_x

+1	+2	+1
0	0	0
-1	-2	-1

G_y

Perform the edge detected output image using G_x and G_y on the input image given below:

3	1	4	2
3	2	5	1
2	3	4	5
3	4	5	6

Solution:

Sobel Kernels –

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad G_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

Input Image:

$$I = \begin{bmatrix} 3 & 1 & 4 & 2 \\ 3 & 2 & 5 & 1 \\ 2 & 3 & 4 & 5 \\ 3 & 4 & 5 & 6 \end{bmatrix}$$

For each 3×3 window in the image, compute:

$$G_x = I * K_x, \quad G_y = I * K_y$$

Compute gradient magnitude:

$$G = \sqrt{G_x^2 + G_y^2}$$

The all possible 3*3 pixels of the given image is below-

$$(2,2) \longrightarrow \begin{bmatrix} 3 & 1 & 4 \\ 3 & 2 & 5 \\ 2 & 3 & 4 \end{bmatrix}, \quad (2,3) \longrightarrow \begin{bmatrix} 1 & 4 & 2 \\ 2 & 5 & 1 \\ 3 & 4 & 5 \end{bmatrix}$$

$$(3,2) \longrightarrow \begin{bmatrix} 3 & 2 & 5 \\ 2 & 3 & 4 \\ 3 & 4 & 5 \end{bmatrix}, \quad (3,3) \longrightarrow \begin{bmatrix} 2 & 5 & 1 \\ 3 & 4 & 5 \\ 4 & 5 & 6 \end{bmatrix}$$

For (2,2) window —

G_x:

$(-1)(3) + (0)(1) + (1)(4) + (-2)(3) + (0)(2) + (2)(5) +$
$(-1)(2) + (0)(3) + (1)(4)$

$= -3 + 0 + 4 - 6 + 0 + 10 - 2 + 0 + 4$

$= 7$

G_y:

$(1)(3) + (2)(1) + (1)(4) + (0)(3) + (0)(2) + (0)(5) +$
$(-1)(2) + (-2)(3) + (-1)(4)$

$= 3 + 2 + 4 + 0 + 0 + 0 - 2 - 6 - 4$

$= -3$

Gradient Magnitude,

$$G = \sqrt{(7)^2 + (-3)^2} = \sqrt{49 + 9} = \sqrt{58} \simeq 7.6$$

For (2,3) window —

G_x:

$(-1)(1) + (0)(4) + (1)(2) + (-2)(2) + (0)(5) + (2)(1) +$
$(-1)(3) + (0)(4) + (1)(5)$

$= -1 + 0 + 2 - 4 + 0 + 2 - 3 + 0 + 5$

$= 1$

G_y:

$(1)(1)+(2)(4)+(1)(2)+(0)(2)+(0)(5)+(0)(1)+(-1)(3)$
$+(-2)(4)+(-1)(5)$

$= 1+8+2+0+0+0-3-8-5$

$= -5$

Gradient Magnitude,

$G = \sqrt{(1)^2+(-5)^2} = \sqrt{1+25} = \sqrt{26} \simeq 5.1$

For (3,2) - window —

G_x:

$(-1)(3)+(0)(2)+(1)(5)+(-2)(2)+(0)(3)+(2)(4)+$
$(-1)(3)+(0)(4)+(1)(5)$

$= -3+0+5-4+0+8-3+0+5$

$= 8$

G_y:

$(1)(3)+(2)(2)+(1)(5)+(0)(2)+(0)(3)+(0)(4)+$
$(-1)(3)+(-2)(4)+(-1)(5)$

$= 3+4+5+0+0+0-3-8-5$

$= -4$

Gradient Magnitude,

$G = \sqrt{(8)^2+(-4)^2} = \sqrt{64+16} = \sqrt{80} \simeq 8.9$

For (3, 3) window —

G_x:

$(-1)(2)+(0)(5)+(1)(1)+(-2)(3)+(0)(4)+(2)(5)+$
$(-1)(4)+(0)(5)+(1)(6)$

$= -2+0+1-6+0+10-4+0+6$

$= 5$

Gy:

$(1)(2)+(2)(5)+(1)(1)+(0)(3)+(0)(4)+(0)(5)+$
$(-1)(4)+(-2)(5)+(-1)(6)$

$= 2+10+1+0+0+0-4-10-6$

$= -7$

Gradient Magnitude,

$$G = \sqrt{(5)^2+(-7)^2} = \sqrt{25+49} = \sqrt{74} \approx 8.6$$

Final Edge-Detected Output —

$$\begin{bmatrix} 7.6 & 5.1 \\ 8.9 & 8.6 \end{bmatrix}$$

13) Explain Basic steps of Digital Image Processing in details.

Solution:

Digital Image Processing (DIP) involves various steps to enhance, analyze, and extract meaningful information from an image. The fundamental steps in image processing are:

(i) Image Acquisition

Image acquisition is the first step in digital image processing, where an image is captured using devices like cameras, scanners, or satellites.

process—

a) A real-world scene is captured using an imaging device.

b) The image is converted into a digital format.

c) Pre-processing may be applied to remove noise and enhance image quality.

Example—

a) Taking an X-ray of a fractured bone.

(ii) Image Preprocessing (Enhancement and Restoration)

Preprocessing is applied to improve the quality of the image and prepare it for further processing.

techniques—

a) Noise Reduction

b) Contrast Enhancement

c) Edge Smoothing and Sharpening

d) Geometric Corrections

Example –

a) Removing noise from a blurry security camera image.

(iii) Image Segmentation

Segmentation is the process of dividing an image into meaningful regions or objects.

Techniques –

a) Thresholding
b) Edge Detection
c) Region-Based Segmentation
d) Clustering Methods

Example –

a) Detecting tumors in medical images.

(iv) Feature Extraction

Feature extraction is the process of identifying important details or patterns in an image for analysis.

Techniques –

a) Texture Analysis
b) Shape Detection
c) Color Features

Example –

Fingerprint recognition in biometric security.

(v) Image Representation and Description

After segmentation and feature extraction, images are represented in a way that describes their properties.

Techniques —

a) Boundary Representation
b) Region Representation
c) Descriptive Statistics

Example —

a) Analyzing traffic flow using drone images.

(vi) Image Compression

Image compression reduces file size while maintaining quality, making storage and transmission efficient.

Techniques —

a) Lossless Compression
b) Lossy Compression
c) Transform Coding

Example —

Reducing file size for medical imaging storage.

(vii) Image Recognition

Image recognition involves identifying objects, patterns, or faces within an image.

Techniques —

a) Machine Learning
b) Deep Learning

c) Template Matching

Example –

a) Face recognition in smartphones.

(viii) Image Interpretation

Image interpretation involves analyzing image content and making decisions based on extracted information.

Techniques –

a) Object Classification

b) Scene Understanding

c) AI-Based Decision Making

Example –

a) Analyzing satellite images to predict weather changes.

14) Explain Image formation model with diagram.

Solution:

The image formation model explains how an image is created when light interacts with objects and is captured by an imaging system (camera, human eye, or sensor). It describes the transformation of a 3D scene into a 2D digital image through physical and mathematical processes.

The image formation model consists of the following components –

(i) Illumination (Light Source)

→ Light originates from a source

→ The intensity and direction of light affect how objects appear.

(ii) Scene Objects (Reflectance Properties)

→ Objects in the scene reflect, absorb, and scatter light.

→ The reflectance property of an object determines its brightness in an image.

(iii) Optical System (Camera / Eye)

→ The lens of a camera or eye collects and focuses light onto a sensor or retina.

→ Lens properties, focal length, and aperture affect image clarity.

(iv) Sensor (Image Detector)

→ Converts light energy into electrical signals.

→ The amount of light captured determines the pixel intensity.

(v) Digitization (Image Sampling and Quantization)

→ The continuous scene is converted into a discrete image (pixels).

→ Sampling defines resolution, and quantization assigns intensity values to pixels.

<u>Diagram of Image Formation Model</u>

Light Source (L)

↓

Scene Object	(Reflectance R)

↓ Reflected Light

Optical System (Lens)

↓

Image Sensor (CCD/CMOS)

↓

Digitization (Sampling and Quantization)

↓

Digital Image (I)

15) Is there any affect in size of an image by color quantisation. Justify.

Solution:

Yes, color quantization affects the size of an image because it reduces the number of unique colors used in the image, which leads to a reduction in file size.

(i) Reduction in Bits per Pixel (bpp)

→ A typical RGB image stores 24 bits per pixel.

→ If we apply color quantization to reduce colors to 256, the image will require 8 bits per pixel instead of 24 bits.

→ This reduces the image size to one-third of its original size.

(ii) Compression Efficiency

→ Formats like GIF and PNG use indexed color tables, where each pixel stores a reference to a palette instead of storing full color values.

→ With fewer unique colors, lossless compression algorithms like LZW (GIF) and DEFLATE (PNG) work more efficiently, further reducing file size.

(iii) Effect on Lossy Compression (JPEG)

→ JPEG compresses images by removing color information and applying quantization in a different way.

→ If an image has fewer colors, JPEG can achieve higher compression with fewer artifacts, reducing the file size.