UNIT I

Image Processing

Image processing is a method used to perform operations on an image to enhance it or to extract useful information from it. It involves various techniques and algorithms that process images in a digital format. This can include a range of tasks such as improving the visual quality of images, detecting patterns, segmenting objects, and transforming images into different formats. Image processing can be used for both photos and video frames. The process usually involves steps such as inputting the image, processing the image through various algorithms, and then outputting the results in a format that is usable or can be further analyzed.

Types of Image Processing

1. Analog Image Processing

Analog image processing refers to techniques used to process images in their analog form, such as photographs, printed pictures, or images captured on film. This type of processing involves modifying images through physical or chemical means. Before the advent of digital technology, all image processing was done using analog methods. These methods are generally less flexible and more time-consuming compared to digital techniques, but they have historical significance and specific applications.

2. Digital Image Processing

Digital image processing involves the use of computer algorithms to perform operations on digital images. Unlike analog processing, digital techniques offer more flexibility, precision, and automation. Digital images are composed of pixels, and processing these images involves manipulating pixel values to achieve the desired effect. The use of digital processing is widespread due to its efficiency and the vast array of tools and techniques available.

Image Processing Techniques

1. Image Enhancement

1. Contrast Adjustment

Contrast adjustment is a technique used to improve the visibility of features in an image by enhancing the difference between the light and dark areas. This can be achieved through methods like contrast stretching, which adjusts the intensity values of pixels to span the full range of the histogram.

2. Histogram Equalization

Histogram equalization is a method used to enhance the contrast of an image by transforming its intensity values so that the histogram of the output image is evenly distributed. This technique improves the global contrast and is particularly useful in images with backgrounds and foregrounds that are both bright or both dark.

3. Noise Reduction

Noise reduction techniques are used to remove unwanted random variations in brightness or color, known as noise, from an image. Common methods include median filtering, Gaussian smoothing, and bilateral filtering, each of which aims to smooth the image while preserving important details.

2. Image Restoration

1. Deblurring

Deblurring techniques are used to restore sharpness to an image that has been blurred due to factors like camera shake or motion. Methods such as inverse filtering and Wiener filtering are commonly employed to reconstruct the original image.

2. Inpainting

Inpainting involves reconstructing lost or deteriorated parts of an image. This technique is often used for restoring old photographs, removing objects, or filling in missing data. Algorithms for inpainting include patch-based methods and partial differential equations (PDE) based methods.

3. Denoising

Denoising is the process of removing noise from an image while preserving its details. Techniques such as wavelet thresholding and non-local means filtering are used to achieve this, ensuring that the image quality is improved without losing significant features.

3. Image Segmentation

1. Thresholding

Thresholding is a simple technique for segmenting an image by converting it into a binary image. This is done by selecting a threshold value, and all pixels with intensity values above the threshold are turned white, while those below are turned black.

2. Edge Detection

Edge detection involves identifying the boundaries within an image. Techniques like the Sobel, Canny, and Prewitt operators are used to detect edges by finding areas of high intensity gradient.

3. Region-Based Segmentation

Region-based segmentation divides an image into regions based on predefined criteria. This can include methods like region growing, where adjacent pixels are grouped based on similar properties, and watershed segmentation, which treats the image like a topographic map.

4. Image Compression

1. Lossy Compression

Lossy compression reduces the size of an image file by permanently eliminating certain information, especially redundant data. Techniques like JPEG compression are used to significantly reduce file size at the cost of some loss in quality.

2. Lossless Compression

Lossless compression reduces the image file size without any loss of quality. Methods such as PNG compression ensure that all original data can be perfectly reconstructed from the compressed file.

5. Image Synthesis

1. Texture Synthesis

Texture synthesis generates large textures from small sample images, ensuring that the generated texture looks natural and continuous. This technique is widely used in computer graphics and game design.

2. Image Generation

Image generation involves creating new images from scratch or based on existing images using techniques such as generative adversarial networks (GANs). This can be used in applications like creating realistic human faces or artistic images.

5. Feature Extraction

1. Shape and Texture Analysis

Shape and texture analysis techniques are used to identify and quantify the shapes and textures within an image. Methods like edge detection, contour analysis, and texture filters help in understanding the geometric and surface properties of objects in the image.

2. Color Detection

Color detection involves identifying and segmenting objects based on their color properties. Techniques such as color thresholding and color histograms are used to analyze the color distribution and extract relevant features.

3. Pattern Recognition

Pattern recognition is the process of classifying input data into objects or classes based on key features. Techniques such as neural networks, support vector machines, and template matching are used to recognize patterns and make classifications.

6. Morphological Processing

1. Dilation and Erosion

Dilation and erosion are basic morphological operations used to process binary images. Dilation adds pixels to the boundaries of objects, making them larger, while erosion removes pixels from the boundaries, making objects smaller.

2. Opening and Closing

Opening and closing are compound operations used to remove noise and smooth images. Opening involves erosion followed by dilation, which removes small objects and smooths contours. Closing involves dilation followed by erosion, which fills small holes and gaps.

3. Morphological Filters

Morphological filters are used to process images based on their shapes. These filters, including hit-or-miss transform and morphological gradient, are used to extract relevant structures and enhance image features.

Classical Filtering Operations

Filtering in image processing is a fundamental technique used to enhance the quality of images. It involves the application of mathematical operations to an image to extract important features, remove noise, or blur images. Image filtering is an essential step in various image processing applications such as computer vision, medical imaging, and satellite imagery. In image processing, an image is treated as a function f(x,y), where x and y are the spatial coordinates of the image. Each pixel in the image represents a value of this function at a specific location. The values of this function can be manipulated using various image-processing techniques, including filtering.

Mathematically, an image function can be defined as:

$$f(x,y)=I$$

where (x, y) are the spatial coordinates of a pixel in the image, I is the intensity value at that pixel location, and f(x,y) is the image function. For grayscale images, the intensity value I is usually a single value representing the brightness of the pixel. For color images, the intensity values represent the intensities of the red, green, and blue (RGB) color channels. The image function can be discretized and represented as a matrix or an array of values. The size of the matrix corresponds to the dimensions of the image, and each element of the matrix represents the intensity value of a pixel in the corresponding location. In digital image processing, smoothing operations are use to remove noises. Image filtering is a most important part of the smoothing process. Filtering techniques are use to enhance and modify digital images. Also, images filters are use to blurring and noise reduction , sharpening and edge detection. Image filters are mainly use for suppress high (smoothing techniques) and low frequencies (image enhancement, edge detection). Classification of image filters is as follows According to this classification, image filters can be divide in to two main categories. Spatial filtering is the traditional method of image filtering. it is use directly on the image pixels. Frequency domain filters are use to remove high and low frequencies and smoothing.

Mean/Box filter - The idea of mean filtering is simply to replace each pixel value in an image with the mean (`average') value of its neighbors, including itself. This has the effect of eliminating pixel values which are unrepresentative of their surroundings. Mean filtering is usually thought of as a convolution filter. Like other convolutions it is based around a kernel, which represents the shape and size of the neighborhood to be sampled when calculating the mean. Often a 3×3 square kernel is used, as shown in Figure 1, although larger kernels (*e.g.* 5×5 squares) can be used for more severe smoothing. (Note that a small kernel can be applied more than once in order to produce a similar but not identical effect as a single pass with a large kernel.)

$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$

Figure 1 3×3 averaging kernel often used in mean filtering

Gaussian Filter- This filter is a 2-D convolutional operator. It use to blur images. Also, it removes details and noises. Gaussian filter is similar to mean filter. But main difference is, Gaussian filter use a kernel. That kernel has a shape of gaussian hump. Gaussian kernel weights pixels at its center much more strongly than its boundaries. There are different gaussian kernels. Based on the kernel size, output image will be different.

$$1/16 \begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

3x3 kernel

$$1/173 \begin{bmatrix} 1 & 4 & 7 & 4 & 1 \\ 4 & 16 & 26 & 16 & 4 \\ 7 & 26 & 41 & 26 & 7 \\ 4 & 16 & 26 & 16 & 4 \\ 1 & 4 & 7 & 4 & 1 \end{bmatrix}$$

5x5 kernel

Median Filter- Median filter is a non-linear filter. It replaces each pixel values by the median values of it's neighbor pixels. This is the efficient way for remove salt-and-pepper noise. The calculation of the median value is given below.

30	35	40	42	42
35	42	37	37	40
38	39	40	41	42
40	41	42	43	43
42	43	45	44	46

		41		

37, 37, 39, 40, **41**, 42, 42, 43

Edge Detection:-

Edge detection is a critical task in image processing and computer vision. It involves identifying and locating sharp discontinuities in an image, which typically correspond to significant changes in intensity or color. These discontinuities are referred to as edges, and they play a crucial role in understanding the structure and contents of an image. Edge detection is a technique used to identify the boundaries of objects within images. It helps in simplifying the image data by reducing the amount of information to be processed while preserving the structural properties of the image. This simplification is essential for various image analysis tasks, including object recognition, segmentation, and image enhancement.

Common Edge Detection Techniques

1. Sobel Operator

The Sobel operator computes the gradient of the image intensity at each point, giving the direction of the largest possible increase from light to dark and the rate of change in that direction. It uses two 3x3 convolution kernels to calculate the gradient in the horizontal and vertical directions.

Compute Horizontal and Vertical Gradients: Apply the Sobel kernels to the image to obtain the gradients in the x (horizontal) and y (vertical) directions.

Sobel Kernel (Horizontal)= $\begin{matrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{matrix}$

Sobel Kernel (Vertical)= $\begin{matrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{matrix}$

2. Prewitt Operator

Similar to the Sobel operator, the Prewitt operator calculates the gradient of the image intensity. The main difference is in the convolution kernels used. Compute Horizontal and Vertical Gradients: Apply the Prewitt kernels to the image to obtain the gradients in the x and y directions.

Prewitt Kernel (Horizontal): $-1 -1 -1$

$0 \quad 0 \quad 0$

$1 1 1$

Prewitt Kernel (Vertical)$= -1 \ 0 \ 1$

$-1 \ 0 \ 1$

$-1 0 1$

3. Robert Filter

The Roberts Cross operator performs a simple, quick-to-compute 2x2 gradient measurement on an image. It emphasizes regions of high spatial frequency, which often correspond to edges.
Compute Diagonal Gradients: Apply the Roberts kernels to the image to obtain the gradients along the diagonals.
Roberts Kernel (Diagonal 1)=[10
0−1]
Roberts Kernel (Diagonal 2)=[0 1
−1 0]

<u>Corner & Interest Point Detection:-</u>
Interest point detection refers to the detection of interest points for subsequent processing. The main application of interest points is to detect important points/regions in an image which are useful for image matching and view-based object recognition. An interest point is a point in an image which in general can be characterized as follows:
The interest points should be clear and preferably mathematically definable.
• They should locate at well-defined positions in an image.
• They should be stable under local and global perturbations in an image, such as illumination variations. The interest points should be reliably computed with high degree of repeatability.
• The ideal interest point should be invariant to illumination conditions and geometric transformations such as scale, translation, and rotation to be suitable for real-life images under different variations.

1. A corner is a point in an image where the intensity changes significantly in two perpendicular directions.
   - Flat region → small change in all directions.
   - Edge → change in one direction only.
   - Corner → large change in both directions.
   2. Steps

   Step 1: Compute image gradients
   - Use Sobel or Prewitt filters to calculate Ix and Iy:
     $Ix = \partial I/\partial x$
     $Iy = \partial I/\partial y$

   Step 2: Compute structure tensor (second moment matrix)
   For each pixel, calculate:
     $M = [[\Sigma\, w(x,y) * Ix^2 , \Sigma\, w(x,y) * Ix*Iy],$

$[\ \Sigma\ w(x,y) * Ix*Iy\ ,\ \Sigma\ w(x,y) * Iy^2\ ]]$

where w(x,y) is a Gaussian window.

Step 3: Corner response function

$R = \det(M) - k * (\mathrm{trace}(M))^2$

where:

$\det(M) = (Ix^2)(Iy^2) - (IxIy)^2$

$\mathrm{trace}(M) = Ix^2 + Iy^2$

k is a constant (0.04–0.06)

Step 4: Threshold and non-maximum suppression

- Keep only points where R is greater than a threshold.
- Apply non-maximum suppression to retain the strongest corners.

3. Interpretation of R

- R large positive → corner
- R negative → edge
- R small → flat region

4. Advantages

- Rotation invariant
- Efficient to compute

5. Limitations

- Not scale-invariant
- Sensitive to noise

Morphological Operations

Morphological operations are image processing techniques based on the shape and structure of objects in an image. They are typically applied to binary images but can also be extended to grayscale images.
They work using a structuring element (a small shape like a square, disk, or line) to probe and modify image shapes.

1. Basic Operations

A. Erosion

- Removes pixels on object boundaries.
- The structuring element slides over the image; a pixel in the output is set to 1 only if all pixels under the structuring element are 1 in the input image.
- Effect: Shrinks objects, removes small noise, breaks thin connections.

Formula:

$A \ominus B = \{ z \mid (B)z \subseteq A \}$

B. Dilation

- Adds pixels to the boundaries of objects.
- A pixel in the output is set to 1 if at least one pixel under the structuring element is 1.

- Effect: Enlarges objects, fills small holes, connects nearby objects.
Formula:
$A \oplus B = \{ z \mid (\hat{B})z \cap A \neq \emptyset \}$

C. Opening
- Opening = Erosion followed by Dilation.
- Effect: Removes small noise while keeping the shape and size of larger objects.
Formula:
$A \circ B = (A \ominus B) \oplus B$

D. Closing
- Closing = Dilation followed by Erosion.
- Effect: Fills small holes and gaps in boundaries without changing the overall shape.
Formula:
$A \bullet B = (A \oplus B) \ominus B$

2. Advanced Morphological Operations

Morphological Gradient:
- Difference between dilation and erosion → highlights boundaries.
Gradient = $(A \oplus B) - (A \ominus B)$

Top-hat Transform:
- Extracts small bright elements from an image.
Top-hat = $A - (A \circ B)$

Black-hat Transform:
- Extracts small dark elements from an image.
Black-hat = $(A \bullet B) - A$

3. Applications
- Noise removal in binary images
- Shape extraction and boundary detection
- Image preprocessing for OCR
- Medical image analysis
- Feature extraction in object detection