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Image Processing

SEMESTER-VI

BACHELOR OF COMPUTER APPLICATION

BLOCK- 1

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COURSE INTRODUCTION

This is a course on **Image Processing.** The course deals with image processing techniques where the learners will learn both the theory behind the techniques as well as practical implementation of them. Image processing has various applications in recent times such as in remote sensing, forensic studies, computer science, medical science, material science, texttile, film industries, printing etc. The course is divided into two blocks. The major topics of image processing are explained with suitable illustrations and programs in both the blocks of this course.

Block 1 provides an overview of the image processing system which includes various elements like basic definitions and types of image, sampling, quantization, transforms, Fourier transform, image enhancement, image histogram and about filtering.

Block 2 starts with image enhancement. Image restoration, image noise, image segmentation, image compression, binary image processing, colour image processing, wavelet-based image processing etc.are discussed in this block.

BLOCK INTRODUCTION

This is the first block of the course ***Image Processing.*** After completing this block, learners will be able to learn various introductory concepts of Image Processing. We begin with certain basic definitions in each unit of this block. Learners will also be able to write simple program related to Image Processing in Python.

This block comprises the following seven units :

Unit 1 provides an overview of image processing system which includes various elements like definition of image, types of image, advantages and disadvantages of image and concept of pixel in image processing.

Unit 2 describes the concept of image sampling and quantization in spatial domain.

Unit 3 describes the classification and types of digital image. Raster and vector image has been explained in this unit.

Unit 4 deals with different image transforms. Transform is basically a representation of the signal. Image transforms are extensively used in image processing and image analysis. Transform is basically a mathematical tool, which allows us to move from one domain to another domain.

Unit 5 describe the image enhancement in spatial domain. The objective of image enhancement is to improve the visual quality of image. An enhancement algorithm is one that yields a better quality image for the purpose of some particular application.

Unit 6 explains the concept of image histogram. The histogram of an image is a plot of the number of occurrences of gray levels in the image against the gray level values. The histogram provides a convenient summary of the intensities in an image.

Unit 7 describe the image filtering. Filters are used to increase brightness and contrast as well as to add a wide variety of textures, tones and special effects to an image. Image processing operations implemented with filtering include smoothing, sharpening and edge enhancement. The purpose of smoothing in image filtering is to reduce noise and improve the visual quality of the image.

Each unit of this block includes some along-side boxes to help you know some of the difficult, unseen terms. Some “EXERCISES” have been included to help you apply your own thoughts. You may find some boxes marked with: “LET US KNOW”. These boxes will provide you with some additional interesting and relevant information. Again, you will get “CHECK YOUR PROGRESS” questions. These have been designed for you to self-check your progress of study. It will be helpful for you if you solve the problems put in these boxes immediately after you go through the sections of the units and then match your answers with “ANSWERS TO CHECK YOUR PROGRESS” given at the end of each unit.

UNIT 1 : FUNDAMENTALS OF IMAGE

UNIT STRUCTURE

1.1 Learning Objectives

1.2 Introduction

1.3 Image

1.4 Advantage and Disadvantages of Digital Image

1.5 Pixel and Neighbours of Pixel

1.6 Digital Image Representation

1.7 Let Us Sum Up

1.8 Further Reading

1.9 Answers to Check Your Progress

1.10 Model Questions

1.1 LEARNING OBJECTIVES

After going through this unit, you will able to:

- define image
- differentiate between analog and digital image
- state the characteristics of analog and digital image
- learn how to represent digital image, pixel and neighbours of pixel

1.2 INTRODUCTION

This is an introductory unit of image processing. Image processing involves the manipulation of images to extract information for the purpose of analysis. It is a type of signal processing in which the input is an image and the output may be image or characteristics/features associated with that image.

Image is basically a picture. Image processing deals with the processing on images. What we observe on a photographic film, television, video, is an analog picture. It is required to convert an analog picture into digital because of the ease of storing and processing it with the use of a computer. Digital image can be generated directly using a digital

camera, capturing a frame from a video or by scanning a conventional photograph by a scanner. With the advent of smartphones digital image has become very common for everyone. People can easily take photographs of anything with their smartphone in digital format.

In this unit we will discuss image, types of image and their representation.

1.3 IMAGE

Before giving the definition of an image let us first learn about signals. A signal is defined as any physical quantity that varies with time, space, or any other independent variable(s). Mathematically, a signal can be represented as a function of one or more independent variables. For example, the function

$$f(t) = 10t$$

varies linearly with the independent variable time (t). Similarly,

$$f(x,y) = 5x + 3xy$$

describes a signal of two independent variables x and y that could represent the two spatial coordinates in a plane. An image signal is a signal which is a function of two independent variables. The independent variables in this case are the spatial coordinates. Spatial coordinates enable you to specify a location in an image.

An image can be defined as a function f(x, y) of two continuous variables x and y, where x and y are the two co-ordinates horizontally and vertically. To be processed digitally, it has to be ***sampled*** and transformed into a matrix of numbers. Since a computer represents the numbers using finite precision, these numbers have to be ***quantized*** to be represented digitally. *Digital image processing* consists of the conversion of a physical image into a corresponding digital image and the extraction of significant information from the digital image by applysing various algorithms. Now, let us discuss Analog and Digital image.

- **Analog Image:** An analog image is continuous in nature. It can be mathematically represented as a continuous range of values representing position and intensity. It is characterised by a physical

magnitude varying continuously in space.

- **Digital Image:** A digital image is composed of picture elements called *pixels*. A pixel represents the brightness at one point. Digital image data is represented in the form of grayscale, corresponding to the intensity. Grayscale images contain only brightness information. It can be processed using the digital computers. A colour image has three values per pixel.

Raster images are mapped to grids which are not easily scalable. A raster image is resolution dependent as it contains a fixed number of pixels that are used to create the image. The quality of raster image detoriates if it is enlarged beyond a certain limit since there are fixed and limited number of pixels in raster image. Some commonly used raster image formats include JPEG, GIF, BMP, TIFF, PNG, PSD etc.

A *vector image* is defined by objects which are made of lines and curves that are mathematically defined in the computer. A vector can have various attributes such as line thickness, length and colour. Vector images are easily scalable without losing the detail and without altering the resolution. Vector images are suitable for typography, line art and illustrations. In Unit 3, we will learn more about digital images.

Two important operations *sampling* and *quantization* are associated in the conversion of analog image into a digital image.

1.4 ADVANTAGE AND DISADVANTAGES OF DIGITAL IMAGE

The advantages of digital images are:

- Digital images can be effectively stored and efficiently transmitted from on place to another.
- Digital image can be copied very easily. The quality of digital image is not degraded even if it is copied for several times.
- One can see digital image immediately as soon as it is clicked.
- The processing of digital image is faster and cost-effective.

The disadvantages of digital images are:

- A digital image cannot be enlarged beyond a certain limit or size.

The quality will detoriate if that limit is crossed.

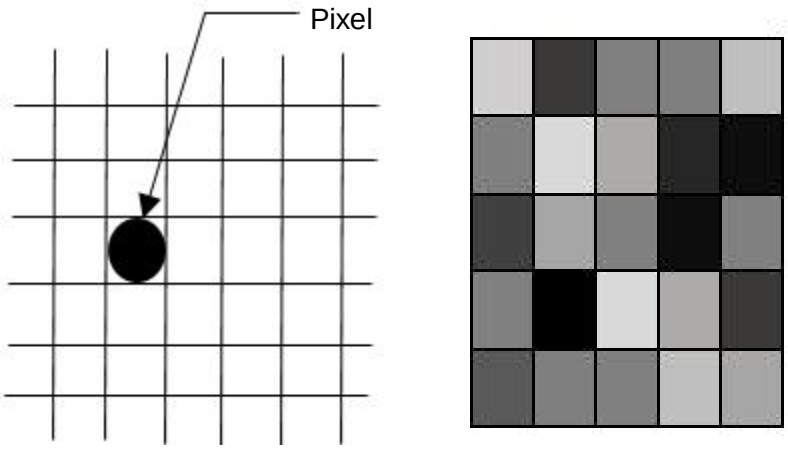
- The memory required for storing and processing a good quality digital image is very high.
- Misuse of copyright has become easier as copying a digital image from the Internet ism so easy just by clicking the mouse a couple of times.
- Processor speed needs to be very fast for real-time implementation of digital image processing alogorithm.

1.5 Pixel and Neighbours of Pixel

A ***pixel*** is the smallest element of a digital image. Each pixel corresponds to any one value. Each pixel has two attributes: position and gray level. At each pixel position, the brightness is sampled and quantized to obtain an integer value which indicates the brightness of the corresponding position in the image. After the conversion of all pixels of an image is completed, the image can be represented by a matrix of integers.

A grayscale image contains many shades of grey. In a 8-bit grayscale image, each picture element has an assigned intensity that ranges from 0 to 255. A 16-bit grayscale image has 65536 grayscales. If a pixel has four neighbours in the East, West, North and South directions, then it is represented as shown in Fig.1.2(a). If a pixel P has eight neighbours, then that is represented as shown in Fig.1.2(b).

Figure 1.1: A pixel and a graeyscale image and colour image. Each pixel has a value from 0(black) to 255(white)



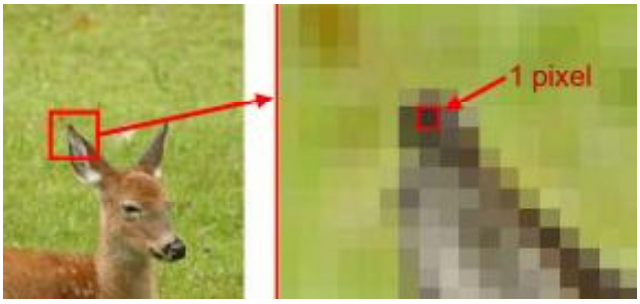


Figure 1.2 (a): Four neighbours of pixel P

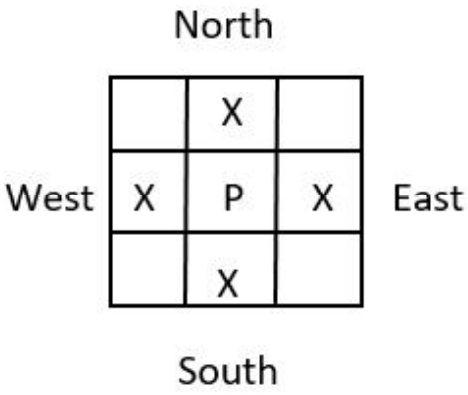
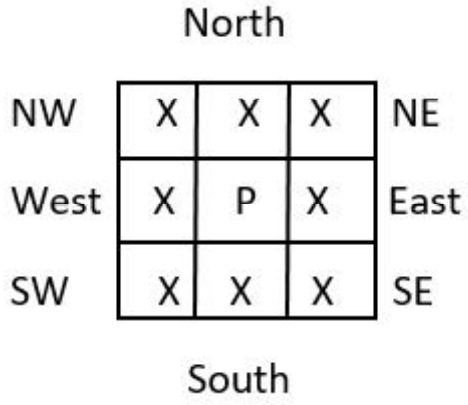


Figure1.2(b): Eight neighbours of pixel P



1.6 DIGITAL IMAGE REPRESENTATION

A digital image is a two-dimentional discrete signal. A digital image can be represented as an n x n array of elements. Each element in the array is a number which represents the sampled intensity. Physical image cannot be directly analyzed by a computer. It is because a computer can only process binary digits. So an image must be converted into a digital form before being processed by a computer. This process of conversion is called *digitization.*

Sampling is the process of measuring the value of the physical image at discrete intervals in space. A continuous image function can be sampled using a discrete grid of sampling points in the plane. *The magnitude of the sampled image is expressed as a digital value in image processing.* The transition between continuous values of the image function and its digital equivalent is called quantization.



CHECK YOUR PROGRESS

Q 1: Write TRUE or FALSE

a. An image is a function of one dimension

b. Pixels are the smallest elements of an image

c. Alalog image is continous in nature

d. Digital image is discrete in nature

Q 2: Give examples of four raster image formats.

.....

.....

3 Q: Give two advantages of digital image.

.....

.....



1.7 LET US SUM UP

- Image processing is a collection of techniques to perform some operations on image in order to get an enhanced image or to extract some useful information from it.
- Digital image processing techniques help in manipulation of the digital images by using computers.
- Analog image is continuous in nature.
- A digital image corresponds to a two-dimentional array of pixels.
- Two important operations *sampling* and *quantization* are associated in the conversion of analog image into a digital image.



1.8 FURTHER READING

1. Joshi, M. A. (2018). Digital image processing: An algorithmic approach. PHI Learning Pvt. Ltd.
2. Gonzalez, R. C., & Woods, R. E. (2008). Digital image processing. Prentice Hall.



1.9 ANSWERS TO CHECK YOUR PROGRESS

Ans to Q No 1: a) False, b) True, c) True, d) True

Ans to Q No 2: Four commonly used raster image formats are JPEG, GIF, BMP, PNG

Ans to Q No 2: Two advantages of digital images are:

i. Digital images can be effectively stored and efficiently transmitted from on place to another.

ii. The processing of digital image is faster and cost-effective.



1.10 MODEL QUESTIONS

Q 1: What is an image? How is it processed?

Q 2: What are the advantages and disadvantages of digital image?

Q 3: How is digital image represented?

Q 4: What is pixel? What is the role of pixel in digital image processing?

Q 5: What are the differences between analog image and digital image?

*** ***** ***

UNIT 2 : IMAGE SAMPLING

UNIT STRUCTURE

2.1 Learning Objectives

2.2 Introduction

2.3 Theory of 2D Sampling

2.4 Violation of Sampling Theorem

2.5 Quantization

2.6 Image Resolution

2.7 Anatomy of Human Visual System

2.8 Let Us Sum Up

2.9 Further Reading

2.10 Answers to Check Your Progress

2.11 Model Questions

2.1 LEARNING OBJECTIVES

After going through this unit, you will be able to:

- learn what image sampling is and why it is necessary
- describe quantization and its usefulness
- explain 2D sampling
- learn about anatomy of human eye
- describe image resolution

2.2 INTRODUCTION

We have already defined some fundamental terms associated with image processing like image, pixel, pixel neighbours etc. in the previous unit. We can now differentiate between analog and digital image with their characteristics.

An image is a continuous light signal, mathematically a continuous function of light.It is defined as a function in a continuous domain which corresponds to analog signal. Therefore, we need to digitize an image to be able to process it in digital computer. Digitalization of an analog

signal is achieved through two operations: Sampling and Quantization. Both operations correspond to a discretization of a signal, but in different domains.

Resolution of an image is the detail it holds. Resolution of an image can be measured in various ways with a common purpose of better visual understanding.

Whatever a digital computer processes it aims to aid human perception and image processing is no exception. Other than providing meta-data, improved human understating of image is another goal of digital image processing and hence, we need to study the anatomy of human vision.

2.3 THEORY OF 2D SAMPLING

The function of light can be expressed by a continuous function $f(x, y)$. An image is a two-dimensional light intensity function $f(x, y)$, where x and y are spatial coordinates and the value of *f* at any point (x, y) is proportional to the brightness or the gray level of the image at that point. The function can be approximated by equally spaced samples arranged in the form of an array as shown below.

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

The right side of the above equation is by definition a digital image. The transformation of the continuous analog light function into the discrete matrix representation is called ***sampling*** and since it is done in 2-dimensional space, it is also called ***2D sampling***. Basically in 2D sampling, time coordinates (t) and instantaneous value f(t) are transformed into spatial coordinates (x,y) and brightness level point wise f(x,y). Sampling theorem states that a continuous-time signal can be reconstructed from its samples. An efficient sampling means more number of pixels in the image.

2.4 VIOLATION OF SAMPLING CRITERION

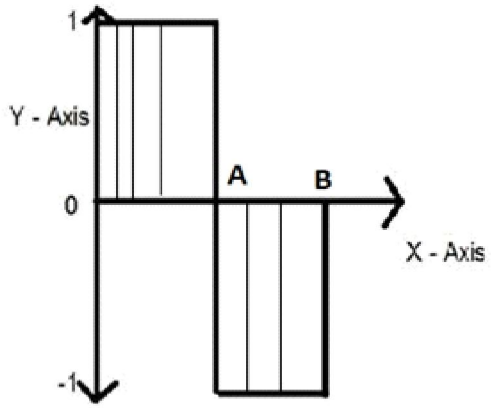
When a continuous function is sampled at a constant rate,there is always an unlimited number of other continuous functions that fit the same set of samples. To avoid this problem Nyquist put forward a theorem which is known as Nyquist theorem. The theorem provides a simple criteria for sampling mechanism. In its most basic form, Nyquist's theorem states that an analog signal can be converted into digital by sampling the analog signal at equal time intervals.The sampling rate must be "equal to, or greater than, twice the highest frequency component in the analog signal." Mathematically themaximumfrequencycomponent of$g(t)$ isf_m. To recoverthesignal$g(t)$ exactlyfromitssamplesit hasto be sampledata rate$f_s \geq 2f_m$. When sampling is done to digitize an image this theorem needs to be obeyed. Otherwise erroneous result may come out and it is termed as violation of sampling criterion.

2.5 QUANTIZATION

Quantization process transforms the range of a signal to discrete form, so that the quantized signal takes on only a discrete set of values. Unlike sampling, where under suitable conditions exact reconstruction is possible, quantization is generally irreversible. It is done on y axis. When we are quantizing an image, we are actually dividing a signal into quanta (partitions). On the X-axis of the signal, are the co-ordinate values (pixels), and on the y axis, we have amplitudes (intensity). So digitizing the amplitudes is known as Quantization.

The figure (Fig. 2.1) below depicts the sampling and quantization process

Figure 2.1: Sampling and Quantization



In Fig 2.1, from origin to point A, there is one quanta and from A to B another quanta (intensity). The vertical lines inside the quanta or intensity levels are sampled point or pixels.



CHECK YOUR PROGRESS

Q 1: State Nyquist's theorem and its importance.

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Q 2: What is the relation between sampling frequency and pixel of an image?

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.....

Q 3: State one major difference between Sampling and Quantization.

.....

.....

2.6 IMAGE RESOLUTION

Resolution of an image is the detail it holds. Image resolution can be defined in many ways. One type of it is pixel resolution the number of pixels per inch (PPI). Pixel density or Pixels per inch is a measure of spatial resolution for different imaging devices.The higher is the PPI, the higher is the quality. Pixel per unit is calculated with following formula:

$$c = \sqrt{a^2 + b^2}$$

where ‘a’ and ‘b’ are the height and width resolutions in pixel and ‘c’ is the diagonal resolution in pixels.

Resolution of an image can be enhanced by higher sampling frequency.

2.7 ANATOMY OF THE HUMAN VISUAL SYSTEM

The eye is nearly a sphere, with an average diameter of approximately 20 mm.Knowledge of how images form in the eye can help us with processing digital images. Broadly, anatomical aspects of human eye can be discussed with the following points: (Fig. 2.2)

a. The lens focuses light from objects onto the retina
b. The retina is covered with light receptors called cones (6-7 million) and rods (75-150 million)
c. Cones are concentrated around the fovea and are very sensitive to colour
d. Rods are more spread out and are sensitive to low levels of illumination.

Muscles within the eye can be used to change the shape of the lens allowing us to focus on objects that are near or far away. An image is focused onto the retina causing rods and cones to become excited which ultimately send signals to the brain. (Fig 2.3)

The human visual system can perceive approximately 1010 different light intensity levels. At any time instance, we can only discriminate between a much smaller numbers –brightness adaptation. Similarly, the perceived intensity of a region is related to the light intensities of the regions surrounding it.

Figure 2.2: Basic structure of Human eye

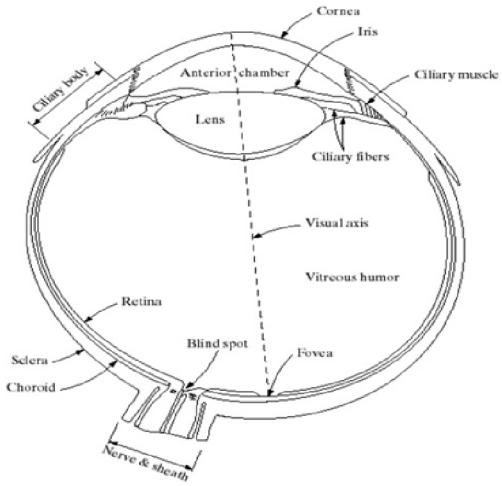
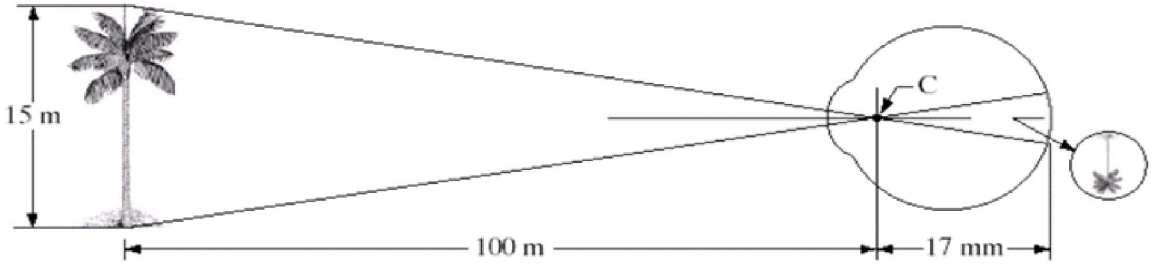


Figure 2.3: Image formation in human eye





CHECK YOUR PROGRESS

Q 4: A LCD screen has a width and height resolution of 1080X1920 pixels. It diagonal size is 5 inch. What is the PPI of the screen?

.....

.....

Q 5: How many different intensity levels can human eye perceive"

.....

.....



2.8 LET US SUM UP

- Image is of analog nature and we have to convert it into digital format for processing.

- Sampling and Quantization are two steps through which image is converted to digital format and hence called digital image.
- Sampling is done on the X-axis.
- Quantization is done on the Y-axis.
- Sampling process is reversible but quantization is not reversible.
- Resolution of an image indicates the clarity of the image.
- Human eye is complex biological system and also one of the best vision models found in nature.



2.9 FURTHER READING

1. Gonzales, R. C., & Woods, R. E. (2008). Digital image processing. Prentice Hall.
2. Easton, R. L. (2010). Fundamentals of digital image processing.
3. Annadurai, S. (2007). Fundamentals of digital image processing. Pearson Education India.



2.10 ANSWERS TO CHECK YOUR PROGRESS

Ans to Q No 1: Nyquist's theorem states that an analog signal can be converted into digital by sampling the analog signal at equal time intervals. The sampling rate must be "equal to, or greater than, twice the highest frequency component in the analog signal." Mathematically,the maximum frequency component of *g(t)* is *fm*. To recover the signal *g(t)* exactly from its samples it has to be sample data rate *fs e" 2fm*. When sampling is done to digitize an image this theorem needs to be obeyed. Otherwise erroneous result may arise.

Ans to Q No 2: Higher the sampling frequency, higher the number of pixels in an image.

Ans to Q No 3: Sampling is done on the X-axis and Quantization is done on the Y-axis.

Ans to Q No 4: Here, a= 1080, b=1920. So putting those values in the equation

$$c = \sqrt{a^2 + b^2}$$

We get, C = 2202.90717

Now we will calculate PPI

PPI = c / diagonal size in inches

The diagonal size in inches of the LCD screen is 5.0 inches

PPI = 2202.90717/5.0

PPI = 440.58

PPI = 441 (approx)

Ans to Q No 5: 10^{10}



2.11 MODEL QUESTIONS

Q 1: Describe 2D Sampling theorem.

Q 2: What is violation of sampling criterion and how it can be avoided?

Q 3: Does sampling result in loss of information? Can it be minimized by quantization?

Q 4: How PPI of an imaging device is calculated?

Q 5: What is the relation between image clarity and quantization?

Q 6: Write down the mathematical form of Nyquist theorem.

Q 7: Briefly discuss the anatomy of human vision.

*** ***** ***

UNIT 3 : DIGITAL IMAGE

UNIT STRUCTURE

3.1 Learning Objectives

3.2 Introduction

3.3 Classification of Digital Image

- 3.3.1 Raster Image
- 3.3.2 Vector Image

3.4 Types of Digital Image

3.5 Elements of Image Processing System

- 3.5.1 Image Sensors
- 3.5.2 Acquisition
- 3.5.3 CCD Sensors
- 3.5.4 CMOS Sensors

3.6 Comparison of CCD and CMOS Sensors

3.7 Digital Camera

3.8 Image File Formats

3.9 Application of Digital Image Processing

3.10 Let Us Sum Up

3.11 Further Reading

3.12 Answers to Check Your Progress

3.12 Model Questions

3.1 LEARNING OBJECTIVES

After going through this unit, you will you will be able to:

- learn the different classes of digital images
- describe the types of digital image
- explain the different image sensors and their pros and cons
- describe the application of Digital Image Processing

3.2 INTRODUCTION

We have acquainted you with image sampling and quantization

in the previous unit. We have also learnt about the anatomy of human visual system. This unit is on digital image. Here we will learn about the various classifications and elements of digital image.

A digital image can be classified into various classes based on their formation and intended application. Based on the formation, there are two types of digital images: raster image and vector image. Based on appearance (gray-level, colour, intensity etc.) there are several types of images. We will discuss each type in brief. We will also learn about the components of digital image processing system and the format for storing them in digital computers.

3.3 CLASSIFICATION OF DIGITAL IMAGE

3.3.1 Raster Image

Raster images are composed of a set of pixels where each pixel is assigned a gray level or colour. The pixels are stored in computer memory as a raster image or raster map, a two-dimensional array of integers. Raster images can be created by a variety of input devices and techniques, such as digital cameras, scanners, coordinate-measuring machines, seismographic profiling, airborne radar, and many more. They can also be synthesized from arbitrary non-image data, such as mathematical functions or three-dimensional geometric models; the latter being a major sub-area of computer graphics. Raster images are resolution dependent. When we transform a raster image, we stretch the pixels themselves, which can result in a “pixelated” or blurry image. When we enlarge an image, your software is essentially guessing at what image data is missing based on the surrounding pixels.

3.3.2 Vector Image

Avector image is a computer-generated image that is composed of pixels, lines, and curves that are based on

mathematical equations, rather than pre-defined number of pixels.This means we can zoom in on the image and the clarity of the image remains smooth. There will never be overlapped lines or blurriness with vector image. Also colors are separated into any type/size of shape (vs a bunch of little squares making a colored area), which makes changing colors within these graphics as easy as the click of a button.

3.4 TYPES OF DIGITAL IMAGE

There are different types of digital image. They are as follows:

- **Binary Image:** Binary images are the most basic type of images and they have two values, black and white, or 0 and 1. A binary image takes only 1 binary digit to represent each pixel and hence it is also called 1-bit image. A typical example of binary image is the scanned copy of handwriting written in black ink. Optical character recognition (OCR) is one of the applications where these types of images are used.
- **Grayscale Image:** A grayscale image is simply one in which the only colors are shades of gray. In more precise way we can say that grayscale image is the collection or the range of monochromic shades, ranging from pure white to pure black. A typical grayscale image contains 8bits/pixel data, which allows us to have 256 different gray levels. One important example of grayscale image is medical images such as X-ray film, MRI scan images etc.
- **Colour Image:** Colour images are defined as three-band image data, where each band of data corresponds to a different colour. Typical colour images are represented as red, green, and blue (RGB images). Using the 8-bit monochrome standard as a model, the corresponding colour image would have 24-bits/pixel (8-bits for each of the three colour bands red, green, and blue).
- **Multispectral Image:** These types of images are not the ones we usually perceive with human vision. They are embedded with information which are mathematically analysed to present a human

understandable form. Multispectral images are the one that capture data within specific wavelength ranges across the electromagnetic spectrum such as radar data. Some typical examples are: Military Target Tracking image, radar image, thermal images etc. Normally, multispectral image contains 10-12 spectral bands.

- **Hyperspectral Image:** Unlike multispectral image, hyperspectral images contain data within varied wavelengths across different electromagnet spectrums. In this type, pixel of the image is employed to acquire a set of images within certain spectral bands, that is eachpixel in a hyperspectral image is composed of a vector of hundreds of elements measuring the reflected signal as a function of wavelength, known as the spectrum. Some of the typical application hyperspectral imagings are: agriculture, food processing, land and land cover analysis, forest and vegetation, soil and land degradation, urban and regional planning, water resource and management, geosciences, oceans, atmosphere, cyclones, flood and disaster management, landslides, forest fire monitoring etc. Normally, hyperspectral image contains upto 220 spectral bands based on satellite sensor quality.

3.5 ELEMENTS OF IMAGE PROCESSING SYSTEM

A digital image processing system consists of several elements, both hardware and software. The dedicated systems are mostly related to specific applications and industrial process such as microscopic image analysis system or printed circuit board (PCB) testing system. The elements are discussed below.

- **Image sensors:**

  It is a physical device which is sensitive to the energy radiated by the object, whose image we want to capture. The second, called a digitizer, is a device for converting the output of the physical sensing device into digital form.Typically charged coupled device (CCD) and complementary metal oxide semiconductor devices (CMOS) are used as light sensors.

- **Acquisition:**

  Image acquisition is the first step of digital image processing. It is the process of capturing the images of some objects and transforming them into suitable digital formats for storing in the computer. Light sensors are used to capture the image. The CCD or CMOS sensors capture analog signal of lights which are not appropriate for computer processing. Another device, called Digitizer, transforms the analog signal to digital form

- **CCD sensor**

  Charged Coupled Device or CCD sensors are major technological instrument for digital imaging. Most of the imaging devices today use CCD sensors for their versatility. They are less susceptible to noise and highly sensitive to light. Technically, a CCD sensor can be defined as a sensor which transports the charge across the array of chip and converts the charges to discrete value. An example isanalog to digital converter (ADC).

- **CMOS sensors**

  Unlike array of capacitors in CCD sensor, complementary metal oxide semiconductor (CMOS) sensor has a photodiode and a transistor for every pixel, enabling each pixel to be amplified individually. One of the advantages of CMOS sensors is that they are inexpensive. Also, it has higher processing speed. But they lack in light sensitivity.

3.6 COMPARISON OF CCD AND CMOS SENSORS

The characteristics of CCD and CMOS sensors are:

- **Manufacturing cost**: CCD sensors use specialized fabrication that uses dedicated and costly manufacturing processes, whereas CMOS sensors rely on standard CMOS technology.
- **Light sensing range**: In the range of light signal a CCD sensor can sense roughly twice as that of CMOS sensor.
- **Power consumption**: CMOS sensors have lower power consumption than CCD sensors.

- **Noise effect**: Two types of noise affect sensors' performance: Temporal Noise and Fixed pattern noise. Fixed pattern Noise is more in CMOS, compared to CCD sensors. In terms of temporal noise, CMOS sensors are better.
- **Image quality**: Due to poor fill factor of CMOS, photosensitivity of CMOS sensors is poor in low light conditions.
- **Speed of processing**: CMOS sensors have higher speed due to the fact that it uses active pixels and converters on the same chip leading to lesser propagation delays.
- **Readout area**: CMOS sensors allow any region or even multiple regions to be read off the sensor. CCDs are limited by vertical scan read out.

3.7 DIGITAL CAMERA

A digital camera records and stores photographic images in digital form. Many current models are also able to capture sound or video, in addition to still images. Capture is usually accomplished by use of a photosensor, using a charged coupled device (CCD). These stored images can be uploaded to a computer immediately or stored in the camera for to be uploaded into a computer or printer later. Images may also be archived on a photographic compact disc or external hard disk.Most digital cameras have a LCD for viewing both images in the viewfinder and those in the camera's memory.

3.8 IMAGE FILE FORMATS

Image file formats are means of organizing and storing digital image in storage devices in a standardized norm. Not only are there standard image formats, but many applications have their own native file format. It is important to understand that there is a difference between a native file type and an image file type. Some of the common file types are discussed below:

- **GIF:** GIF is an image file that stands for "Graphics Interchange

Format." GIF is commonly used for images on the web and bitmaps software application. GIFs uses lossless compression that does not degrade the quality of the image. However, GIFs store image data using indexed colour, meaning a standard GIF image can include a maximum of 256 colours. The important feature of GIF file format are summarised below:

- The GIF file format uses lossless compression scheme.
- GIF interlaced images can be displayed as low resolution images.
- GIF images can be used to create simple animation.

- **JPEG:** JPEG stands for Joint Photographic Experts Group. It is a standard method of compressing photographic images. We also call JPEG the file format which employs this compression. The file extensions for this format are .JPEG, .JFIF, .JPG, OR .JPE although .JPG is the most common on all platforms. JPEG/JFIF is mostly used for storing and transmitting photographs on the World Wide Web, but not as well suited for line drawings and other textual or iconic graphics because its compression method performs badly on these types of images.
- **PNG:** PNG stands for Portable Network Graphics. It is a lossless bitmap image format that is popular on the World Wide Web and elsewhere. PNG was largely developed to deal with some of the shortcomings of the GIF format and allows storage of images with greater colour depth and other important information.
- **TIFF:** Tagged Image File Format, abbreviated asTIFF, is a computer file format for storing raster graphics images. TIFF is widely supported by imaging devices and software application.
- **PSD:** PSD format is not a native type. It is a proprietary format owned by Adobe Photoshop application. PSD files are layered image data.
- **EPS:** EPS is a file extension for a graphics file format used in vector-based images in Adobe Illustrator. EPS stands for Encapsulated PostScript.

vii) BMP: It is a short for Bitmap. The BMP format is a commonly used raster graphic format for saving image files. It was introduced on the Windows platform, but is now recognized by many programs on both Macs and PCs.

3.9 APPLICATION OF DIGITAL IMAGE PROCESSING

Digital image processing has a varied application among several fields. Due to the low cost of electronic imaging devices and digital computers, it has become easy to analyze large image data within a short span of time. Another reason for the emergence of the use of huge image data is availability of large storage at low cost. Some of the applications are discussed below.

- **Medical image processing**: One of the popular applications of image processing is the medical image processing. Medical imaging has been undergoing a revolution in the past decade with the invention of faster and accurate devices. This has driven the requirement for corresponding software development and formulation of new algorithms in signal and image processing. Diagnosis and prognosis of disease by computer is becoming essential to satisfy the urge of the customers for better and better service at our disposal.
- **Remote sensing**: Artificial satellites captures thousands of images of surface of the earth and transmit them to us. It is impossible for human eye to analyse these images. So image processing techniques are employed to obtain the necessary information and present it in human readable form. One particular application of digital image processing in the field of remote sensing is to detect infrastructure damages caused by an earthquake.
- **Optical Character Recognition (OCR):** There are tons of handwritten or manual typed documents in the archives. These documents are digitally stored and often read by human to gather knowledge. But the sheer amount of documents does not permit a person to read all the data. Also some ancient documents are in

unreadable to human eye. Image processing techniques are employed to read the information to extract the desired search string. Now-a-days, mobile devices also have image processing hardware/software to scan physical documents and convert them to word file or excel sheets.

- **Pattern Recognition:** In pattern recognition similar kinds of repeated occurring of events are detected to extract useful information. An example of pattern recognition based on image processing techniques is medical diagnosis system. Visual data aids this process to a great extent.

There are several other fields where image processing is used.



CHECK YOUR PROGRESS

Q 1: State one advantage of Vector image.

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Q 2: Differentiate between multispectral and hyperspectral image.

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Q 3: In a simple digital camera, typically used for indoor photography, what type of sensors should be used for cost effectiveness and quick capturing?

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Q 4: What is the advantage of GIF over JEPF file format?

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3.10 LET US SUM UP

- There are several classes of images based on their formation and they have their own intended use.

- Each class of images has its own pros and cons subject to the use in different application.
- Types of images are based on the information they provide with their pixels characteristics.
- CCD and CMOS are the two sensors used in digital imaging.
- CMOS is cost-effective and easy to fabricate but lacks in efficiency compared to CCD sensors.
- There are numerous fields of application of Digital Image processing.



3.11 FURTHER READING

1. Gonzales, R. C., & Woods, R. E. (2008). Digital image processing. Prentice Hall.



3.12 ANSWERS TO CHECK YOUR PROGRESS

Ans to Q No 1: One significant advantage of Vector image is that zooming does not blur the image.

Ans to Q No 2: Multispectral imagery is produced by sensors that measure reflected energy within several specific bandsof the electromagnetic spectrum. Hyperspectral image is produced by sensors measuringsignals in narrower and more numerous bands than multispectral sensors.

Ans to Q No 3: CMOS sensors

Ans to Q No 4: GIF file format employs lossless compression and hence there is no degradation of quality of image. JPEG file format loses some of the original quality after compression



3.13 MODEL QUESTIONS

Q 1: What are the different types of images?

Q 2: Why vector images are not degraded in quality when zoomed in?

Q 3: What is the maximum number of colours GIF file format can include?

Q 4: What type of sensor consumes less power and why?

Q 5: What is image acquisition?

Q 6: Give one example of each type: Binary image, grayscale image and colour image.

Q 7: Write a short note on elements of Digital image processing.

*** ***** ***

UNIT 4 : IMAGE TRANSFORM

UNIT STRUCTURE

4.1 Learning Objectives

4.2 Introduction

4.3 Image Transform: Necessity and Types

4.3.1 Types of Image Transform

4.4 Fourier Transform

4.4.1 2D Discrete Fourier Transform

4.4.2 Properties of 2D DFT

4.5 Let Us Sum Up

4.6 Further Reading

4.7 Answers to Check Your Progress

4.8 Model Questions

4.1 LEARNING OBJECTIVES

After going through this unit, you will be able to:

- describe image transform and its necessity
- learn the types of image transform
- define the basics of Fourier transform
- explain 2D Discrete Fourier transform and it properties

4.2 INTRODUCTION

In the previous unit we have gathered various concepts associated with digital image. Most of the digital images are confined to spatial domain and image processing operations are carried out in the spatial domain. It is not always suitable to do image processing in spatial domain as some underlying significant information might not be discovered.

Image transform involves the process of the transforming an image from one domain to another. There are various methods for image transformation and we will discuss some of the significant image transformation methods in this unit. Transform means changing the state

of an object from one state to another. For example when we pass a light beam through a prism it changes its state.

4.3 IMAGE TRANSFORM: NECESSITY AND TYPES

Image transforms are extensively used in image processing and analysis. Transform is basically a mathematical tool, which allows us to move from one domain to another domain. The reason to migrate from one domain to another domain is to perform the task in an easier way. Image transforms are useful for fast computation of convolution and correlation.

Depending on the transform function chosen, the input and output images may appear entirely different and have different interpretations. Fourier transforms, cosine transform and discrete wavelet transform are examples of frequently used image transformation procedures.

All the information embedded in an image may not be visible by human eye or may not be detected by spatial processing. Also, in certain applications, spatial coordinates provides too little information. To overcome these problems, image transform is necessary. The following examples will help us to understand its importance:

- Fourier Transform (FT) is widely used method in image processing. In FT variation of intensity in the image is transformed to frequency variation in frequency domain. That is, a slowly varying intensity, such as background of a passport size photos will be represented by low frequency components and suddenly varying regions such as edges are represented by high frequency components. It is possible to remove all low frequency components using suitable (high pass) filter in the FT domain. The filtered image in FT domain will contain only the edges of the image. If we do inversion from FT to spatial domain we get an image that contains only edges. This is one of simplest technique to find edges in an image.
- The other example is discrete cosine transform (DCT). This transform gives coefficients that carry information about the pixels of image. Interestingly, much of the information is contained in a very few

coefficients. The remaining coefficients carry minimal information. These coefficients can be removed without losing much information. By doing so, the file size is reduced in the DCT domain. This technique is used in lossy compression. The decompressed image can be obtained by doing inverse DCT. There are many other uses for DCT.

4.3.1 Types of Image Transform

Some of the commonly used image transforms are:

- **Fourier Transform:** Fast Fourier Transform (FFT), Discrete Fourier Transform (DFT), Windowed Fourier Transform (WFT)
- **Discrete Cosine Transform** (DCT)
- **Walsh-Hadamand Transform** (WHT)
- **Wavelet Transform:** Continuous Wavelet Transform(CWT), Discrete Wavelet Transform (DWT), Fast Wavelet Transform(FWT)

In Fourier Transform and DCT, basis images are fixed, that is, they are input independent and sinusoidal in nature. FFT and DCT only provides frequency information. WHT is non-sinusoidal in nature and easy to implement. Wavelet Transforms provides both time and frequency view. Wavelets give time-scale viewpoint and exhibits multi-resolution characteristics. Fourier is good for periodic or stationary signals but Wavelet is good for transients i.e. for non-stationary data. Localization property allows wavelets to give efficient representation of transients. In the next section we will explain Fourier Transform.



CHECK YOUR PROGRESS

Q 1: What is image transform?

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Q 2: Write down the names of some of the commonly used image transforms.

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Q 3: State two applications image transform.

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4.4 FOURIER TRANSFORM

Functions that are not periodic but whose area under the curve is finite can be expressed as the integral of sines and/or cosines multiplied by a weighting function. This formulation is the Fourier transform. Fourier transform is widely used in the field of image processing. A fourier transform is used to transform an intensity image into the domain of spatial frequency. The Fourier transform of the continuous function f(x) of a continous variable x, is defined as F(u), where u represents the spatial frequency. The relation between f(x) and F(u) as follows

$$F(u) = \int_{-\infty}^{\infty} f(x) \cos(2\pi ux) - j \sin(2\pi ux) dx \qquad (4.1a)$$

This can be expressed in a concise manner in exponential form as

$$F(u) = \int_{-\infty}^{\infty} f(x) e^{-j2\pi ux} dx \qquad (4.1b)$$

where $j = \sqrt{-1}$, The Fourier transform treats all image data as complex number. Similarly, given (u) , it is possible to get back $f(x)$. This is done using the inverse Fourier transform. The inverse Fourier transform is expressed mathematically as

$$F(u) = \int_{-\infty}^{\infty} f(x) \cos(2\pi ux) + j \sin(2\pi ux) dx \qquad (4.2a)$$

This can be expressed in a concise manner in exponential form as

$$F(x) = \int_{-\infty}^{\infty} F(u) e^{+j2\pi ux} du \qquad (4.2b)$$

The exponential term has the opposite sign. These two equations (4.1a) and (4.2a) form the Fourier transform pair. This means any spatial information can be converted to the frequency domain and vice versa without loss of information. It can also be observed that the Fourier transform results in a complex quantity even though the original data is not a complex number.

The Fourier transform can be extended to 2D functions. The Fourier transform for the 2D image $f(x,y)$ is given by

$$F(u,v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)e^{-j2\pi(ux+vy)}dxdy$$

4.4.1 2D Discrete Fourier Transform

The DFT is the sampled Fourier Transform and therefore does not contain all frequencies forming an image, but only a set of samples which is large enough to fully describe the spatial domain image. The number of frequencies corresponds to the number of pixels in the spatial domain image, *i.e.* the image in the spatial and Fourier domain are of the same size.

For a square image of size N×N, the two-dimensional DFT is given by:

$$F(k,l) = \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} f(l,j)e^{-i2\pi\left(\frac{ki}{N}+\frac{lj}{N}\right)}$$

where *f(i,i)* is the input image in the spatial domain and the exponential term is the basis function corresponding to each point *F(k, l)* in the Fourier domain. The value of each point *F(k, l)* is computed by multiplying the spatial image with the corresponding base function and summing up the result.

The basic functions are sine and cosine waves with increasing frequencies, *that is F(0,0)* represents the DC-component of the image which corresponds to the average brightness and *F(N-1,N-1)* represents the highest frequency.

In a similar way, the Fourier image can be re-transformed to the spatial domain. .The inverse Fourier transform is given by:

$$f(a,b) = \frac{1}{N^2}\sum_{k=0}^{N-1}\sum_{l=0}^{N-1} f(k,l)e^{l2\pi\left(\frac{ka}{N}+\frac{lb}{N}\right)}$$

Here, the $1/N^2$ normalization term is the inverse transformation. This normalization is sometimes applied to the forward transform instead of the inverse transform, but it should not be used for both.

To obtain the result for the above equations, a double sum has to be calculated for each image point. However, because the Fourier Transform is *separable*, it can be written as

$$F(k,l) = \frac{1}{N}\sum_{b=0}^{N-1} P(k,b)e^{-l2\pi\frac{lb}{N}}$$

Where,

$$P(k,b) = \frac{1}{N}\sum_{a=0}^{N-1} f(a,b)e^{-l2\pi\frac{ka}{N}}$$

Using these two formulas, the spatial domain image is first transformed into an intermediate image using *N* one-dimensional Fourier Transforms. This intermediate image is then transformed into the final image, again using *N* one-dimensional Fourier Transforms. Expressing the two-dimensional Fourier Transform in terms of a series of *2N* one-dimensional transforms decreases the number of required computations.

Even with these computational savings, the ordinary one-dimensional DFT has N^2 complexity. This can be reduced to $N \log_2^N$ if we employ the Fast Fourier Transform (FFT) to compute the one-dimensional DFTs. This is a significant improvement, in particular for large images. There are various forms of the FFT and most of them restrict the size of the input image that may be transformed, often to $N=2^n$ where *n* is an integer. The mathematical details are well described in the literature.

The Fourier Transform produces a complex number valued output image which can be displayed with two images, either with the real and imaginary part or with magnitude and phase. In image processing, often only the magnitude of the Fourier Transform is displayed, as it contains most of the information of the geometric structure of the spatial domain image. However, if we want to re-transform the Fourier image into the correct spatial domain after some processing in the frequency domain, we must make sure to

preserve both magnitude and phase of the Fourier image.

The Fourier domain image has a much greater range than the image in the spatial domain. Hence, to be sufficiently accurate, its values are usually calculated and stored in float values.

4.4.2 Properties of 2D DFT

a. Separable property

The separable property allows a 2D transform to be computed in two steps by successive 1D operations on rows and columns of an image. Mathematically it can be represented as

$$e^{-2\pi j\left(\frac{xu}{M}+\frac{yv}{N}\right)} = \underbrace{e^{-2\pi j\left(\frac{xu}{M}\right)}}_{\text{depends on x and u only}} \cdot \underbrace{e^{-2\pi j\left(\frac{yv}{N}\right)}}_{\text{depends on y and v only}}$$

b. Spatial Shifts Property

The 2D DFT of a shifted version of the image f(x,y) i.e. f(x – x_0, y) is given by

$$f(x-x_0,y) \overset{DFT}{\rightarrow} \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x-x_0,y)e^{\frac{-j2\pi xu}{M}}e^{\frac{-j2\pi yu}{M}}$$

where represents the number of times that the function is shifted.

c. Scaling Property

Scaling is basically used to increase or decrease the size of an image. According to this property, the expansion of a signal in one domain(either spatial or frequency) is equal to the compression of the signal in another domain.

$$f(x,y) \overset{DFT}{\rightarrow} F(u,v)$$

If DFT $f(x,y)$ of is $f(u,v)$ then

$$DFT[f(ax,by)] = \frac{1}{|ab|}F(u/a, v/b)$$

d. Convolution Property

The convolution of two functions in time is defined by:

$$g(t) * h(t) = \int_{-\infty}^{\infty} g(\tau) h(t-\tau) d\tau$$

The Fourier Transform of the convolution of g(t) and h(t) [with corresponding Fourier Transforms G(f) and H(f)] is given by:

$$\mathcal{F}\{g(t) * h(t)\} = G(f) H(f)$$

All of these properties can be proven via the definition of the Fourier Transform.

e. Rotation: This is a property of the 2D DFT that has no analog in one dimension. Because of the seperability of the transform equations, the content in the frequency domain is positioned based on the spatial location of the content in the space domain. This means that rotating the spatial domain contents rotates the frequency domain contents. This can be formally described by the following relationship:

$$f(x,y) \leftrightarrow F(u,v)$$

$$\downarrow$$

$$f(x',y') \leftrightarrow F(u',v')$$

$$\downarrow$$

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

$$\begin{bmatrix} u' \\ v' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix}$$

f. Periodicity: Periodicity of DFT and its inverse are periodic with period N

$$F(u,v) = F(u+N,v) = F(u,v+N) = F(u+N,v+N)$$

g. Correlation: The correlation is one member of the transform pair. More generally,

$$Corr(g,h) \leftrightarrow G(f) H^*(f)$$

The RHS of the pair is *G(f)H(-f).* Usually *g* & *h* are real, so *H(-f) = H*(f)*

Multiplying the FT of one function by the complex conjugate of the FT of the other gives the FT of their correlation. This is the Correlation Theorem.



CHECK YOUR PROGRESS

Q 4: What is the physical explanation of Scalable property of 2D DFT?

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Q 5: Why there may be loss of information in DFT?

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.....



4.5 LET US SUM UP

- Image transform is very necessary to study images in different domains.
- An image transform converts an image to other domain for ease of analysis.
- Fourier transform is one of the easiest and widely used image transform.
- 2D DFT possess some inherent properties which make it easy for using in different type of images in different domains.



4.6 FURTHER READING

1. Gonzales, R. C., & Woods, R. E. (2008). Digital image processing. Prentice Hall.



4.7 ANSWERS TO CHECK YOUR PROGRESS

Ans to Q No 1: An image transform is applied to an image to convert it from one domain to another. A mathematical definition of image transform can be gives as such “A function or operator that takes an image function or operator that takes an image as its input and produces an image as its output.

Ans to Q No 2: Fourier Transform (FFT, DFT, WFT)
Discrete Cosine Transform (DCT)
Walsh-Hadamand Transform (WHT)
Wavelet Transform (CWT, DWT, FWT)

Ans to Q No 3: Edge detection and image compression

Ans to Q No 4: Shrinking in one domain causes expansion in the other for the 2D DFT that is if an object grows in an image, the corresponding features in the frequency domain will expand.

Ans to Q No 5: The DFT is the sampled Fourier Transform and therefore does not contain all frequencies forming an image, but only a set of samples which is large enough to fully describe the spatial domain image. So there is a chance of data loss.



4.8 MODEL QUESTIONS

Q 1: What is image transform and why it necessary?

Q 2: Does image transform produces same image as that of the original image?

Q 3: What is the computational complexity of 1D DFT?

Q 4: Write down the properties of 2D DFT?

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UNIT 5 : IMAGE ENHANCEMENT IN SPATIAL DOMAIN

UNIT STRUCTURE

5.1 Learning Objectives

5.2 Introduction

5.3 Image Enhancement in Spatial Domain

5.4 Point operation

- 5.4.1 Brightness Modification
- 5.4.2 Image Negative
- 5.4.3 Gray-level Slicing
- 5.4.4 Contrast Adjustment
- 5.4.5 Bit-plane Slicing
- 5.4.6 Log Transformation

5.5 Mask Processing

5.6 Let Us Sum Up

5.7 Further Reading

5.8 Answers to Check Your Progress

5.9 Model Questions

4.1 LEARNING OBJECTIVES

After going through this unit, you will be able to:

- learn about image enhancement
- describe types of Image enhancement
- define different spatial domain method of image enhancement
- learn point operation methods of enhancement
- learn about a mask operation
- learn to write a programme in Python for brightness modification of image
- write a programme in Python for image negative
- write a programme in Python for image Log transformation

5.2 INTRODUCTION

In the previous unit we have learnt image transform and its classification. The most important concept Fourier transform is also described in the unit.

This unit is on image enhancement. The principal objective of image enhancement techniques is to process an image so that the result is more suitable than the original image for a specific application.

5.3 IMAGE ENHANCEMENT IN SPATIAL DOMAIN

The approaches used for image enhancement is of two types **:**

- Spatial domain methods and
- Frequency domain methods

The *spatial domain* refers to the aggregate of pixels composing an image and spatial domain methods are procedures that operate directly on those pixels. Image processing functions in the spatial domain may be expressed as

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

where f (x,y) is the input image, g (x,y) is the output image and T is an operator on f defined over the neighborhood of (x,y). T can operate on a set of pixels such as pixel by pixel sum.There are two methods of Spatial domain. They are:

(a) Intensity (or gray-level) transformations.

(b) Spatial filtering or neighborhood processing on spatial convolution

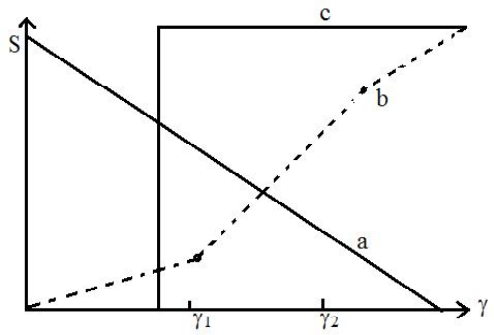
- **Intensity (or gray-level) transformations :**

  Gray-level transformations do not depend on the position of the pixel in the image. The simplest form of T is when the neighborhood is |X|. i.e., here, g depends only on the value of f at (x,y) and T becames a gray-level transformation.

  In other words, gray-scale transformation T of the original brighten from scale (p_0, p_u) into brighten S from a now scale (S_0, S_k) is given by S = T (g)

  The most common gray-scale transformation are shown is Fig.5.1.

Figure 5.1: Intensity Transformation



The straight line a denotes the negative transformation, the piecewise linear function b. enhances the image contrast between brightness values p, and p_2. The function c is called brightness thresholding and results in a black and white image.

Digital images have a very limited number of gray-levels, so gray-scale transformations are easy to realize both in h/w & s/w. only 256 bytes of memory (called a look-up table) are needed. The original brightness is the index to the look-up & the table contain gives the new brightness.

In case of color displays, as color signal consists of 3 components red, green & blue, three, look-up tables called palette provide all possible color scale transformations.

Gray-scale transformations are used mainly when an image is viewed by a human observer and a transformed image night be more easily interpreted if the contrast is enhanced. For example, an X-ray image can often be much cleaner often transformation.

Image enhancement in spatial domain can be done by applying either point operation or mask operation.

5.4 POINT OPERATION

Point operation is a simple image filter where the new value of a pixel is only determined by the original value of that pixel alone. i.e., not dependent on other pixel values. Some of the Image enhancement method based on point processing are as follows:

5.4.1 Brightness Modification

The brightness adjustment helps make the image brighter or darker.

Program 5.1: Program to do Brightness modification in an image

```
# Enhancing brightness of an image
from PIL import Image, ImageEnhance
im = Image.open("OriginalTea.png")
enhancer = ImageEnhance.Brightness(im)
enhanced_im = enhancer.enhance(1.6)
    enhanced_im.save("enhanced.brightness.png")
```

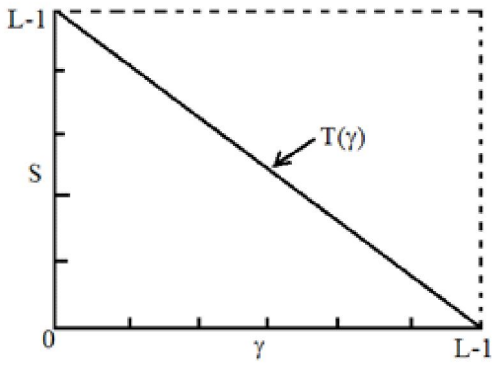
5.4.2 Image Negative

The negative of an image with gray levels in the range (0,L-1) is obtained by using the negative transformation as shown in fig below, which is given by the expression

$$T(y) = L-1$$

where L is the number of gray levels.

Figure 5.2: Negative transformation



The idea of image negatives is to reverse the brightness intensity of the image so that the intensity of the output image decreases as the intensity of the input increases. Negatives of digital images are useful in many applications, such as displaying medical images and photography a screen with monochrome positive film with the idea of using the resulting negatives as normal slides.

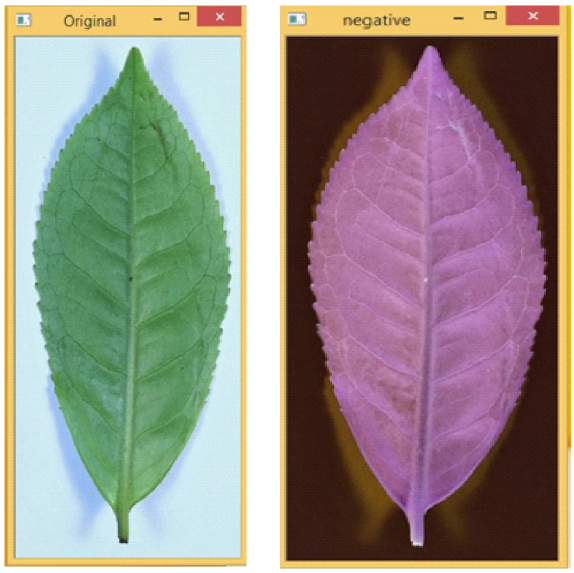
This type of processing is suitable for enhancing white or gray detail embedded in dark regions of an image, especially when the block areas are dominant in size.

Program 5.2: Python code to apply Negative transformation in an image

```
import cv2
# Load the image
img = cv2.imread('tea1b.jpg')
# To show the image
cv2.imshow('Original',img)
# Check the datatype of the image
print(img.dtype)
# Subtract the img from max value(calculated
from dtype)
img_neg = 255 - img
# Show the image
cv2.imshow('negative',img_neg)
cv2.waitKey(0)
```

The output is as follows :

Figure 5.3: Image Negative example



5.4.3 Gray-level Slicing

Highlightening a specific range of gray levels in an image is desired for application like-enhancing features such as masses of water in satellite imagery and enhancing flows in x-ray images. There are several ways of doing gray level slicing, but most of

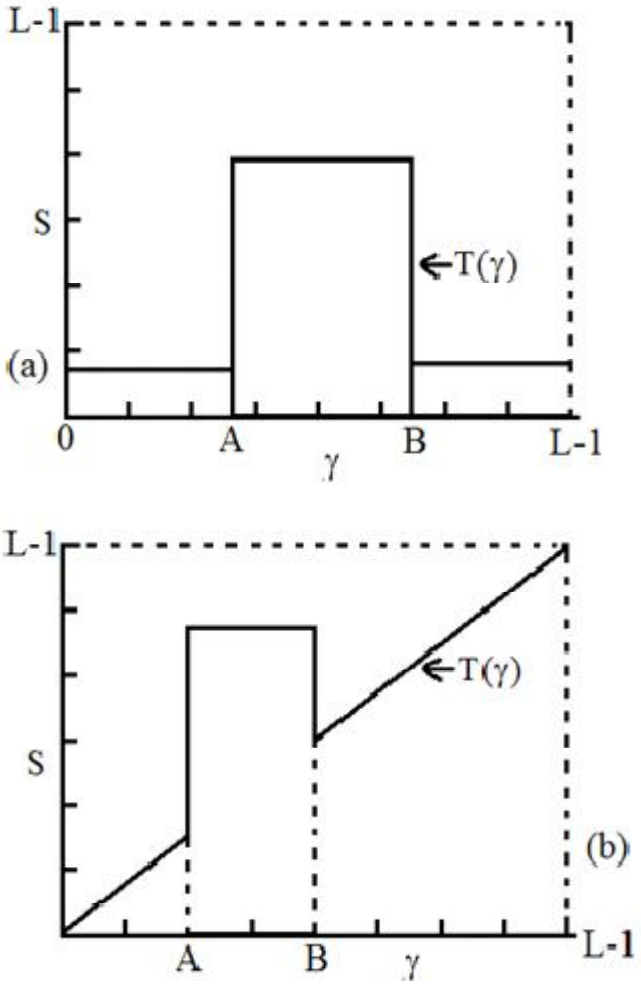
them are variations of two basic methods:

(i) Gray-level slicing without preserving background and

(ii) Gray-level slicing with background

(i) *Gray-level slicing without preserving background*: This approach is used to display high value for all gray levels in the range of interest and a low value for all other gray level. This transformation is shown in Fig.5.3(a).

Figure 5.4: Gray-level slicing

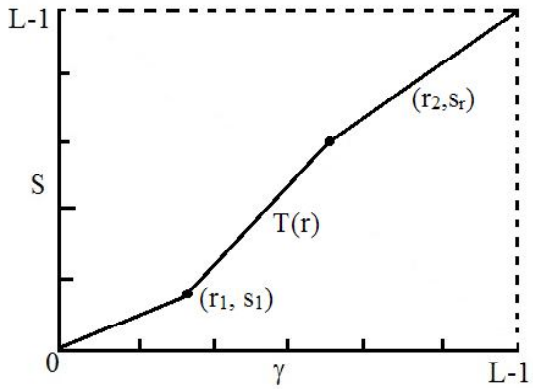


(ii) *Gray-level slicing with background*: This approach gives the brighter desired range of gray levels but preserves the background & gray –level tonalities in the image as shown in Fig.5.4(b).

5.4.4 Contrast Adjustment

Low-contrast images can result from poor illumination, lack of dynamic range in the imaging sensor. The idea of contrast stretching is to increase the dynamic range of the gray levels is the image being processed. Figure 5.5 shows a transformation used for contrast stretching.

Figure 5.5: Contrast Adjustment



The locations of points (γ_1, s_1) and (γ_2, s_2) are the shape of the transformation function.

If $\gamma_1 = s_1$, & $\gamma_1 = s_2$ & s_2, the transformation is a lineal function that produces no changes in gray levels.

If $\gamma_1 = \gamma_1$, & $s_1 = 0$ & $s_2 = L\text{-}1$, the transformation becomes a thresholding function that creates a binary image.

In general $\gamma \leq \gamma_2$ and $s_1 \leq s_2$, so that the function is single valued & monotonically increasing.

5.4.5 Bit-Plane Slicing

It is used for highlighting the contribution made to total image appearance by specific bits.

Let us consider that each pixel in an image is represented by 8 bits. The image can be imagined to be composed of eight 1-bit planes, ranging from bit-plane 0 for the most significant bit. In terms of 8-bit bytes, plane 0 contains all the lowest order bits in the bytes comprising the pixels in the image and plane 7 contains

all the high order bits. The higher order bits contain the majority of the visually significant data.

Separating a digital image into its bit planes is useful for analyzing the relative importance played by each bit of the image. This process aids in determining the adequate of the no. of bits used to quantize the image. This type of decomposition is useful for image compression.

5.4.6 Log Transformation

This transformation is obtained by replacing each pixel value with its logarithm value. The log transformation is given by

$$h = c*\log_2(f+1)$$

where ‘h’ and ‘f’ are the pixel values of the output and input image. The value of ‘c’ is the scaling constant and is used to adjust the kind of enhancement.

For an 8-bit image the value of ‘c’ is given by

$$c = 255/(\log (1+ \max_f)),$$

where ‘max_f’ is the maximum input pixel value.

For 8 bit image, ‘c’ is chosen such a way that it gives maximum value equal to 255.s

This transformation is use to expand the dark pixels in an image comparing to higher pixel values and compress values of bright pixels.

The log transformation can be use to make highly skewed distributions less skewed i.e.it can be use to map the wide range of high level gray scale intensities into a narrow range of high level output values. Similarly can also be use to map the wide range of low level gray scale intensities into a wide range of output values.

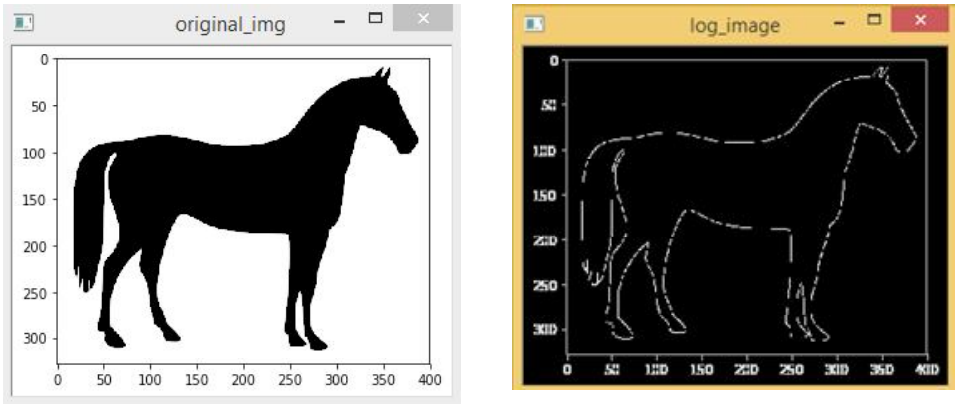
In this transformation in each of the pixel value of the input image value 1 is added so that if there is any pixel with intensity 0 in the image, then log (0) is equal to infinity and the minimum value is at least one.

Program 5.3: Program to apply Log transformation in an image

```
import cv2
import numpy as np
# Load the image
img = cv2.imread('horse.png')
# Apply log transform
img_log = (np.log(img+1)/(np.log(1+np.max(img))))
*255
# Specify the data type
img_log = np.array(img_log,dtype=np.uint8)
# Display the image
cv2.imshow('log_image',img_log )
cv2.imshow('original_img',img)
cv2.waitKey(0)
```

The output is as follows :

Figure 5.6: Log transformation



5.5 MASK PROCESSING

Mask processing or area processing or neighborhood processing operation is an image filter where the new value of a pixel is determined by its old value and the values of pixels in its vicinity. Various image enhancement techniques based on neighborhood processing are as follows:

(i) Low pass Filtering or smoothing

(ii) Noise

(iii) Low pass averaging filter

(iv) Low pas Median filtering

Details about the Mask processing will be described In the next unit.



CHECK YOUR PROGRESS

Q 1: (a) Why Bit plane slicing is important?

.....

.....

(b) Perform Bit plane slicing of the following image.

6	6	7	7	6
1	2	0	0	0
2	3	1	1	1
4	5	5	4	2
7	7	6	6	6

Q 2: *What is Dynamic range? How log transformation enhances an image by compressing the dynamic range of an image?*

.....

.....

Q 3: *State whether the following statements are true (T) or false(F).*

(i) Image negative is produced by subtracting each pixel from the maximum bit value of the image

(ii) Both Gray level slicing and Bit plane slicing are same

(iii) During log transformation, the dark pixels in an image are expanded as compared to the higher pixel values

(iv) A gray scale image may contain wavelength information

(v) Digital image processing has many advantages over analog image processing.



5.6 LET US SUM UP

- The goal of Image enhancement is to improve the perception of the image through modification of intensity functions, image spectral content or combination of these functions so that the result is more suitable than the original image

- The image enhancement approaches are of two types : (i) spatial domain methods and (ii) Frequency domain methods, depending on the type of application.
- The spatial domain refers to the aggregate of pixels composing an image & spatial domain methods are procedures that operate directly on those pixels.
- Spatial domain methods are of two types-
  (a) Intensity (or gray-level) transformations
  (b) Spatial filtering or neighbourhood processing on spatial convolution.
- Point operation methods of enhancement are image filter where the new value of a pixel is only determined by the original value of that pixel alone without depending on the other pixel values.
- Different image enhancement method based on point processing are –Brightness modification, Image negative, Gray-level slicing, Contrast adjustment, Bit-Plane slicing, Log transformation
- Mask Processing is an image filter where the new value of a pixel is determined by its old value or the values of pixels in its vicinity.
- Different image enhancement techniques based on neighbourhood processing are Low pass filtering or smoothing filter, Low pass averaging filter or Low pass Median filtering



5.7 FURTHER READING

1. Gonzales, R. C., & Woods, R. E. (2008). Digital image processing. Prentice Hall.
2. Jayaraman, S., Esakkirajan, S., & Veerakumar, T. (2009). Digital image processing.Tata McGraw-Hill, Education Private Limited

5.8 ANSWERS TO CHECK YOUR PROGRESS

Ans to Q No 1: (a) Bit plane slicing is a method of representing an image with one or more bits of the byte used for each pixel. One can use MSB to represent the pixel, thus converting the original gray level to a binary image. Bit plane slicing is important as it is possible to :

(i) convert a gray image to a binary image.

(ii) do image compression

(iii) do image enhancement.

(b) The given image is a 3-bit image as the maximum gray value is 7. To separate the bit planes the image is converted to a binary image as follow:

110	*110*	*111*	*111*	*110*
001	*010*	*000*	*000*	*000*
010	*011*	*001*	*001*	*001*
100	*101*	*101*	*100*	*010*
111	*111*	*110*	*110*	*110*

After separating the bit planes the MSB, Central bit plane and LSB planes are

Ans to Q No 2: Dynamic range of an image is the ratio of maximum to minimum intensity values of the image.

If dynamic range of an image is greater than that of displaying device, the lower values are suppressed. This problem can be overcome by applying log transform. Log transformation at first compresses the dynamic range and then upscales the image to a dynamic range of the display device. Thus enhancing the lower values and showing the most significant details.

Ans to Q No 3:

(i) F

(ii) F

(iii) T

(iv) F

(v) T



5.9 MODEL QUESTIONS

Q 1: What is image enhancement in spatial domain.

Q 2: What are the different techniques used in image enhancement in spatial domain

Q 3: What is a bit plane?

Q 4: Write python code that performs bit-plane slicing of the input grayscale image.

Q 5: If the pixel intensity values are reversed in an image than what will be the output image.

Q 6: How to increase the brightness of a gray scale image?

Q 7: What is contrast adjustment?

*** ***** ***

UNIT 6 : IMAGE HISTOGRAM

UNIT STRUCTURE

6.1 Learning Objective

6.2 Introduction

6.3 Introduction to Histogram

6.4 Histogram Equalization

6.5 Methods for Histogram Equalization

6.5.1 Global Histogram Equalization

6.5.2 Local Histogram Equalization

6.6 Let Us Sum Up

6.7 Further Reading

6.8 Answers to Check Your Progress

6.9 Model Questions

6.1 LEARNING OBJECTIVES

After going through this unit, you will be able to:

- learnabout histogramand image histogram
- learn to use histogram in image processing
- describe the methods of histogram equalization

6.2 INTRODUCTION

The previous unit describes image enhancement in spatial domain. We have learnt various operations like point operation, mask operation etc. from the unit. In this unit, we are discussing Image Histogram.

In general, a histogram is a graph that shows the frequency of anything.An image histogram is a graphical representation of the number of occurrences of gray level pixels in an image against the gray level values.

In this unit, we will also discuss how histogram can be equalizedand as well as about the global and local histogram equalization.

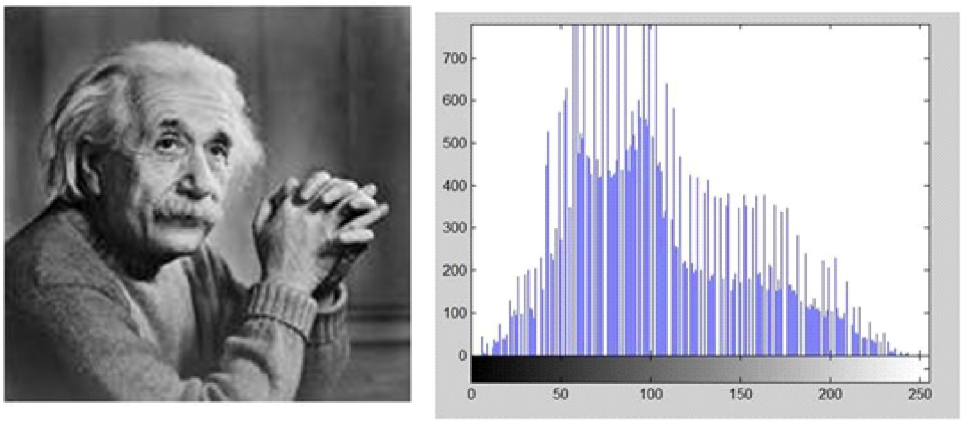
6.3 INTRODUCTION TO HISTOGRAM

A histogram is a bar graph, whose X-axis represents the number of pixelsand Y-axis represents the frequency count of the pixels intensity value. In other wordsthe histogram of a digital image is the representation of frequency of different pixel values in a bar graph. In general, for a grey scale image the pixel values ranges from 0 to 255, where 0 means black and 255 means white. If we plot a histogram for a grey level image, then the X-axis has the range of different pixel values (i.e. 0 to 255) and Y-axis have the frequency values. For example, in the figure 6.1, the histogram of a grey scale image is shown. We can represent the histogram of a digital image with intensity levels in the range [0, L - 1] as a discrete function

$h(r_k) = n_k$,

where r_k is the k^{th} intensity value and n_k is the number of pixels in the image with intensity r_k.

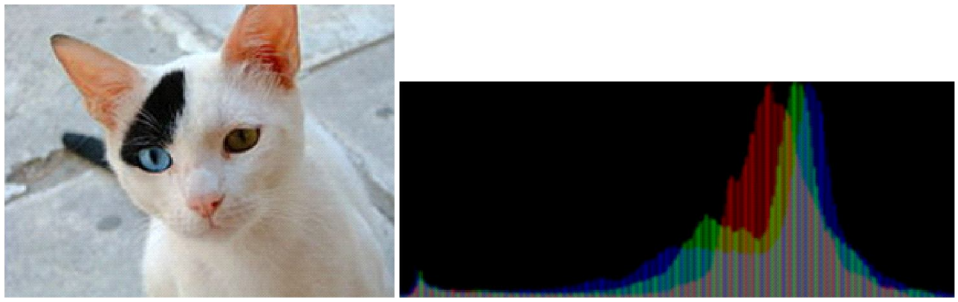
Figure 6.1: Histogram of grey scale image



On the other hand, a colour histogram of an image represents the distribution of the composition of colours in the image. It shows the different types of colours that appear and the number of pixels in each type of the colours.The colour histogram can be built for any kind of colour model, although most often we use for three-dimensional colour model like RGB or HSV or four dimensional colour model like CMYK. A colour histogram focuses only on the proportion of the number of different types of colours, regardless of the spatial location of the colours. Colour histogram can be shown in different ways, in the following figure (Fig

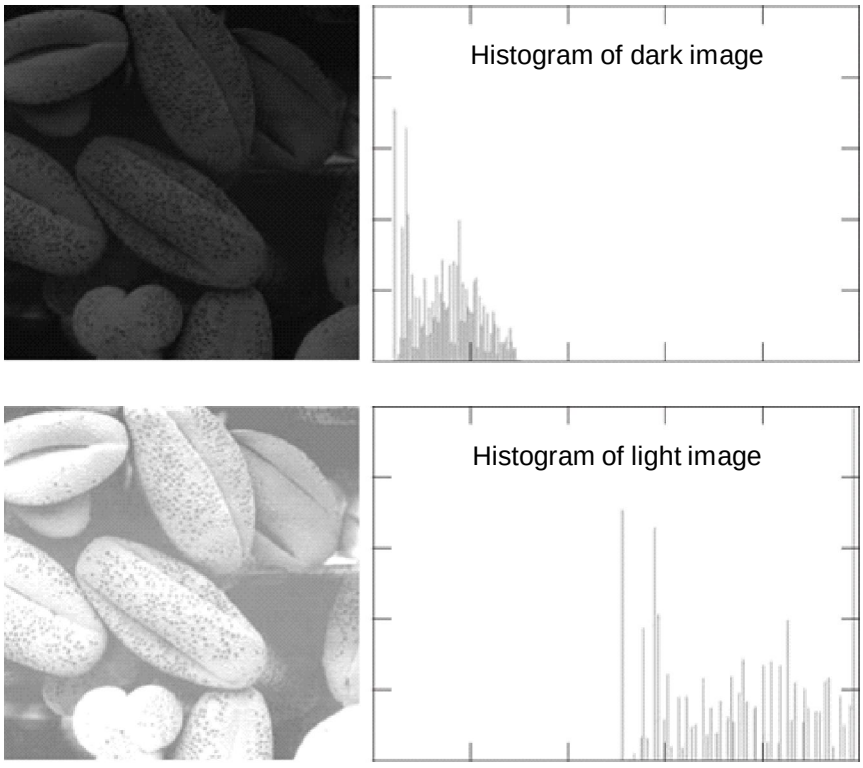
6.2) colour histogram is shown for the left side image.

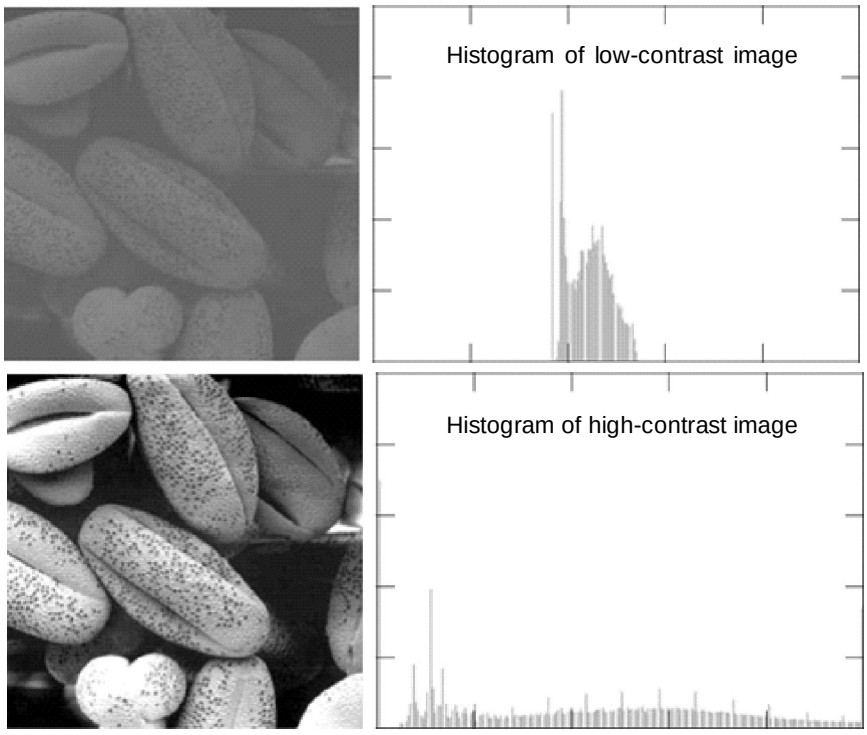
Figure 6.2: Histogram of colour image (RGB)



Histograms have many uses in image processing. The first use of it is that by looking at the image histogram we can say what type of image it is. The second use of histogram is for brightness purposes. The histogram has wide application in image brightness. Not only for brightness, but histograms are also used in adjusting contrast of an image.Another important use of histogram is to equalize an image. Histogram also has wide use in thresholding. This is mostly used in computer vision.Figure 6.3 explain the changes in histogram according to the modification of contrast and brightness.

Figure 6.3: dark, light, low contrast, high contrast, image histograms





From figure 6.3 we can see that the dark image has most of the high histograms on the low (dark) side of the intensity scale. Similarly, the high histograms of the light image are biased toward the high (light) side of the scale. An image with low contrast has a narrow histogram located in the middle of the intensity scale. For a high contrast image, the height of the histogram is less and the histograms are almost uniformly distributed over the X-axis.From the above diagram it is reasonable to conclude that an image whose pixels tend to occupy the entire range of possible intensity levels and, in addition, tend to be distributed uniformly over the X-axis exhibit to be a good image. In the next unit we will discuss how to develop such a transformation function that can automatically achieve this effect, based only on information available in the histogram of the input image.

6.4 HISTOGRAM EQUALIZATION

Contrast enhancement is a significant image processing technique which creates different contents of images that are apparent during appropriate increase in contrast.Histogram specification is a technique where contrast enhancement is attained by altering the image histogram into a preferred one. Histogram Equalization is widely employed in different

ways to perform contrast enhancement in images which aims at information maximization.

Histogram Equalization is used for image enhancement on account of its simplicity and higher performance on all images. The process of Histogram Equalization is carried out by remapping the grey levels of the image depending on the probability distribution of the input grey levels. It compresses and elongates the dynamic range of the image's histogram and leads to contrast enhancement. Histogram equalization is used in medical imaging, satellite imagery and other applications wherepattern recognition is performed.Histogram Equalization results in improvement of the image visibility in a significant way.

6.5 METHODS FOR HISTOGRAM EQUALIZATION

The methods for histogram equalization are:

- Global Histogram Equalization
- Local Histogram Equalization

6.5.1 Global Histogram Equalization (GHE)

Global Histogram Equalization is an image contrast enhancement technique used for pre-processing the image. Global Histogram Equalization is a commonly used technique because of its simplicity and high efficiency. The basic idea lies in remapping the intensity value of the pixels based on the cumulative distribution function of the input image. Given a digital image X and grey level values of the pixels range from [0,255], let X_k denote the pixels with grey level value k. The probability of occurrence of X_k in the image is calculated by following equation (eq. 6.1)-

$$p(X_k) = \frac{n}{N}$$

where,

N stands for the total number of pixel in an image.

n stands for the number of pixels having the intensity X_K.

k varies from 0 to L-1

L refers to highest grey level value.

Based on the Probability distribution function the Cumulative distribution function(CDF) for X_k is computed using the following equation (eq. 6.2)-

$$c(X_k) = \sum_{j=0}^{k} p(X_j)$$

where k varies from 0 to L-1.

Finally, the transformation function for remapping the gray scale value is given by the following equation (eq. 6.3)-

$$T(X_k) = X_0 + (X_{L-1} - X_0)C(X_k)$$

where, $T(X_k)$ represents the transformation function which maps a given pixel value Xk into a different value.

For example, let us consider the following sub-image (Portion of a large image)

Figure 6.4: (a)

The 8×8 sub-image

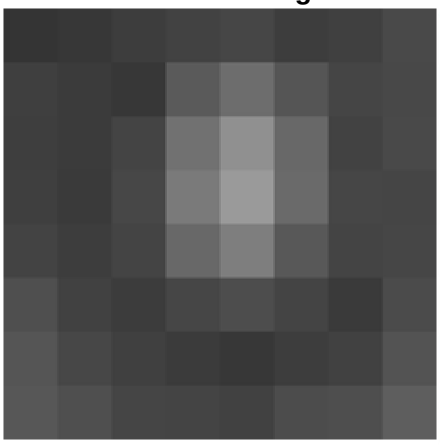


Figure 6.4: (b)

Grayscale intensity values

52	55	61	59	70	61	76	61
62	59	55	104	94	85	59	71
63	65	66	113	144	104	63	72
64	70	70	126	154	109	71	69
67	73	68	106	122	88	68	68
68	79	60	70	77	66	58	75
69	85	64	58	55	61	65	83
70	87	69	68	65	73	78	90

The histogram for this image is shown in the following table. Pixels with zero count are excluded in the table.

Table 6.1

Value	Count	Value	Count	Value	Count	Value	Count	Value	Count
52	1	64	2	72	1	85	2	113	1
55	3	65	3	73	2	87	1	122	1
58	2	66	2	75	1	88	1	126	1

59	3	67	1	76	1	90	1	144	1
60	1	68	5	77	1	94	1	154	1
61	4	69	3	78	1	104	2		
62	1	70	4	79	2	106	1		
63	2	71	2	83	1	109	1		

The Cumulative Distribution function(CDF) is shown below. Here also pixel values that do not contribute to an increase in the cdf are excluded.

Table 6.2

v, Pixel Intensity	cdf(v)	h(v), Equalized v
52	1	0
55	4	12
58	6	20
59	9	32
60	10	36
61	14	53
62	15	57
63	17	65
64	19	73
65	22	85
66	24	93
67	25	97
68	30	117
69	33	130
70	37	146
71	39	154
72	40	158
73	42	166
75	43	170
76	44	174
77	45	178
78	46	182
79	48	190
83	49	194
85	51	202

87	52	206
88	53	210
90	54	215
94	55	219
104	57	227
106	58	231
109	59	235
113	60	239
122	61	243
126	62	247
144	63	251
154	64	255

This CDF shows that the minimum value in the subimage is 52 and the maximum value is 154. The CDF of 64 for value 154 coincides with the number of pixels in the image. The CDF must be normalized to [0-255]. The general histogram equalization formula is:

$$h(v) = round\left(\frac{cdf(v) - cdf_{min}}{(M \times N) - cdf_{min}} \times (L-1)\right)$$

where cdf_{min} is the minimum non-zero value of the cumulative distribution function (in this case 1), M × N gives the image's number of pixels (for the example above 64, where M is width and N the height) and L is the number of grey levels used (in most cases, like this one, 256).

$$h(v) = \left(\frac{cdf(v) - 1}{63} \times 255\right)$$

For example, the cdf of 78 is 46. (The value of 78 is used in the bottom row of the 7th column.) The normalized value becomes

$$h(78) = round\left(\frac{46-1}{63} \times 255\right) = round(0.71428 \times 255) = 182$$

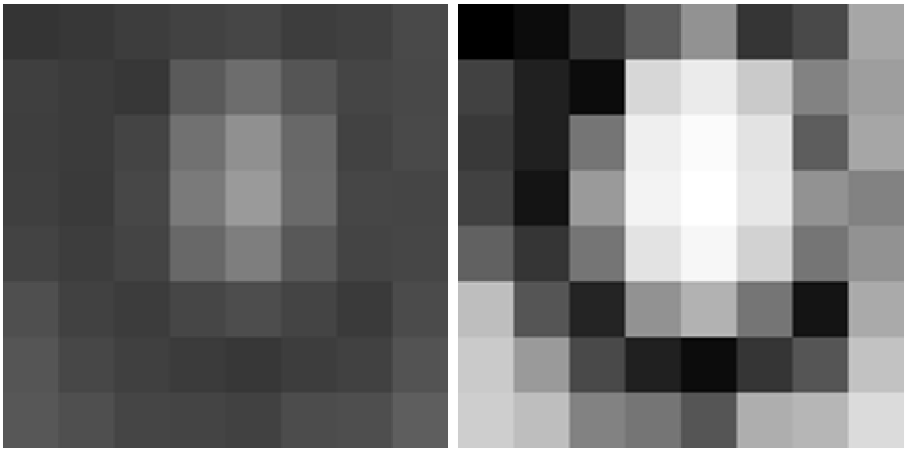
Once this is done then the values of the equalized image are directly taken from the normalized cdf to yield the equalized values:

Figure 6.5: Normalized pixel values

0	12	53	32	146	53	174	53
57	32	12	227	219	202	32	154
65	85	93	239	251	227	65	158
73	146	146	247	255	235	154	130
97	166	117	231	243	210	117	117
117	190	36	190	178	93	20	170
130	202	73	20	12	53	85	194
146	206	130	117	85	166	182	215

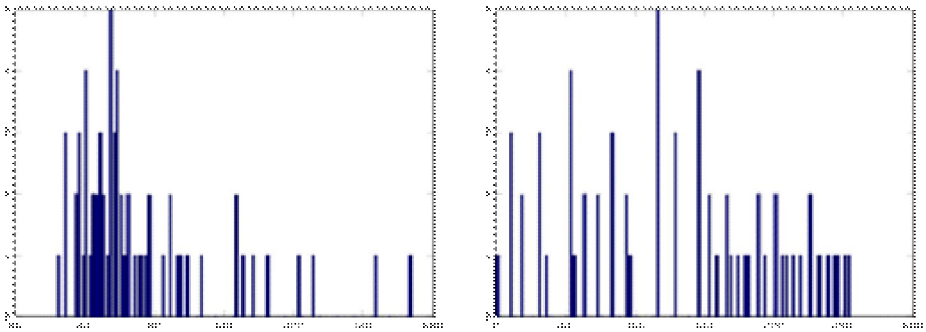
Here we can see that the minimum value (52) is now 0 and the maximum value (154) is now 255.

Figure 6.6: Original and Equalized images



Original sub-image Equalized sub-image

Figure 6.7: Histogram of Original and Equalized image



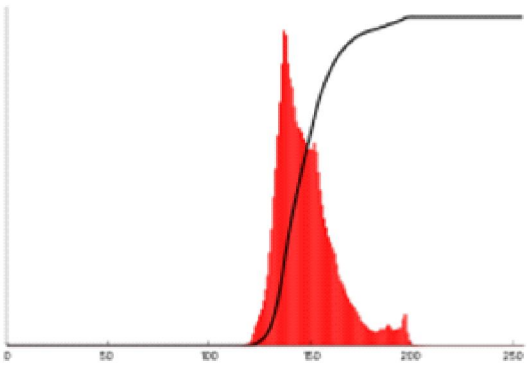
Original image Equalized image

In the following figure shows the enhancement of contrast for a photograph

Figure 6.8: Result of Histogram Equalization



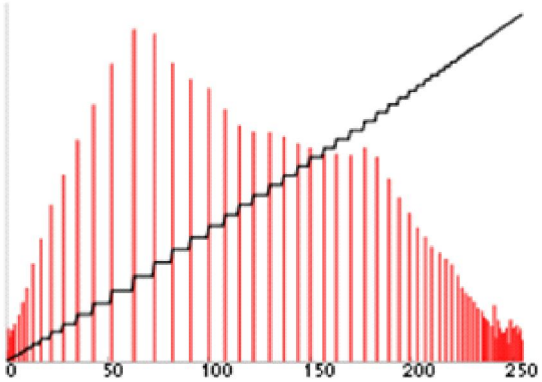
Before Histogram Equalization



Corresponding histogram (red) and cumulative histogram (black)



After Histgram Equalization



Corresponding histogram (red) and cumulative histogram (black)

Limitations of GHE

Some of the Limitations of GHE are as follows:

- GHE introduces a significant change in the brightness of the image.
- Annoying artefacts are present and the brightness of the image is not preserved.
- This technique uses the global information to derive the global transformation function but it cannot adapt to local brightness.

Local Histogram Equalization (LHE) and Partially Overlapped Sub-Block Histogram Equalization (POSHE) are two of the methods proposed to overcome the challenges of GHE. These techniques localize the global technique, which

subsequently adapts to the local conditions of the image.

6.5.2 Local Histogram Equalization (LHE)

Local Histogram Equalization, also called block-overlapped histogram equalization, is adaptive to local brightness changes and it increases the overall contrast of the input image. In local histogram equalization, first a small square size window or mask is defined; they are typically 3x3 or 5x5 matrix.In this method histograms are computed for themaskand then histogram equalization function is determined based on the mask. In this method the centre pixel of themask is equalized using the equalization function. After equalizing the centre pixel, the centre of the window is moved to the next adjacent pixel. The same procedure is again repeated for each pixel in the input image.

In figure 6.9 the intensity value of an image is shown. In the next figures (figures 6.10 (a), (b)) the masks of size 3x3, 5x5 are defined on the input image.In Figure 6.10 (a), using the transformation function derived for the region covered by the 3x3 mask centre pixel 54 is equalized. Similarly in Fig 6.10(b)thecentre pixel value 63 is equalized by using the transformation function derived for the region covered by the 5x5 mask. This process continues for every pixel in the image by shifting the mask to the adjacent pixel of the image.

Figure 6.9: Image and its corresponding Intensity values

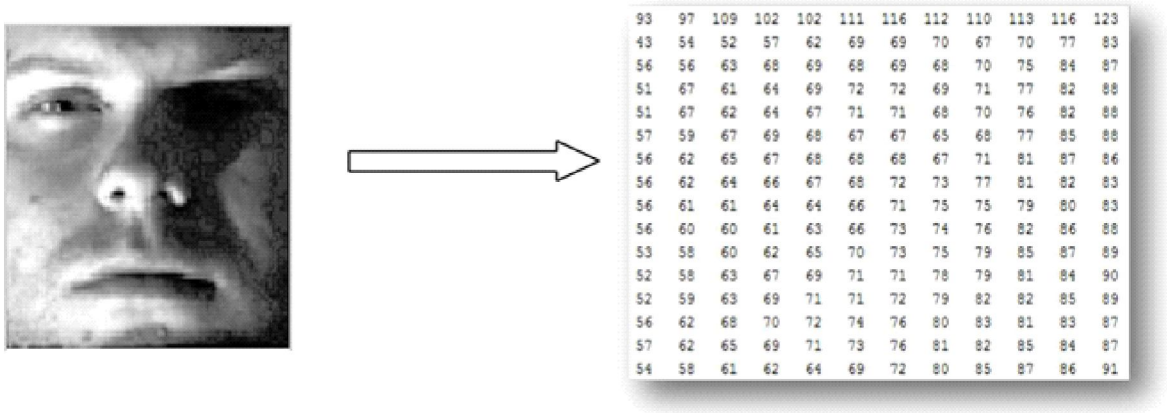
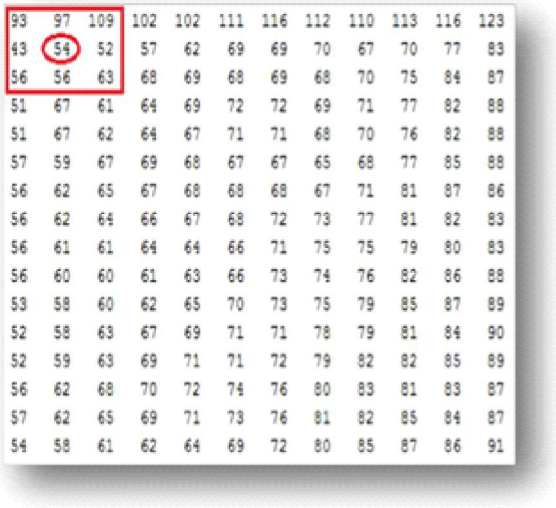
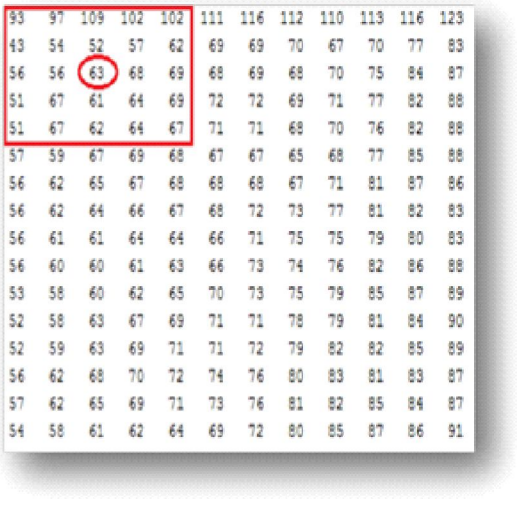


Figure 6.10: (a)LHE with 3x3 mask



93	97	109	102	102	111	116	112	110	113	116	123
43	54	52	57	62	69	69	70	67	70	77	83
56	56	63	68	69	68	69	68	70	75	84	87
51	67	61	64	69	72	72	69	71	77	82	88
51	67	62	64	67	71	71	68	70	76	82	88
57	59	67	69	68	67	67	65	68	77	85	88
56	62	65	67	68	68	68	67	71	81	87	86
56	62	64	66	67	68	72	73	77	81	82	83
56	61	61	64	64	66	71	75	75	79	80	83
56	60	60	61	63	66	73	74	76	82	86	88
53	58	60	62	65	70	73	75	79	85	87	89
52	58	63	67	69	71	71	78	79	81	84	90
52	59	63	69	71	71	72	79	82	82	85	89
56	62	68	70	72	74	76	80	83	81	83	87
57	62	65	69	71	73	76	81	82	85	84	87
54	58	61	62	64	69	72	80	85	87	86	91

Figure 6.10: (b) LHE with 5x5 mask



93	97	109	102	102	111	116	112	110	113	116	123
43	54	52	57	62	69	69	70	67	70	77	83
56	56	63	68	69	68	69	68	70	75	84	87
51	67	61	64	69	72	72	69	71	77	82	88
51	67	62	64	67	71	71	68	70	76	82	88
57	59	67	69	68	67	67	65	68	77	85	88
56	62	65	67	68	68	68	67	71	81	87	86
56	62	64	66	67	68	72	73	77	81	82	83
56	61	61	64	64	66	71	75	75	79	80	83
56	60	60	61	63	66	73	74	76	82	86	88
53	58	60	62	65	70	73	75	79	85	87	89
52	58	63	67	69	71	71	78	79	81	84	90
52	59	63	69	71	71	72	79	82	82	85	89
56	62	68	70	72	74	76	80	83	81	83	87
57	62	65	69	71	73	76	81	82	85	84	87
54	58	61	62	64	69	72	80	85	87	86	91

Limitations of LHE

Some of the limitations of LHE are as follows:

- Local histogram equalization results in an over enhanced image.
- For any mask size considered, histogram equalization has to be performed for all pixels in the entire image; hence the computational complexity is high in LHE.



CHECK YOUR PROGRESS

Q 1: Choose the correct option:

a. Histogram is an image

b. Histogram is a Photo

c. Histogram is a graph

d. None of the above

Q 2: Range of pixel values of a gray scale image is

a. from 1 to 256

b. from 0 to size of the image

c. from 0 to 255

d. from 0 to 1024

Q 3: Histogram equalisation is mainly used for

a. blurring

b. image enhancement

c. pixel counting

d. none of the above

Q 4: CDF Stands for

a. Cumulative Distribution Function

b. Computer Distribution Function

c. Computer Detection Function

d. Cumulative Direction Function

Q 5: The type of Histogram Equalization in which pixels are modified based on the intensity distribution of the pixel is called

a. Pixel summarization

b. Local Histogram Equalization

c. Global Histogram Equalization

d. None of the above

Q 6: The type of Histogram Equalization in which mask are used to calculate the mean pixel is called

a. Pixel summarization

b. Local Histogram Equalization

c. Global Histogram Equalization

d. None of the above



6.6 LET US SUM UP

- A histogram is a graph that shows the frequency count of intensity of anything.
- An image histogram is a graphical representation of the number of pixels in an image.
- In a gray scale image the pixel values ranges from 0 to 255, where 0 means black and 255 means white.
- Colour histogram of an image represents the distribution of the composition of colours in the image.
- A colour histogram focuses only on the proportion of the number

of different types of colours, regardless of the spatial location of the colours.

- For a high contrast image the height of the histogram are less and the histograms are almost uniformly distributed over the X-axis.
- Histogram equalization is widely employed in different ways to perform contrast enhancement in images which aims at information maximization.
- Histogram equalization is used in medical imaging, satellite imagery and other applications where pattern recognition is performed.
- Histogram equalization results in improvement of the image visibility in a significant way.
- Two basic methods of histogram equalization are Global Histogram Equalization and Local Histogram Equalization
- Global Histogram Equalization is a commonly used technique because of its simplicity and high efficiency.
- The basic idea of Global Histogram Equalization lies in remapping the intensity value of the pixels based on the cumulative distribution function of the input image.
- Local Histogram Equalization also called block-overlapped histogram equalization, is adaptive to local brightness changes and increases the overall contrast of the input image.
- In local histogram equalization first a small square size window or mask is defined; they are typically 3x3 or 5x5 matrix. In this method histograms are computed for the mask and then histogram equalization function is determined based on the mask.
- In Local Histogram Equalization method the centre pixel of the mask is equalized using the equalization function.



6.7 FURTHER READING

1. Gonzales, R. C., & Woods, R. E. (2008), Digital Image Processing, Prentice Hall.

2. Easton, R. L. (2010). Fundamentals of digital image processing.
3. Annadurai, S. & Sharmugalakshmi, R. (2007), Fundamentals of digital image processing, Pearson Education India.



6.8 ANSWERS TO CHECK YOUR PROGRESS

Ans to Q No 1: c. Histogram is a graph

Ans to Q No 2: c. from 0 to 255

Ans to Q No 3: b. image enhancement

Ans to Q No 4: a. Cumulative Distribution Function

Ans to Q No 5: c. Global Histogram Equalization

Ans to Q No 6 b. Local Histogram Equalization



6.9 MODEL QUESTIONS

Q 1: What is Image Histogram? Explain with example.

Q 2: Discuss the advantages of histogram equalization.

Q 3: Explain the global histogram equalization in detail.

Q 4: Explain the local histogram equalization in detail.

Q 5: Explain the global histogram equalization with an example.

Q 6: How mask is used in local histogram equalization? Explain with example.

Q 7: Explain the function to calculate Cumulative distribution function.

*** ***** ***

UNIT 7 : FILTERING

UNIT STRUCTURE

7.1 Learning Objectives

7.2 Introduction

7.3 Filtering

7.4 Spatial Filtering

7.5 Linear Filtering

7.6 Low Pass Filter

7.7 Weight Average Filter

7.8 Gaussian Filter

7.9 Median Filter

7.10 High Pass Filtering

7.11 Let Us Sum Up

7.12 Further Reading

7.13 Answers to Check Your Progress

7.14 Model Questions

7.1 LEARNING OBJECTIVES

After going through this unit, you will be able to:

- learn about filtering
- describe the different filtering techniques
- explain filtering in different domain
- learnabout the advantages and disadvantages of different filtering techniques

7.2 INTRODUCTION

In the previous unit (unit 6) we have already discussed what histogram is, how it is used and the equalization of histogram in the previous unit.

In this unit, we will learn different filters and filtering techniques required for image processing. Filtering is an important component of image

processing. For modifying or enhancing an image, filtering is necessary.We can filter an image to emphasize certain features or to remove other features. Image processing operations implemented with filtering include smoothing, sharpeningand edge enhancement. The purpose of smoothing in image filtering is to reduce noise and to improve the visual quality of the image.

7.3 FILTERING

In general filtering is a neighbourhood operation, in which the value of any given pixel in the output image is determined by applying some functionson the values of the neighbourhood pixels of the corresponding input pixel. A pixel's neighbourhood is the set of pixels, within a certain distance from that pixel.

A filter is defined by a kernel. A kernel is a small matrix or array which is applied to the pixel and its neighbourhood pixelsof that pixel. A variety of algorithms are available for kernel design and for applying the kernel in the image. Image filtering makes several useful tasks to be possible in image processing.

- A filter can be applied to reduce the amount of unwanted noise in a particular image.
- Another type of filter can be used to reverse the effects of blurring on a particular picture.

Algorithms available for filtering can be categorized into two groups linear and nonlinear. In section 7.3 to 7.9 we have discussed about the linear different filtering techniques. Nonlinear filters havequite different behaviour compared to linear filters. For nonlinear filters, the filter output or response of the filter does notobey the principles of linear filters, particularly scaling and shift invariance. Moreover, a nonlinear filter can produceresults that vary in a non-intuitive manner.

7.4 SPATIAL FILTERING

Spatial filtering is an image processing technique for changing the intensities of a pixel according to the intensities of the neighbouring

pixels. Using spatial filtering, the image is transformed (convoluted) based on a kernel. A kernel for spatial filtering technique looks like

Figure 7.1: Spatial Filtering Kernel

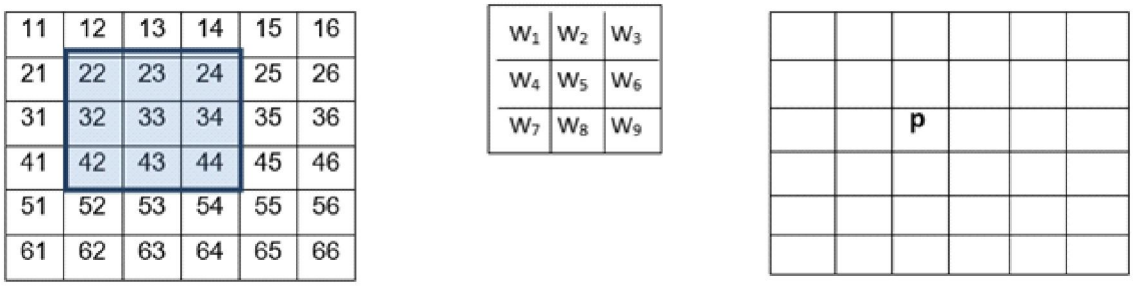
W_1	W_2	W_3
W_4	W_5	W_6
W_7	W_8	W_9

A Kernel is a two dimensional array (matrix) having certain height and width **(x, y)**, (here it is $(3,3)$) defining both the area and the weight of the pixels (here W_1, W_2, W_3 … are the weights).In spatial filtering this kernel is applied on all the pixels of the input image and replace the value of the pixels of the image. The corresponding process is called convolve. If the input image is $I(i,j)$ and filter function is $H(x,y)$, it produce the new filtered image:

$$I'(i,j) = I(i.j) \odot H(x,y)$$

The mathematical operation here is a multiplication. The spatial filtering can be characterized as a “shift-and-multiply” operation: the kernel is shifts over the initial image and multiplies with the pixel and its neighbours corresponding pixel values of the image. The result is a new value that replaces the central value of the mask in the new image. The procedure is shown schematically in Figure 7.2. For a kernelgiven in Figure 7.1 the calculated output image is given by the following formula as follows:

Figure 7.2: Spatial filtering on an image



The value for p is :

p = (2,2) × W_1 + (2,3) × W_2 + (2,4) × W_3 + (3,2) × W_4 + (3,3) × W_5 + (3,4) × W_6 + (4,2) × W_7+ (4,3) × W_8 + (4,4) × W_9

7.5 LINEAR FILTERING

Linear filtering is a filtering technique in which the value of an output pixel is a linear combination of the values of the pixels in the input pixel's neighbourhood. In linear filtering we construct a new array, the same size as the image. Fill each location of this new array with a weighted sum of the pixel values from the locations surrounding the corresponding location in the image, using the same set of weights (kernel) each time. The result of this procedure is shift-invariant; meaning that the value of the output depends on the pattern in an image neighbourhood, rather than the position of the neighbourhood and it is linear meaning that the output for the sum of two images is the same as the sum of the outputs obtained for the images separately. The procedure itself is known as linear filtering.

Convolution: The process of applying the filter is usually referred to as convolution. In particular, given a filter kernel H, the convolution of the kernel with imageFis an image R. The (i, j)th component of R is given by:

$$Rij = \sum_{u,v} H_{i-u,j-v} R_{u,v}$$

7.6 LOW PASS FILTER

The most basic of filtering operations is called "low-pass" filter. A low-pass filter, also called a "blurring" or "smoothing" filter, averages out rapid changes in intensity. The simplest low-pass filter just calculates the average of a pixel and all of its eight immediate neighbours. The result replaces the original value of the pixel. The process is repeated for every pixel in the image.

Figure 7.3: Low pass filtering on an image

11	12	13	14	15	16
21	22	23	24	25	26
31	32	33	34	35	36
41	42	43	44	45	46
51	52	53	54	55	56
61	62	63	64	65	66

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

	22	23	24		
	32	33	34		
	42	43	44		

$$new(3,3) = (2,2) \times \frac{1}{9} + (2,3) \times \frac{1}{9} + (2,4) \times \frac{1}{9} + (3,2) \times \frac{1}{9} + (3,3) \times \frac{1}{9}$$
$$+ (3,4) \times \frac{1}{9} + (4,2) \times \frac{1}{9} + (4,3) \times \frac{1}{9} + (4,4) \times \frac{1}{9}$$

After use of low-pass filter image looks a lot blurrier. Often images can be noisy– no matter how good the camera is, it always adds an amount of "snow" into the image. The statistical nature of light itself also contributes noise into the image.

Noise always changes rapidly from pixel to pixel because each pixel generates its own independent noise. The image from the telescope is not "uncorrelated" in this fashion because real images are spread over many pixels. So the low-pass filter affects the noise more than it does the image. By suppressing the noise, gradual changes can be seen that were invisible before. Therefore, a low-pass filter can sometimes be used to bring out faint details that were smothered by noise. To perform a low-pass filter by simply averaging adjacent pixels, the following kernel is used:

Figure 7.4: Kernel for low pass averaging filter

+1/9	+1/9	+1/9
+1/9	+1/9	+1/9
+1/9	+1/9	+1/9

When this kernel is applied, each pixel and its eight neighbours are multiplied by 1/9 and added together. The pixel in the middle is replaced by the sum. Werepeat this procedure for all the pixels in the image.

We could also make the kernel larger. The example in Fig.7.4 is a 3x3 pixel kernel for a total of nine. We could use 5x5 or 7x 7 or even more. The only problem with using larger kernels is the number of calculations required becomes very large. In figure 7.5 value for a pixel p is calculated as

Figure 7.5: calculation of pixel value for low pass averaging filter

5	7	9	4	5	2
3	1	5	6	5	8
4	6	3	8	7	6
7	4	2	3	6	9
5	2	7	3	5	5
6	9	5	8	2	6

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

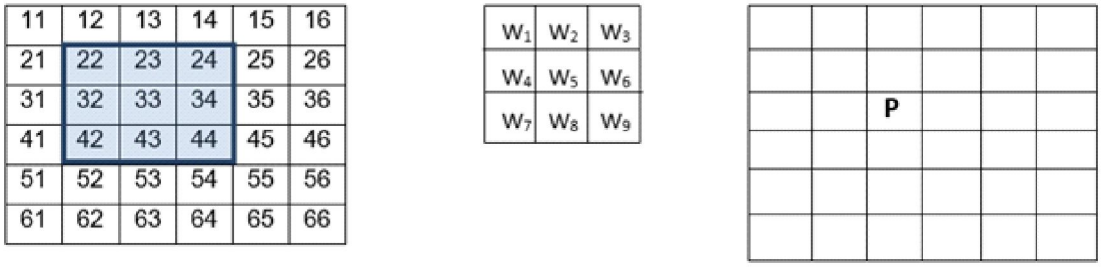
	P				

$$P = \frac{1}{9} \times [5 + 7 + 9 + 3 + 1 + 5 + 4 + 6 + 3] = \frac{1}{9} \times 43 = 4.77 \approx 5$$

7.7 WEIGHT AVERAGE FILTER

Weight average filter is a modification of low pass filter. The basic idea is to give higher weight to the centreof the kernel.

Figure 7.6: Weight averaging filter



where W_1, W_2, W_3 … are the weights.

P= (2,2) × W_1 + (2,3) × W_2 + (2,4) × W_3 + (3,2) × W_4 + (3,3) × W_5 + (3,4) × W_6 + (4,2) × W_7+ (4,3) × W_8 + (4,4) × W_9

In the weight average terminology pixels are multiplied bydifferent coefficients, thus giving more importance (weight) to some pixels at theexpense of others. In the kernel shown in Figure 7.7 the pixel at the centre of the kernel is multiplied by a higher value than any other, thus giving this pixel moreimportance in the calculation of the average. The other pixels are inverselyweighted as a function of their distance from the centrein the second mask.The diagonalterms are further away from the centre than the orthogonal neighbours and, thus, weighed less than the immediate neighbours of the centre pixel. The basic strategy behind weighing the centre point the highest and thenreducing the value of the coefficients as a function of increasing distance from the origin is simply an attempt to reduce blurring in the smoothing process.We couldhave chosen other weights to accomplish the same general objective. The sums of all the coefficients in the following kernels are 10 and 16 respectively.

Figure 7.7: Kernel for Weight Average Filter

$1/10$

1	1	1
1	2	1
1	1	1

$1/16$

1	2	1
2	4	2
1	2	1

When these kernels are applied, each pixel in the mask are multiplied by the weights and we then find the average by dividing total weights in the mask and the pixel in the middle is replaced by the sum. This is repeated for each pixel in the image.

Similar to low pass filter here also we could use larger kernels of size 5x5 or 7x 7 or even more.

Figure 7.8: Calculation of pixel value for Weight Average Filter

5	7	9	4	5	2
3	1	5	6	5	8
4	6	3	8	7	6
7	4	2	3	6	9
5	2	7	3	5	5
6	9	5	8	2	6

$1/10$

1	1	1
1	2	1
1	1	1

P					

$$P = 1/10\,[5\times1+7\times1+9\times1+3\times1+3\times1+1\times2+5\times1+4\times1+6\times1+3\times1]$$

$$= 1/10 \times 44 = 4.4 \approx 4$$

7.8 GAUSSIAN FILTERING

The Gaussian Filter is a 2-D convolution operator that is used to 'blur' images and remove detail and noise. Shape of the kernel of the Gaussian filter is like a bell. This kernel has some special properties as explained below.

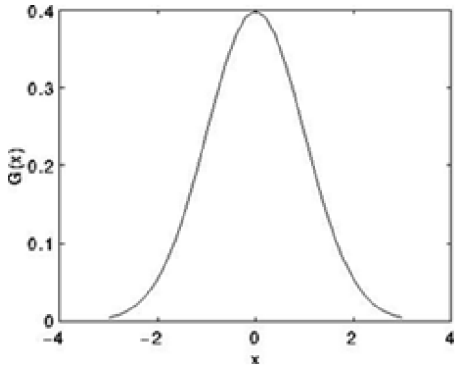
The Gaussian distribution in 1-D has the form is:

$$G(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{\frac{x^2}{2\sigma^2}}$$

Here σ is the standard deviation of the distribution. We have also assumed that the distribution has a mean of zero (i.e. it is centred on the line x=0). The distribution is illustrated in the following figure-

σ

Figure 7.9: 1-D Gaussian distribution with mean 0 and σ =1

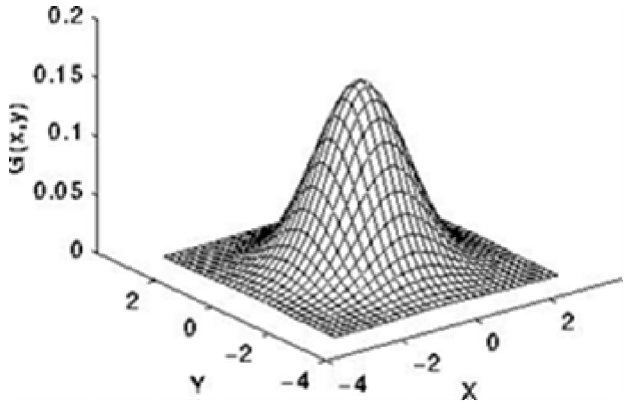


In 2-D, an isotropic (i.e. circularly symmetric) Gaussian function has the form:

$$G(x,y) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{x^2+y^2}{2\sigma^2}}$$

This distribution is shown in the following figure:

Figure 7.10: 2-D Gaussian distribution with mean (0, 0) and σ =1



The basic idea of Gaussian smoothing is to use this 2-D distribution as a 'point-spread' function, and this is achieved by convolution. Since the image is stored as a collection of discrete pixels we need to produce a discrete approximation to the Gaussian function before we can perform the convolution. In theory, the Gaussian distribution is non-zero everywhere, which would require an infinitely large convolution kernel, but in practice it is effectively zero aftera distance from the centre, and so we can truncate the kernel at this point. The following figure shows a suitable integer-valued convolution kernel that approximates a Gaussian filter with a σ = 1.0.

Figure 7.11: Discrete approximation to Gaussian function with σ =1.0

$$\frac{1}{273}\begin{bmatrix} 1 & 4 & 7 & 4 & 1 \\ 4 & 16 & 26 & 16 & 4 \\ 7 & 26 & 41 & 26 & 7 \\ 4 & 16 & 26 & 16 & 4 \\ 1 & 4 & 7 & 4 & 1 \end{bmatrix}$$

Once a suitable kernel has been calculated, then the Gaussian smoothing can be performed using the standard convolution methods. The convolution can in fact be performed fairly quickly since the equation for the 2-D isotropic Gaussian shown above is separable into x and y components. Thus the 2-D convolution can be performed by first convolving with a 1-D Gaussian in the x direction, and then convolving with another 1-D Gaussian in the y direction.

A further way to compute a Gaussian smoothing with a large standard deviation is to convolve an image several times with a smaller Gaussian. While this is computationally complex, it can have applicability if the processing is carried out using a hardware pipeline.

The Gaussian filter not only has utility in engineering applications. It is also attracting attention from computational biologists because it has been attributed with some amount of biological plausibility, e.g., some cells in the visual pathways of the brain often have an approximately Gaussian response.

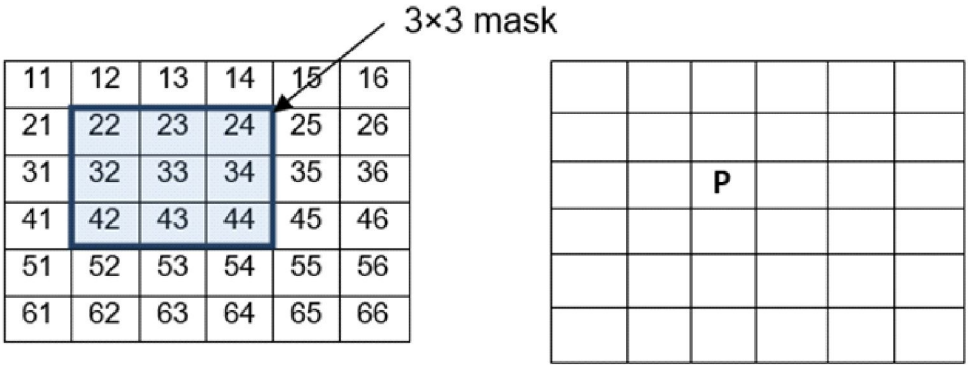
7.8 MEDIAN FILTERING

The median filter is a nonlinear digital filtering technique, often used to remove noise. Such noise reduction is a typical pre-processing step to improve the image quality(for example, edge detection on an image). Median filtering is very widely used in digital image processing because, under certain conditions, it preserves edges while removing noise.

Median filter is a spatial filtering operation. So it uses a 2-D mask that is applied to each pixel in the input image. To apply the mask means to centre it in a pixel, evaluating the covered pixel brightnesses and determining which brightness value is the median value. The following

figure 7.12 presents the concept of spatial filtering based on a 3x3 mask:

Figure 7.12: Shows concept of spatial filtering

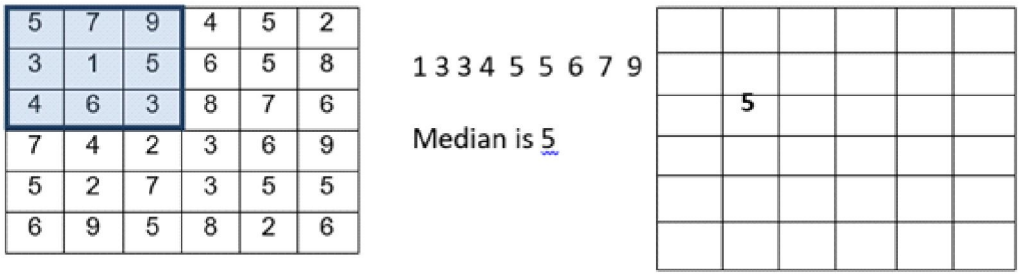


Input Image Output Image

P = median of (22, 23, 24, 32, 33, 34, 42, 43, 44)

The median value is determined by sorting all the pixel values from the surrounding neighbourhood into numerical order and then replacing the pixel being considered with the middle pixel value. If the neighbourhood under consideration contains an even number of pixels, the average of the two middle pixel values is used. Figure 7.13 illustrates the calculation of median value.

Figure 7.13: The median value of a pixel



Input Image Output Image

As we can see that, the central pixel value of 1 is rather unrepresentative of the surrounding pixels and is replaced with the median value: 5. Here,a 3×3 neighbourhood is used; however, larger neighbourhoods will produce more severe smoothing. By calculating the median value of a neighbourhood rather than the mean filter we have the following advantages:

- The median is more robust than the mean and so a single very unrepresentative pixel in a neighbourhood will not affect the median value significantly.

- Since the median value must actually be the value of one of the pixels in the neighbourhood, the median filter does not create new unrealistic pixel values, when the filter straddles an edge. For this reason, the median filter is much better at preserving sharp edges than the mean filter.

The main problem of the median filter is its high computational cost for sorting N pixels, the temporal complexity is $O(N \cdot log\ N)$, even with the most efficient sorting algorithms.In general, the median filter allows a great deal of high spatial frequencydetail to pass while remaining very effective at removing noise on images where less than half of the pixels in a smoothing neighbourhood have been effected. As a consequence of this, median filtering can be less effective at removing noise from images corrupted with Gaussian noise.

7.10 HIGH PASS FILTERING

A high pass filter is the basis for the most sharpening methods. An image is sharpened when contrast is enhanced between adjoining areas with little variation in brightness or darkness. A high pass filter tends to retain the high frequency information within an image while reducing the low frequency information. The kernel of the high pass filter is designed to increase the brightness of the centre pixel relative to neighbouring pixels. The kernel array usually contains a single positive value at its centre, which is completely surrounded by negative values. The following are the examples of 3 by 3 kernel for high pass filter:

Figure 7.14: Some Kernel of High Pass Filter

-1/9	-1/9	-1/9
-1/9	+8/9	-1/9
-1/9	-1/9	-1/9

-1	-1	-1
-1	+8	-1
-1	-1	-1

-1/4	-1/4	-1/4
-1/4	+2	-1/4
-1/4	-1/4	-1/4

A high-pass filter can be used to make an image appear sharper. These filters emphasize fine details in the image – exactly the opposite

of the low-pass filter. High-pass filtering works in exactly the same way as low-pass filtering; it just uses a different convolution kernel. In the example below, notice the minus signs for the adjacent pixels. If there is no change in intensity, nothing happens. But if one pixel is brighter than its immediate neighbours, it gets boosted

Unfortunately, while low-pass filtering smooths out noise, high-pass filtering does just the opposite: it amplifies noise. High-pass filtering can also cause small, faint details to be greatly exaggerated. An over-processed image will look grainy and unnatural, and point sources will have dark donuts around them. So while high-pass filtering can often improve an image by sharpening detail, overdoing it can actually degrade the image quality significantly.

Figure 7.14: Calculation of pixel value using High Pass Filter

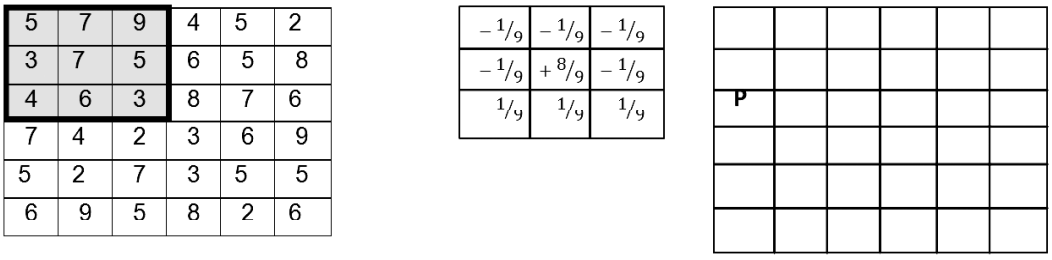


Image Input 3×3 matrix Output Image

$$P = (-\tfrac{1}{9} \times 5) + (-\tfrac{1}{9} \times 7) + (-\tfrac{1}{9} \times 9) + (-\tfrac{1}{9} \times 3) + (\tfrac{8}{9} \times 7)$$
$$+(-\tfrac{1}{9} \times 5) + (-\tfrac{1}{9} \times 4) + (-\tfrac{1}{9} \times 6) + (-\tfrac{1}{9} \times 3)$$
$$= \tfrac{8}{9} \times 7 + (-\tfrac{1}{9}) + 42 = 1.56 \approx 2$$



CHECK YOUR PROGRESS

Q 1: Which of the following filter results in a value as average of pixels in the neighbourhood of filter mask?

a) High pass filter

b) Median filter

c) Lowpass filter

d) All of the mentioned

Q 2: At which of the following scenarios averaging filter is/are used?

a) High pass filter

a) In the reduction of irrelevant details in an image

b) For smoothing of false contours

c) For noise reductions

d) All of the mentioned

Q 3: What is kernel in filtering ?

a) Core of an image

b) Average value of the image

c) A weighted matrix

d) none of the above

Q 4: Convolution is

a) the process of applying the filter in the image

b) adjusting the image for display

c) merging of two images

d) None of the above



7.11 LET US SUM UP

- Filtering is a technique for modifying or enhancing an image.
- Image processing operations implemented with filtering include smoothing, sharpening and edge enhancement.
- The purpose of smoothing in image filtering is to reduce noise and improve the visual quality of the image.
- Filtering is a neighbourhood operation in which the value of any given pixel in the output image is determined by applying some functions on the values of the neighbourhood pixels
- A filter is defined by a kernel.
- A kernel is a small matrix or array which is applied to the pixel and its neighbourhood pixels
- Algorithms available for filtering can be categorized into two groups linear and nonlinear.
- Spatial filtering is an image processing technique for changing the intensities of a pixel according to the intensities of the neighbouring pixels.

- The spatial filtering can be characterized as a “shift-and-multiply” operation: the kernel is shifts over the initial image and multiplies with the pixel and its neighbours
- Linear filtering is a filtering technique in which the value of an output pixel is a linear combination of the values of the pixels in the input pixel’s neighbourhood.
- Convolution is the process of applying the filter in the image.
- A low-pass filter, also called a “blurring” or “smoothing” filter, averages out rapid changes in intensity.
- The simplest low-pass filter just calculates the average of a pixel and all of its eight immediate neighbours.
- Weight average filter is a modification of low pass filter. The basic idea is to give higher weight to the centre of the kernel.
- In the weight average terminology pixels are multiplied bydifferent coefficients, thus giving more importance (weight) to some pixels at theexpense of others.
- The Gaussian Filter is a 2-D convolution operator that is used to ‘blur’ images and remove detail and noise.
- Shape of the kernel of the Gaussian filter is like a bell.
- The basic idea of Gaussian smoothing is to use this 2-D distribution as a ‘point-spread’ function, and this is achieved by convolution.
- The median filter is a nonlinear digital filtering technique, often used to remove noise.
- The new pixel value for median filter is the median of the neighbours.
- The median is more robust than the mean and so a single very unrepresentative pixel in a neighbourhood will not affect the median value significantly.
- The main problem of the median filter is its high computational cost for sorting N pixels.A high pass filter is the basis for most sharpening methods.
- A high pass filter tends to retain the high frequency information within an image while reducing the low frequency information.
- A high-pass filter can be used to make an image appear sharper.



7.12 FURTHER READING

1. Gonzales, R. C., & Woods, R. E. (2008) Digital Image Processing, Prentice Hall.
2. Easton, R. L. (2010). Fundamentals of digital image processing.
3. Annadurai, S. (2007). Fundamentals of digital image processing. Pearson Education India.
4. https://in.mathworks.com



7.13 ANSWERS TO CHECK YOUR PROGRESS

Ans to Q No 1: c. Lowpass Filter

Ans to Q No 2: d. All of the mentioned

Ans to Q No 3: c. A weighted matrix

Ans to Q No 4: a. Convolution is the process of applying the filter in the image



7.14 MODEL QUESTIONS

Q 1: What is Image Filtering? Why do we need to filter image?

Q 2: What is spatial filtering? Explain briefly.

Q 3: What is linear filtering? Explain briefly.

Q 4: What is low pass filtering? Explain with an example.

Q 5: What is weight average filtering? Explain with an example.

Q 6: What is median filtering? Explain with an example.

Q 7: What is high pass filtering? Explain with an example.

Q 8: What is kernel in image filtering? What is the size of a kernel?

Q 9: What is convolution?

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Name of the Paper: Course Code:

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City Office, Housefed Complex, Guwahati- 06

Learner's Feedback on Course

Dear Learner,

Regarding the course as mentioned above, we would like to know your opinions and comments so as to improve the quality of self learning materials in future. Please respond to the following statements by ticking the number you feel most reflect your opinion. After completion of the additional comments, please detach the page and send/mail the same to us at the address given below.

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1. Approximately how many hours did you spend for studying the units in the course? | | | |
2. Please give your opinions (by √ mark) to the following items based on your reading of the block:

Sl. No.	Statements	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I.	The SLMs of the course fulfil the learning objectives set out in the beginning of each unit					
II.	The units of the SLM could satisfy my academic needs and expectations					
III.	The Unit writers have excellent knowledge about the course contents					
IV.	Language and contents of the units were presented at a level which I could readily understand					
V.	Ample opportunity for participation in the activities provided in the units					
VI.	Used enough Illustrations (Diagrams, tables etc.) for conceptual clarity					
VII.	Quality of content is engaging, relevant, and up-to-date					
VIII.	The self check questions are very helpful					
IX.	The Possible/model questions and the answers to check my progress have benefited me a lot					

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1. Which aspects of the SLM, according to you, worked well?

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2. What sort of changes/improvements do you feel KKHSOU could implement to improve the overall quality of the SLM?

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