Department of ECE, GAT

17EC72 – Image Processing

Module-1

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Unit - 1

Introduction to Image processing

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Image:

An image may be defined as 2D function $f(x,y)$ where x and y are known as spatial (plane) coordinates and the amplitude of f at any point of coordinate x,y is called intensity or Gray level or image at that point.

Digital image:

When x,y and f values are finite discrete quantities, then the image is called digital image.

A digital image consist of finite number of elements each of which has particular location x,y and the value of f, these elements are referred to as Pixel or Picture element or image element or pels.

Fundamental steps in image processing.

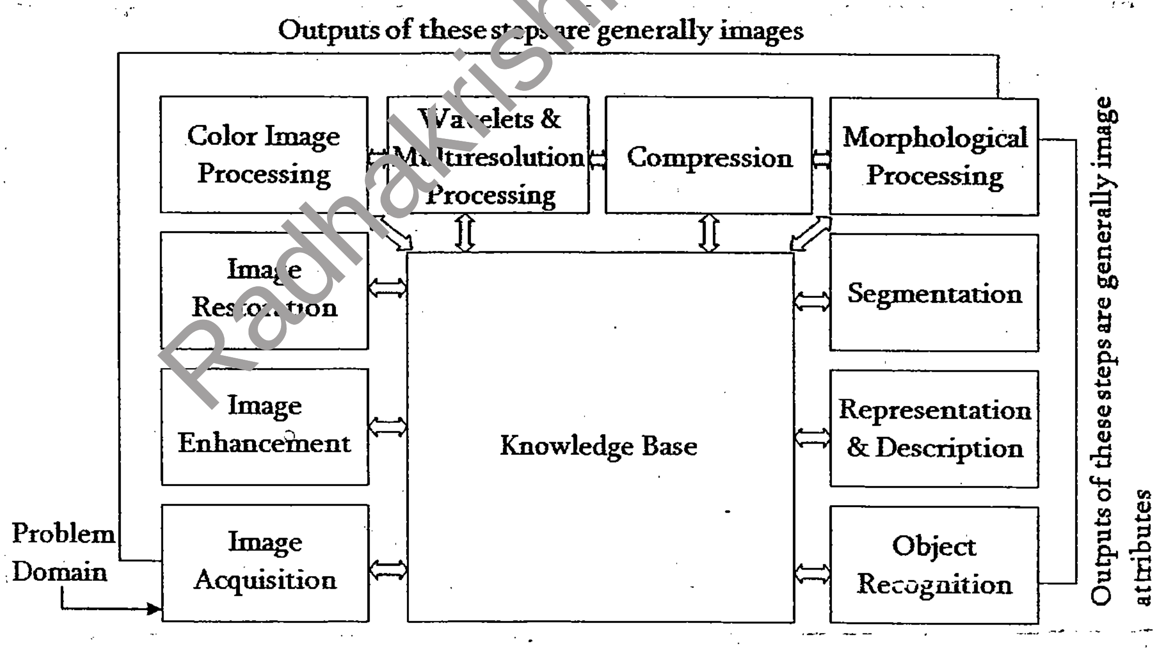


fig: Fundamental steps in image processing

The fundamental steps in Digital image processing is shown in above figure.

Problem domain (Problem definition)

This step involves defining the type of processing to be done on input image.

Image acquisition

It is the first process which involves preprocessin (scaling) i.e capturing image and storing them.

Digital camera captures image directly and stores in its memory. The sensor used in digital camera can be single sensor or line of sensor.

Image Enhancement

It is a process of manipulating image so that the result is more suitable (clear) than the original image for specific application.

The goal of image enhancement is to hightlight certain image features i.e Enhancement alters an image to make it clear to the observer.

Image enhancement can be done in 2 domains

1) Spatial domain :- Manipulations are done directly on image pixels.

2) Frequency domain :- Manipulations are done on fourier transform of an image.

Image Restoration

It is an objective technique, based on Mathematical Model.

Image restorations deals with removal or minimization of known degradations in an image.

Degradation can occur due to noise or blurring. Blurring can happen because of shaking a camera while capturing an image, or by using out of focus

Restoration can be done both in spatial and frequency domain.

Colour image processing

It is a very important field in digital image processing. It is helpful in highlighting a perticular feature in an image.

Wavelets and multiresolution processing

Using wavelets, images can be represented in various degrees of resolution & using wavelet image can be subdivided into smaller region.

Compression

It is a technique used to reduce the storage required to save an image.

By using compression technique, it is possible to communicate and access digital data at very high speed.

JPEG (Joint photographic expert group) is a very popular image compression technique.

Morphological processing

It deals with the tools for extracting image components that are useful in represention and description of shape, such as boundaries, skeletal part (integral part) etc.

Segmentation

Segmentation is related to partitioning of an image into its constituent parts (Meaningful part) Meaningful part may be complete object or a part of it.

i.e Edge detection, boundary extraction etc

Representation and description

Representation and description stage follows segmentation. Boundary representation is suitable when the focus is on external shape. Regional representation is useful when the internal properties such as skeletal or texture is to be used.

Description is also called feature selection deals with extracting attributes that result in some quantitative information to identify objects.

Recognition

Recognition is a process that assigns a label to an object based on its description.

Knowledge base

A knowledge base is a special kind of data base for knowledge management. Knowledge data base gives knowledge about problem domain in image processing system.

Ex: In case of industrial inspection process, knowledge base may be detailed list of all possible major defects in a material.

It also guides the operation of each processing module & controls the interaction between modules.

Components of the image processing

Components of image processing system is shown in below fig.

Image sensors

Image sensor is a physical device that is sensitive to the energy radiated by the object that we wish to image.

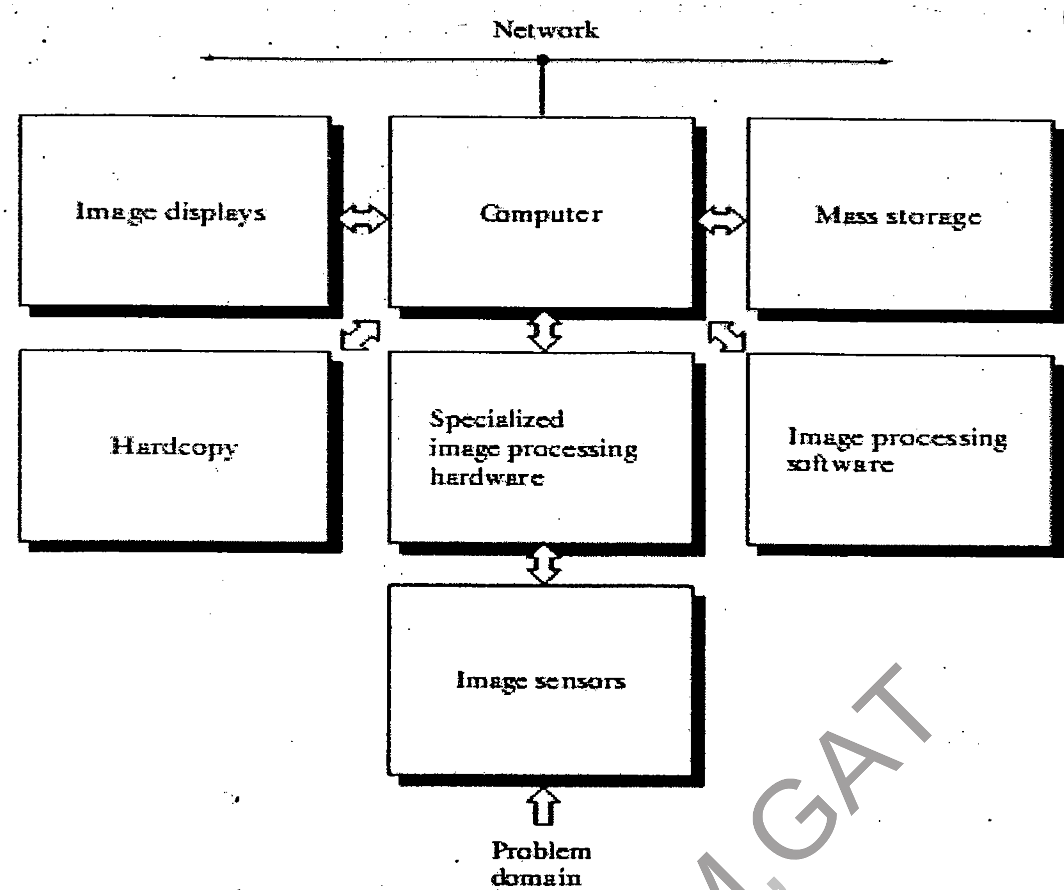


fig:- Components of image processing system

The device used as image sensor may vary from simple camera to multi spectral scanners. i.e The sensors can be a single sensor or Line of sensors array of sensors depending on object/scene to be imaged. In digital video camera, the sensors produce an electrical output proportional to light insensity. example CCD (charge coupled device), Photodiodes etc.

Digitizer is a part of image sensor in digital camera, which will convert output of physical sensing device into digital form.

Specialized image processing hardware

It consist of digitizer and hardware to perform some operations (ALU) i.e Arithmetic & logical operations at a very high speed (real time).

Ex:- After image acquisition images are digitized and averaged for noise reduction, by specialized image processing hardware.

Computer

The computer used for image processing system can range from a personal computer to a super computer. special systems are designed to perform some specific application.

Image processing software

It consist of spealized modules to perform specific task i.e enhancement, edge detection, corner detection, boundary or region extraction etc

Software packages have pre written functions to perform image processing tasks and they also allow users to add codes for other tasks.

Mass storage

Huge mass storage facility is a must for image processing application. one image may require a space upto 1 megabyte. When dealing with thousands of such images large storage devices are needed. Digital storage space can be broadly classified into 3 categories.

i) Short term storage :- To be used during processin
ii) On-line storage :- For fast retrieval
iii) Archival (mass storage) :- For slow access

Image display

It is a part of computer system. It produ visual form of numerical values stored in the computer. TV monitors & CRT's are mainly usec as display devices.

Handcopy

Hand copies are printers ranging from line printers, dot matrix printer to laser printers.

Networking

Lot of information and images need to be shared between different people. As large amount of data is associated with image processing applications, — transmission bandwidth is the key consideration.

Structure of human eye

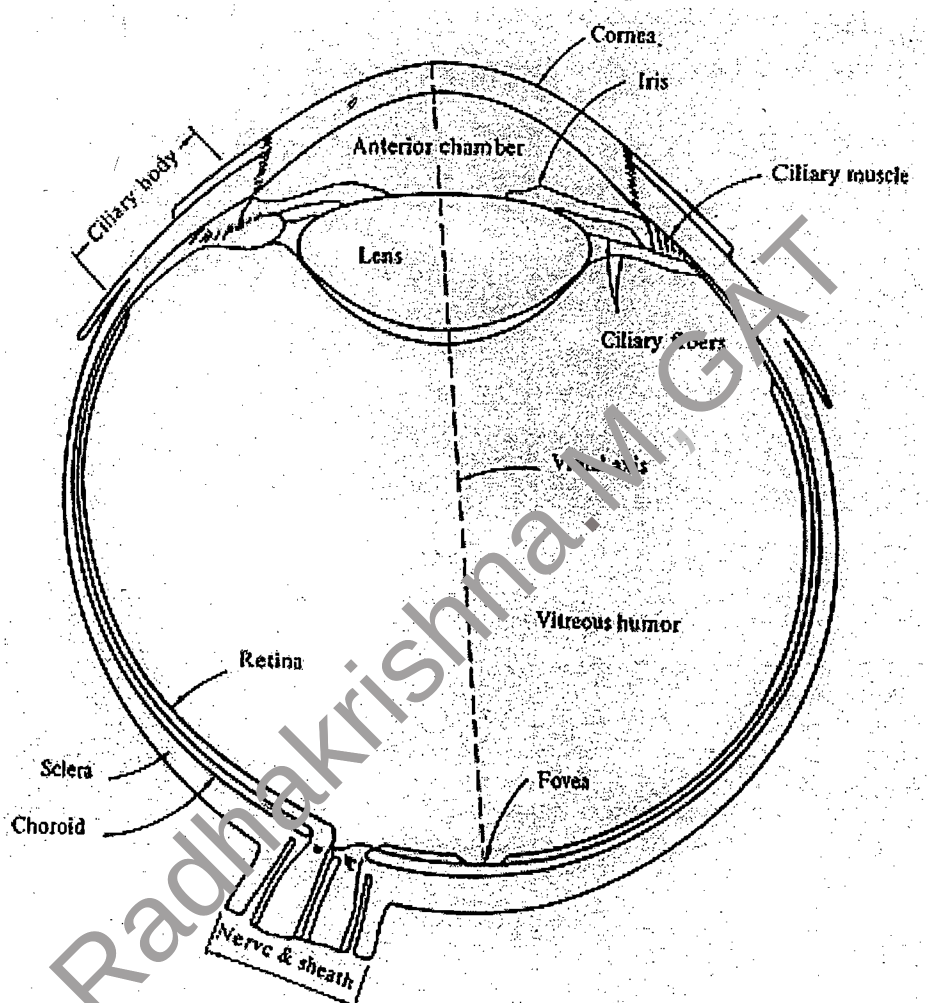


fig: Simplified diagram of a cross section of human eye

The eye is nearly a sphere with an average diameter of approximately 20mm.

Three membranes enclose the eye as shown in fig

1. Cornea
2. Choroid
3. Retina.

When the light rays hit the eye, it first passes through cornea, then iris (lens) & finally reaches retina.

Cornea

Cornea is a tough transparent tissue that cove the anterior surface of the eye. The outermost sclera is 1mm thick & Merges into transparent cornea

Choroid

The choroid directly lies below the sclera with a network of blood vessels. Any small damage to Choroid leads to eye damage

The choroid is divided into cilliary body & iris The iris contracts & expands to control the amount of light that enters the eye. The front of the iris contains visible pigment of the eye, where as the bac contains black pigment.

Lens is made up of concentric layers of fibrous cells & is suspended by cilliary fibers. Lens is coloured by yellow pigmentation & it increase as age increases. Lens contains 60 to 70% of wate about 6% of fat and more protein than any other tissue in the eye. Lens absorbs approximately 8% of visible light spectrum. The shape of the lens is controlled by tension in fibers of cilliary body.

Retina

Retina is the innermost membrane of the eye In the retina, light rays are detected and converte to electrical signal by photo receptors. Eye has 2 types of photoreceptors called as cones & Rods

Cones in each eye is between 6 to 7 million. cones are located in central portion of retina called fovea. & are highly sensitive to colour. Under bright sunlight cones are most activ hence cones vision are called as photopic or bright light vision or Day vision.

Rods are about 75 to 150 million and are distributed over the retinal surface. Rods are sensitive to light. Fovea is the area of Retina where there are no Rods. At night or under dark condition (When light source is absent), only rods are active. Rods are not involved in colour vision, & are sensitive to low levels of illumination. Rod vision is called scotophic or night vision or dim light vision.

Fine details can be seen with cones because each cone is connected to its own nerve end. Rods give a general overall ~~view~~ picture of the field of view as several rods are connected to a single nerve end.

No photoreceptors (cones & Rods) are found at a point where optic nerve attches to the eye called blind spot.

Distribution of rods and cones in Retina

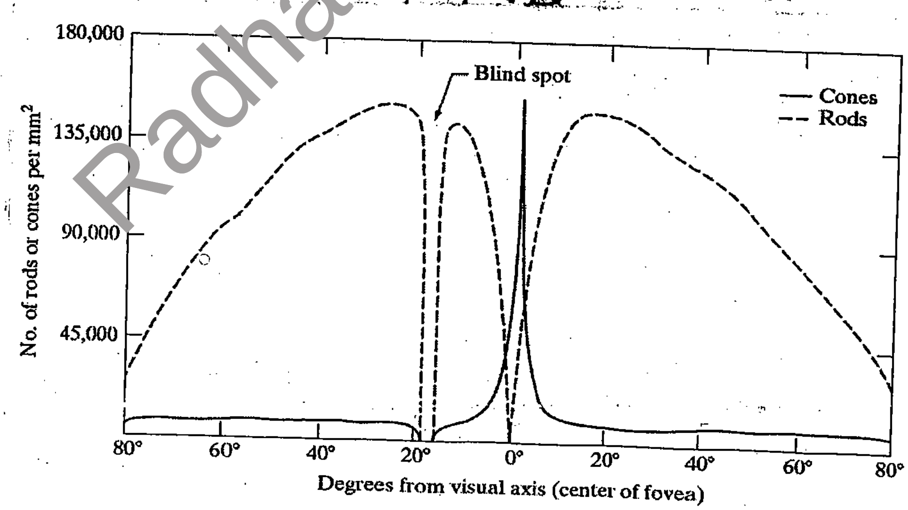


fig: Distribution of Rods and cones in Retina

No photoreceptors (cones & Rods) are found at point where optic nerve attches to eye called blind

Receptors density is measured in degrees from fovea. As shown in fig, cones are more dense in the center of the retina (fovea) & distributed lightly in the remaining part of eye. Rods are distributed equally over the surface of eye.

Image formation in the eye

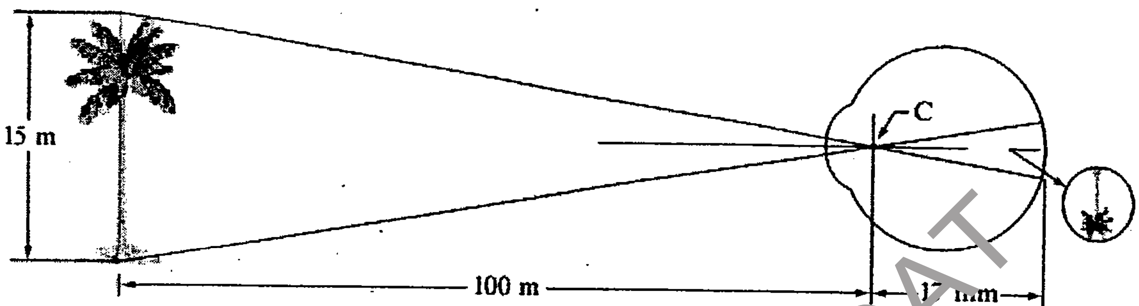


fig: Graphical representation of eye looking at a tree. Point C is the optic center of the lens.

The lens of the eye is flexible. The shape of the lens is controlled by tension in the fibers of cilliary body. To focus the distant object lens will become relatively flat & to focus the object near to eye, the lens become thicker.

The distance between center of the lens & retina, which is called as focal length varies from approximately 17mm to 14mm

For far objects (distance > 3m), lens uses its lower Refractive power. For near objects lens ~~is~~ strongly refractive.

To find the height (h) of an object formed in retina, which is placed 100m from eye and actual size of ~~eye~~ object being 15m, simple calculation can be used

$$\frac{15}{100} = \frac{h}{17} \rightarrow \boxed{h = 2.55mm}$$

Brightness adaptation and Discrimination

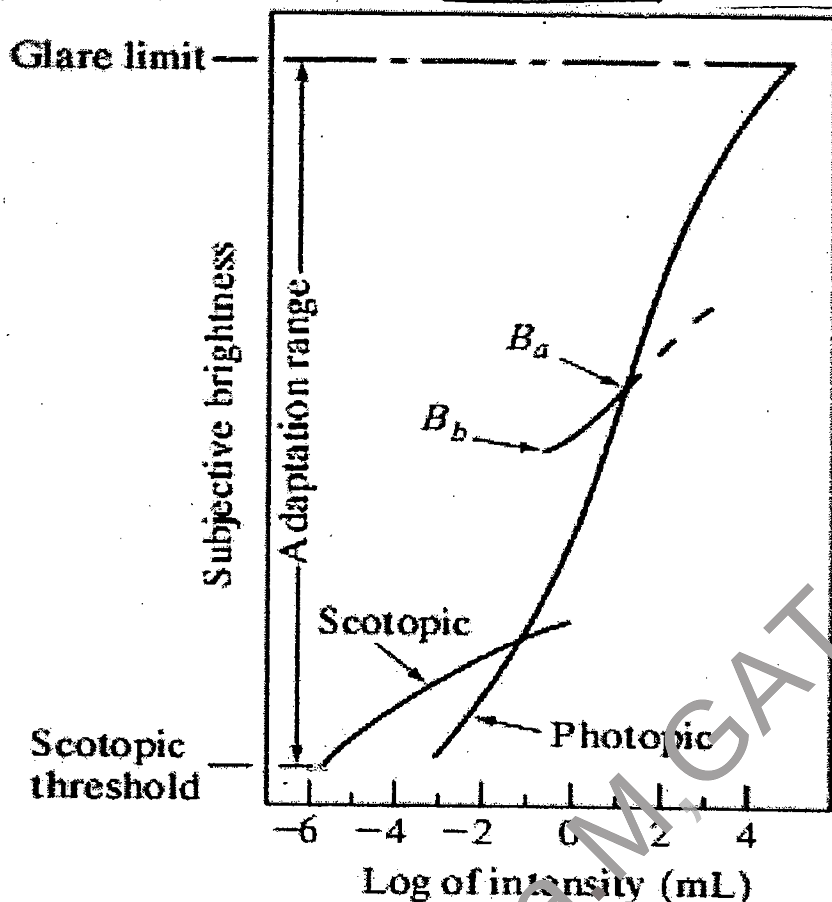


fig: Log of intensity verses subjective brightness shown for a particular adaptation level

The eye's abdility to discriminate between different intensity levels in an image is an importent consideration in presenting image processing results.

Subjective brightness (intensity as perceived by human visual system) is a logarithmic function of the light intensity incident on eye.

In the above fig solid curve represents the range of intensities to which visual system can adapt. The visual system cannot operate over such a range simultaneously. Brightness adaptation is basically getting used to changes in brightness or changes in the intensity of light.

The total range of distinct intensity levels it can discriminate simultaneously is small. The short intersecting curve represents range of subjective brightness that the eye can perceive when adapted to level Ba. This range is restricted having a level Bb at the below, where it is completly black

The upper portion ...

Brightness discrimination

Consider a flat, uniformly illuminated area. The flat area is opaque glass that is illuminated from behind by a light source whose intensity I can be varied as shown in below figure.

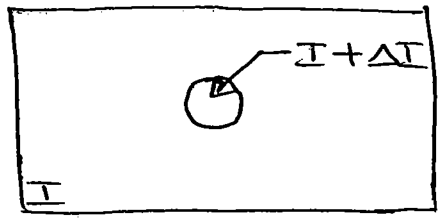


fig: Basic experimental setup used to charecterize brightness discrimination

A new light source is made to fall on an opaque glass. This light source added an increment of illumination (ΔI) in the form of short duration flash that appears as circle in the centre of uniformly illuminated field. As ΔI becomes stronger changes in the intensity levels can be observed. The quantity $\Delta I / I$ is called weber ratio.

A small value of $\Delta I / I$ means that a small % change in intensity is discriminable

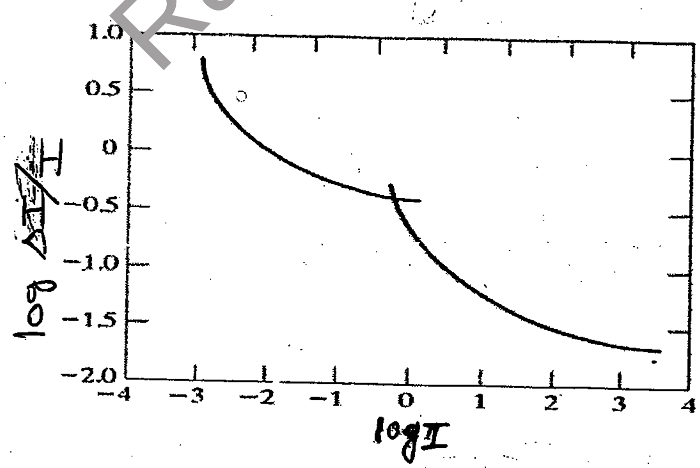


FIGURE Typical Weber ratio as a function of intensity.

Above figure is a plot of $\Delta I / I$ versus log I. It is seen that brightness descrimination is poor at low levels of illumination. The low levels of illumination

Two phenomena demonstrate that perceived brightness is not a simple function of intensity

1) Mach bands
2) simultaneous contrast

Mach bands

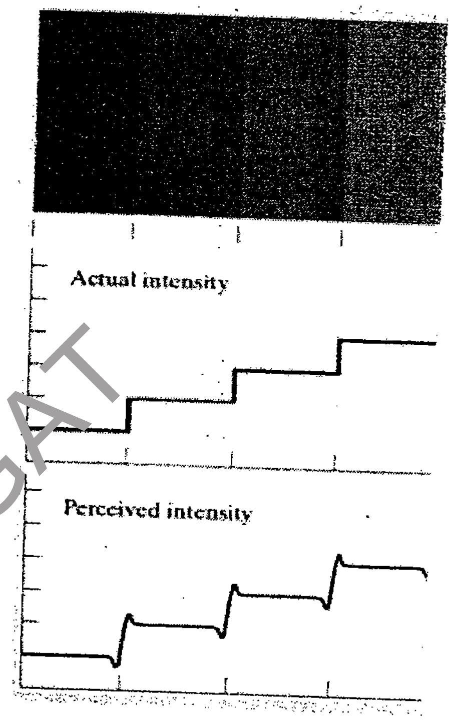
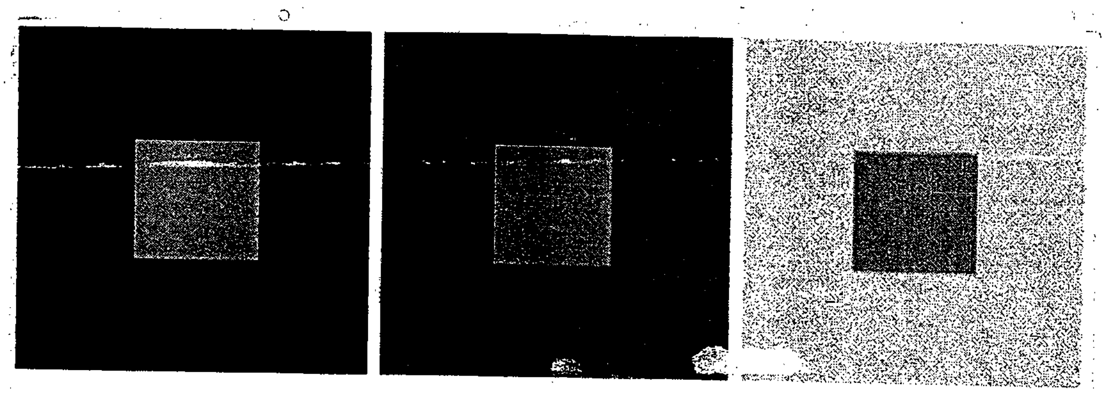


fig: Mach band

Each bar is uniformly Grey, but human visual system perceive luminance change differently. overshoots & undershoots appears in the brightness graph. Bright side of contrast jump appears extra light & dark side appears extra dark. Because of Mach band effect human visual system sharpens the edges of the objects.

Simultaneous Contrast

Perceived brightness does not depend simply on intensity but also on its background. As shown in below fig, the center square is of equal brightness in all the images, but first one appears more lighter compared to other two.



a b c

FIGURE. Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes

Examples of simultaneous contrast (optical illusions)

In optical illusions eyes fills in non existing information as shown in below fig.

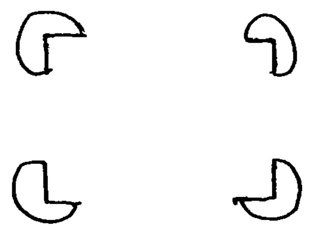


fig (a)

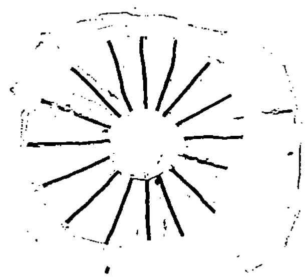


fig (b)

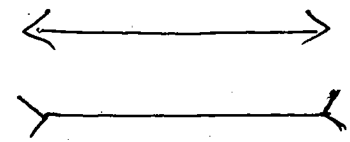


fig (c)

In fig (a) square seems to be existing between the circles, but there is no outlining of the square.
In fig (b) circle seems to be existing in the center of the lines.
In fig (c) two horizontal lines are of same length but one seems to be shorter than the other.

Applications of Image processing

1) Medicine

CT scan, X-ray imaging, ultrasound scanning, Magnetic resonance imaging (MRI) are used in Medical imaging. Filtering, segmentation and pattern recognition techniques are used for identifying various abnormalities, in human body.

2) Industrial Automation (Machine vision)

Automative inspection system, non destructive testing, process control etc are some of industrial Automation examples.

Missing component in PCB, bottle not filled to accurate level are some of the examples of quality control.

3. Remote sensing

* Natural resource mapping like forest, ground water, mineral etc
* Estimation related to agriculture, pollution control, Pollution pattern study, Monitoring traffic and airfields etc are some of the application of image processing in remote sensing.

4. office automation

optical character recognition, to check answer scripts for multiple answer questions, document processing logo recognition etc.

5. Criminology

Finger print recognition, face registration & matching, iris recognition helps to find criminals.

6. security

Face recognition, weapon detection, vehicle tracking are used for surveillance and monitoring.

7. consumer domain

Video editing, Multimedia, image and video compressing algorithm are some of the application of image processing in consumer domain.

8. Astronomy and space application

Capturing and analyzing images of mars and moon etc

9. Automatives

Automatic cruise control, vehicle tracking using GIS and GPS, Google maps are some of the applicati used by Automative industry.

10. Military application

Missile guidance & detection, automatic target identification, are some of the IP algorithms used in

Energy sources and its application

1) Infrared band

Range = (0.76 — 2.35 μm)

Application → Remote sensing & true colour photography

2) Ultraviolet band

Range = (100 — 10 nm)

Application → Biological imaging

3) X-Ray

Range = (0.01 — 10 nm)

Application = Angiography, Astronomy etc

4) Gamma Ray

Range = (Less than 0.02 nm)

Application = Nuclear medicine & Astronomical observation

5) Microwave band

Range = (0.3 G — 300 GHz)

Application = RADAR, Remote sensing

6) Radio band

Range = (1 — 100 MHz)

Application = MRI & Astronomy

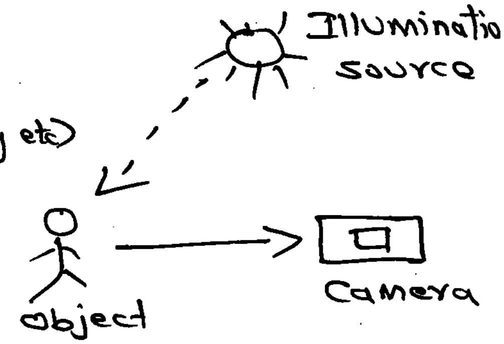
7) Ultra sound imaging

Range = (1 — 5 MHz)

Application = visualize fetus, thyroid glands, liver, kidney stones, SONAR etc.

Image sensing and Acquisition

Object to be imaged is illuminated by a a light source and the reflected energy is imaged by a camera.



Illumination source emits electromagnetic energy (visible, infrared, x-Ray etc) on the object. The energy is reflected (Plane surface) or transmitted (x ray to human body) through the object. The energy gets converted into electrical signal by image sensors

Depending on kind of ~~image~~ to be imaged, scanning mechanism can be of three types as shown in below fig.

1) using single sensor
2) using sensor strip
3) using sensor array

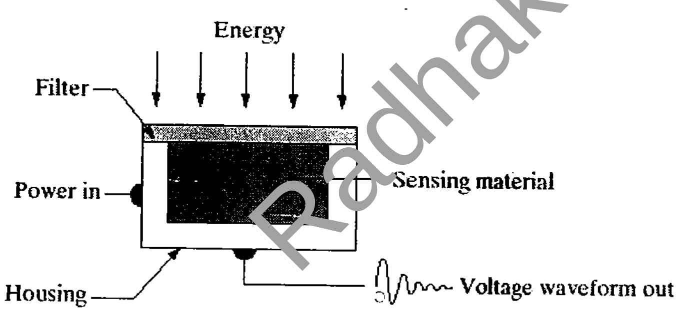


fig ⓐ :- single image sensor

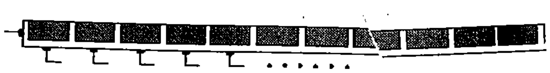


fig ⓑ :- Line sensor

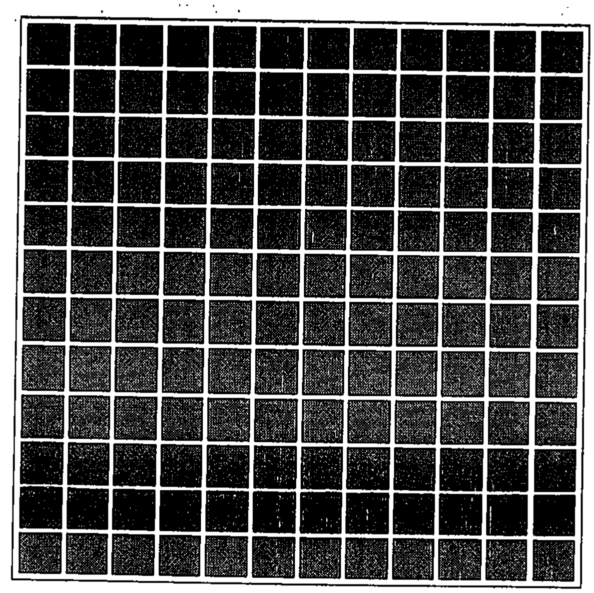


fig ⓒ :- Array sensor

* In fig (a) incoming energy is transformed into Voltage by the combination of input electrical power (power in) and sensing material.

Photodiode is the most familiar form of sensor which is constructed using silicon material whose output waveform is directly proportional to light.

The use of filter in front of sensor improves selectivity.

* In fig (b), A strip of sensors consisting of more than one sensor are used for image acquisition. Around 4000 sensors are used in these strips which generate one line of image at a time.

* In fig (c), n number of line sensors are arranged in the form of array, where it will scan n number of lines at a time. The sensor array size can be 4000 X 4000 or more.

Image Acquisition using single sensor

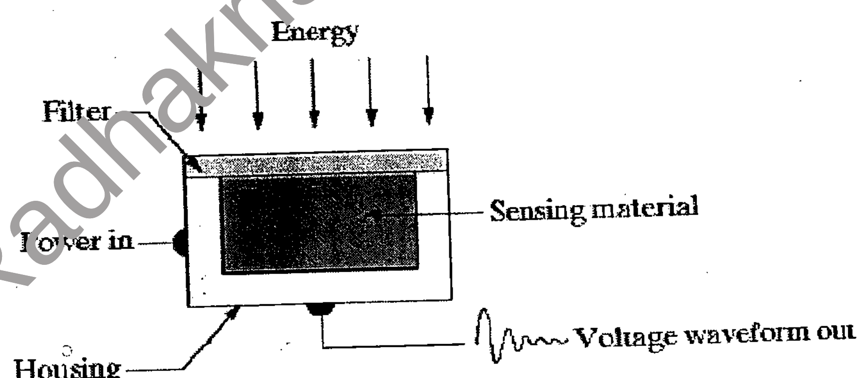


fig (a): single imaging sensor

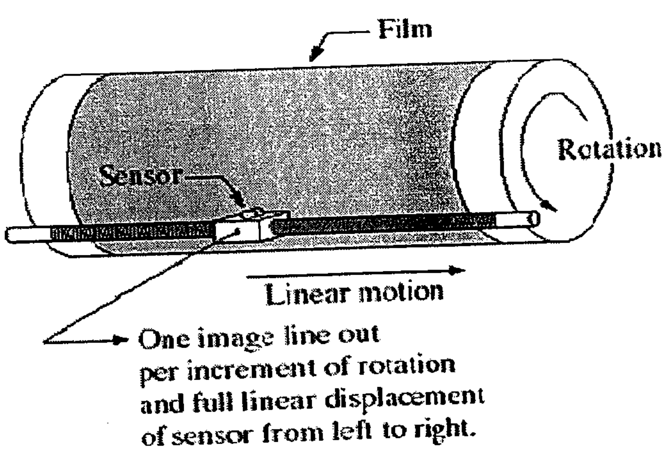


fig b:- single sensor with motion to generate a 2D image

In order to generate a 2D image using a single sensor, there has to be relative displacement in both x and y directions between the sensors and area to be imaged.

fig ⓐ shows single imaging sensor, photo diode is the most familiar form of sensor which is ~~construc~~ constructed using silicon material, whose output waveform is directly proportional to light. The use of filter in front of sensor improves <u>selectivity</u>

Ex: A Green filter in front of light sensor favours the light in the green band of colour spectrum.

In fig ⓑ a film negative is mounted on a drum, whose mechanical rotation provides displacement in vertical direction.

A single sensor is mounted on lead screw that provides a motion ⊥r to direction. In this way 2D image can be acquired using a single sensor.

This type of mechanical digitizer is called a <u>Microdensitometer</u>.

* A Mechanical motion should be controlled with high precision.
* This method is inexpensive and speed of operation is low.

<u>Image Acquisition using line sensor</u> [sensor strip]

Two types of line sensors are

1) Linear sensor strip
2) circular sensor strip

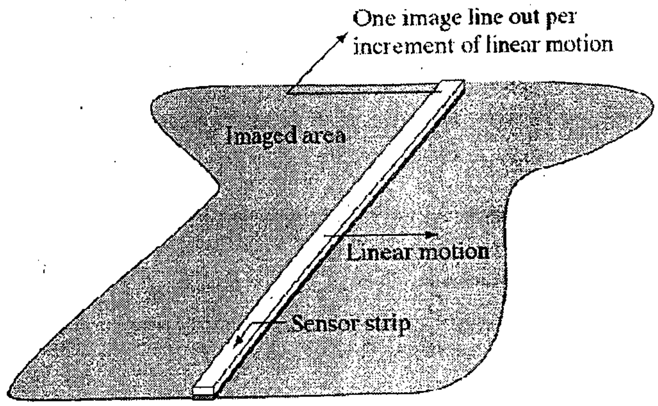


fig ⓐ :- Image Acquisition using a linear sensor strip

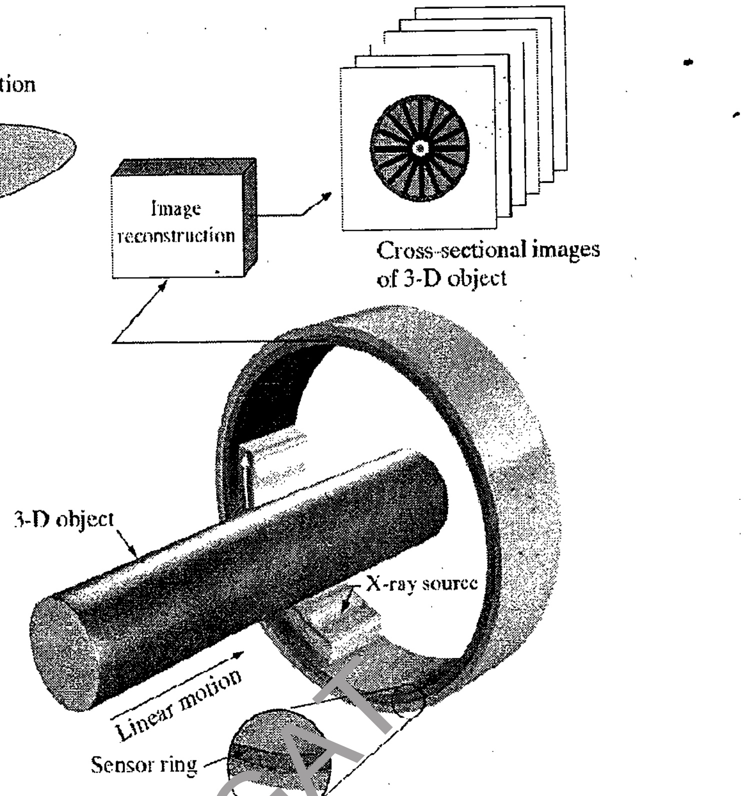


fig b :- Image Acquisition using circular sensor strip

In fig (a), a number of single sensors are arranged linearly to form a sensor strip. Around 4000 sensors are used in these strip which generate one line of image at a time. A strip provides imaging element in one direction. Motion perpendicular to strip provides imaging in the other direction. This type of imaging sensing is used in airborne application

Sensor alignment shown in fig (b) is used in Medical and industrial application to obtain cross sectional images of a 3D object. A rotating X-Ray source provides illumination and portion of the sensor opposite the source collect the X-Ray energy that pass through the object. The output of the sensors must be processed by reconstruction algorithm whose objective is to transform the sensed data into meaningful cross sectional images. The cross sectional image of 3D object consist of stack images where these images are generated as the object is moved in a direction $\perp^r$ to the sensor ring.

ex: MRI scanning.

Image Acquisition using sensor array

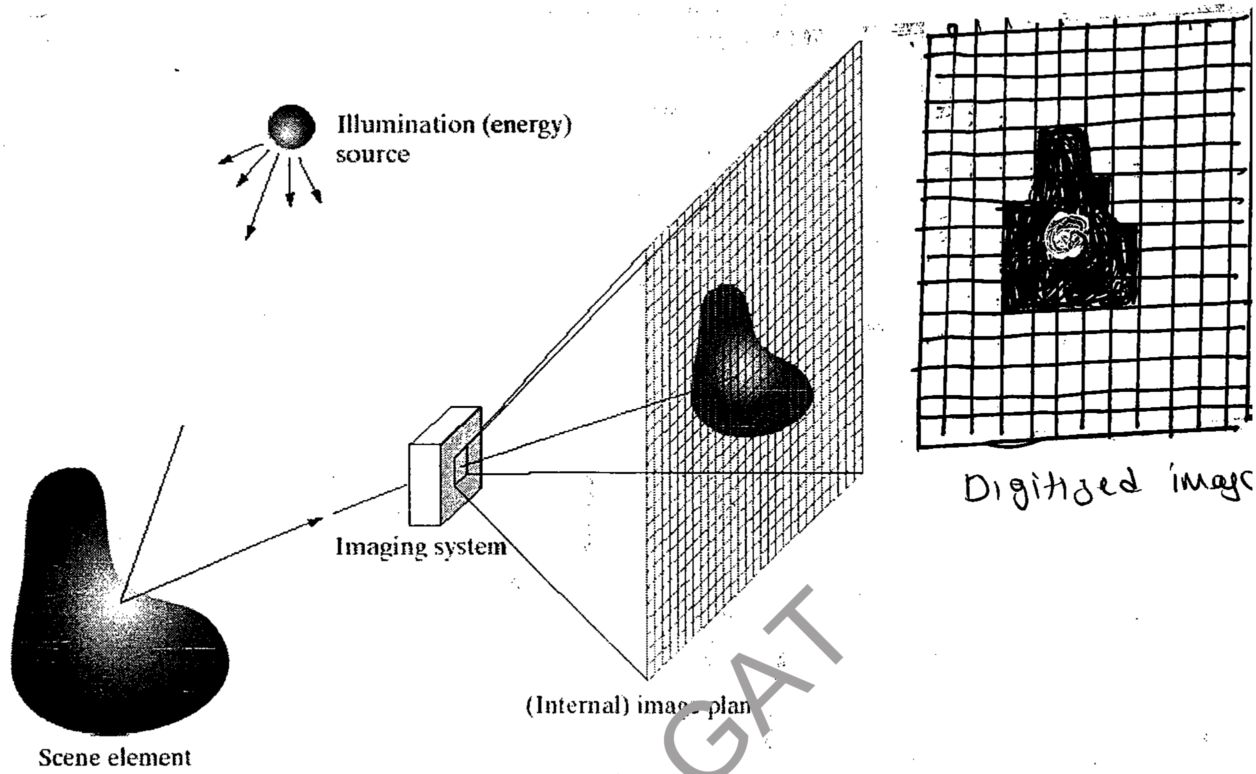


fig:- Digital image Acquisition process

Image acquisition using sensor array consist of energy source, scene element, imaging system, projection of the scene onto a image plane and digitized image. This type of image acquisition is used in digital camera.

The sensor array size can be 4000 × 4000 or more. A 2D complete image can be obtained without any moment of array sensor.

Most of the camera generates analog image and digitizer is required to get a digital image.

The energy from illumination source is either reflect or transmit through the scene element. The imaging system which consist of sensor array collect the incoming energy and focus it on image plane.

The sensor array which is coincident with a focal plane produces output proportional to the light received at each sensor. Digital and analog circuit are used to convert output into video signal, which is

A simple image formation model

An image can be represented by 2D function $f(x,y)$ where x and y are spatial co-ordinates and f is the amplitude or intensity level or grey level of an image.

Practically an image $f(x,y)$ must be non-zero and finite quantity i.e

$$0 < f(x,y) < \infty$$

The function $f(x,y)$ is characterized by 2 factors

(i) The amount of source illumination incident on scene element (object) being imaged. Let us represent it by $I(x,y)$

(ii) The amount of illumination reflected or absorbed by the object in the scence. Let us represent it by $r(x,y)$

$\therefore$ The $f(x,y)$ can be represented by

$$f(x,y) = I(x,y) \cdot r(x,y)$$

where $0 < I(x,y) < \infty$

It means illumination is non non zero and finite quantity and its quality depends upon — illumination source.

$$0 \leq r(x,y) \leq 1$$

Here 0 means no reflection & Total absorption

1 means no absorption & Total reflection

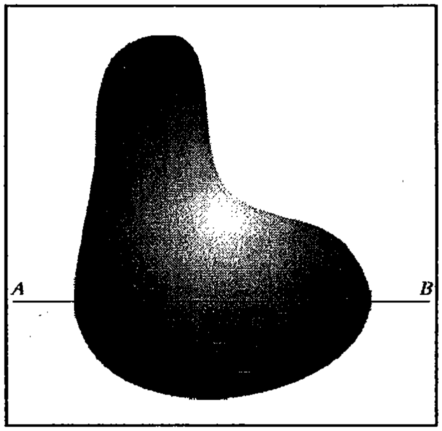
→ The quantity of absorption or reflection depends upon the characteristics of imaged object.

Monochrome image $L = f(x,y)$

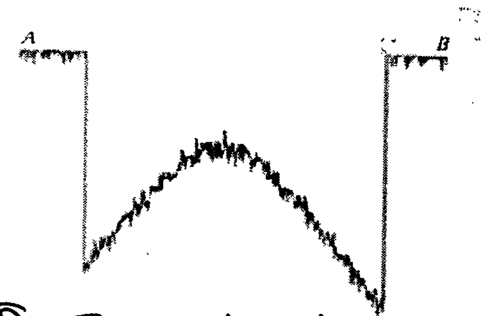
$L_{min} \leq L \leq L_{max}$ Where $L_{min} = I_{min} \times r_{min}$

$L_{max} = I_{max} \times r_{max}$

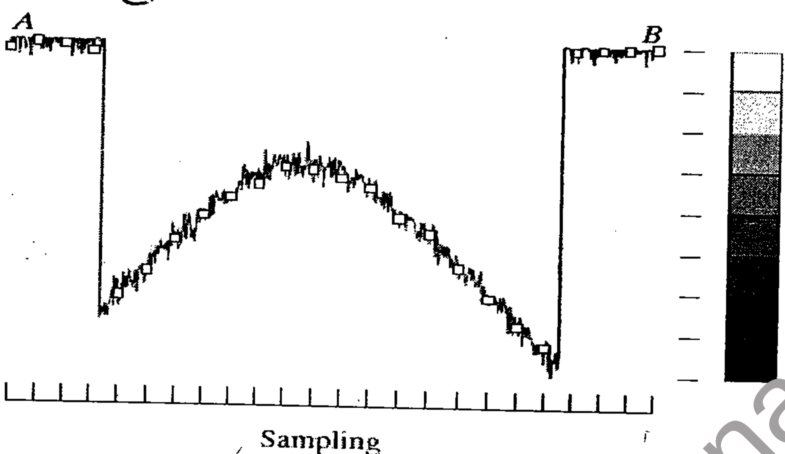
Sampling and quantization



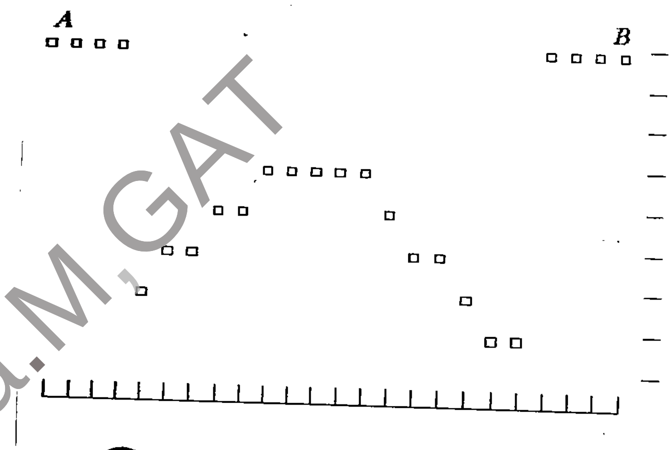
ⓐ Continuous image



ⓑ Scan line from A to B



ⓒ Sampling & quantization



ⓓ Digital scan line

fig: Generating a digital image

To create a digital ~~form~~ we need to convert continuous sensed data into digital form

This involves 2 processes

1) Sampling
2) quantizatation

Fig ⓐ shows continuous image f(x,y). This image should be converted into digital form. An image may be continuous w.r.t x and y coordinate and also in amplitude.

To convert it into digital form, we have to sample the function in both coordinates and amplitude.

Digitizing the co-ordinate values is called sampling
Digitizing the amplitude value is called quantization

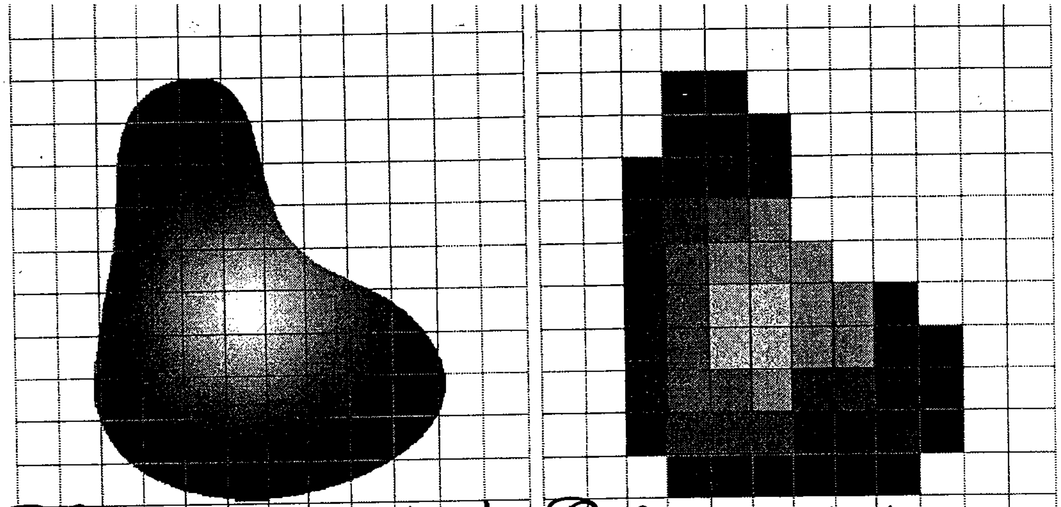
The one dimentional function shown in fig (b) is a plot of amplitude values of the continuous image along the line segment AB as in fig (a). The random variation is due to image noise.

To sample this function, we take equally spaced samples along the line AB. The location of each sample is given by vertical tick mark in the bottom of fig (c). The set of these discrete locations gives the sampled function. The samples are shown as small squares superimposed on the function.

In order to form a digital function the gray level values of these samples must be converted (quantized) into discrete quantities. The gray scale is divided into 8 levels ranging from black to white. The right side of fig (c) shows this quantization levels. The vertical tick mark indicate the specific value assigned to each of the sample from 8 grey levels.

Now the continuous grey levels are quantized simply by assigning one of the 8 discrete grey levels to each sample as shown in fig (d).

Starting at the top of the image and carrying out this procedure line by line produces a 2D digital image as shown in below fig. The quality of digital image is determined by the number of samples and discrete gray levels used in sampling and quantization.



(a) Image projected onto a sensor array (b) Result of image sampling & quantization

The Method of sampling is determined by the sensor arrangement used to generate the image.

<u>Using single sensor element</u> → sensor is made to move on a image parts one after the other and output of the sensor is quantized in a manner described above.

<u>Using line sensor</u> → The number of sensors in strip establishes sampling in only one image direction. Line sensors are moved on image line by line to scan complete image.

<u>Using sensor array</u> → sensor array scans the complete image (n lines) at once. There is no movement of sensors and number of sensors in in the array establishes sampling in both direction

Representation of digital image

The result of sampling and quantization is a matrix of real numbers. Assume that an image $f(x,y)$ is sampled so that the resulting digital image has m rows and n column's. The values of the coordinates (x,y) is a discrete quantity.

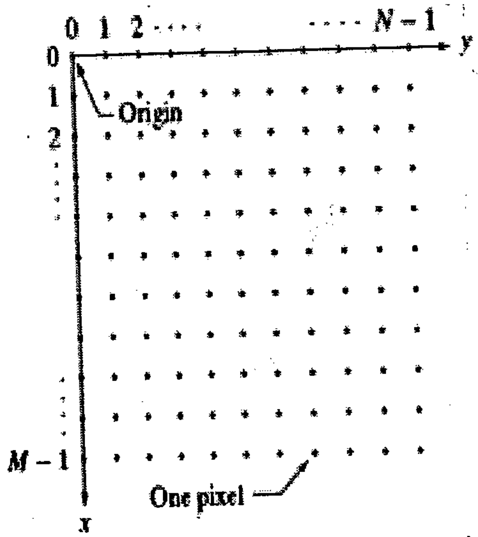


fig: Representation of Digital image.

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

fig: M×N digital image

Each element of this matrix array is called an image element or pixel. All these are totally positive and cannot be Negative. The amplitude of f (gray level) has been digitized in the range [0, L−1]. This range is called dynamic range of an image. The number of Gray levels is typically an integer power of 2

i.e $L = 2^K$ where L = Grey level
K = no of bits

Ex: If an image has 256 ~~values~~ gray levels then it is an 8 bit image

i.e $L = 2^K$

$256 = 2^8$

$\boxed{K = 8}$

Discrete levels are equally spaced & they are integers in the interval [0, L−1]

The number of bits (b) required to store a digital image is

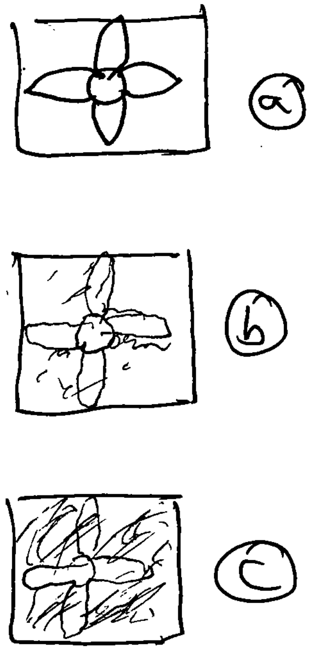
$$\boxed{b = M \times N \times K}$$

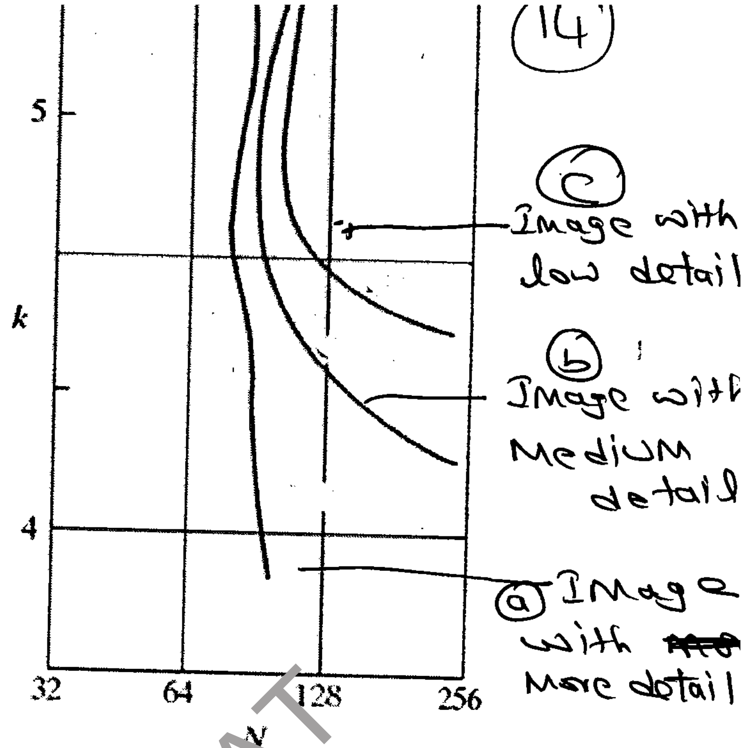
M − rows
N − columns
K = bits in each pixel.

When Rows = columns (M = N)

$$\boxed{b = N^2 K}$$

Isopreference curve





Isopreference curve are drawn in the N, K plane as shown in above fig. Each point in N, K plane represents an image having values of N and k equal to co-ordinates of that point.

Point lying on Isopreferece curve corresponds to image of equal subjective quality.

The Isopreference curve tend to become more vertical as the detail in the image increases.

As shown in above fig fig (a) with more clear, isopreference curve is almost vertical. In fig (b) & (c) image is not much clear due to less no of gray levels.

Zooming and shrinking of digital image

Zooming can be viewed as oversampling and shrinking can be viewed as undersampling.

Zooming

Zooming requires 2 steps

1. Creation of new pixel locations
2. Assigning the gray levels to these new locations.

Three methods for gray level assignments are

1. Nearest neighbor interpolation.
2. Pixel replication.
3. Bilinear interpolation.

Nearest neighbor interpolation

Suppose we have an image of 500×500 pixels and we want to enlarge it 1.5 times i.e 750×750 pixels, then an imaginary 750×750 grid are placed over the original image. Spacing in the grid would be less than one pixel. Closest pixel's gray level is assigned to the new pixels. Expand it to original specified size to obtain the zoomed image.

$$\begin{bmatrix} 1 & 3 & 5 \\ 4 & 6 & 8 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 3 & 0 & 5 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 6 & 0 & 8 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ 0.5 & 1 & 1.5 & 2 & 2.5 & 3 \\ 4 & 5 & 6 & 7 & 8 & 4 \\ 2 & 2.5 & 3 & 3.5 & 4 & 4.5 \end{bmatrix}$$

Pixel Replication

Pixel replication is applicable to increase the size of an image an integer number of times. For ex to double the size of the image, we can duplicate both column and each row.

$$\begin{bmatrix} 1 & 3 & 5 \\ 4 & 6 & 8 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 3 & 0 & 5 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 6 & 0 & 8 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 3 & 3 & 5 & 5 \\ 1 & 1 & 3 & 3 & 5 & 5 \\ 4 & 4 & 6 & 6 & 8 & 8 \\ 4 & 4 & 6 & 6 & 8 & 8 \end{bmatrix}$$

Bilinear interpolation

This uses 4 nearest neighbours of a point to assign a gray level.

$$\begin{bmatrix} 1 & 3 & 5 \\ 4 & 6 & 8 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 3 & 0 & 5 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 6 & 0 & 8 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 2 & 3 & 4 & 5 & 2.5 \\ 2.5 & 3.5 & 4.5 & 5.5 & 6.5 & 3.25 \\ 4 & 5 & 6 & 7 & 8 & 4 \\ 2 & 2.5 & 3 & 3.5 & 4 & 2 \end{bmatrix}$$

Newly created pixel value is calculated by taking average of neighbouring pixels. For the last row and column, other pixel is assumed to be zero.

— Shrinking → Refer Page 26

Relationship between pixels

To extract boundary or region of image, to draw the boundary in an image, we need to join connected pixels. Thus we need to find the relationship between pixels. Various Relationship between pixels are

1) Neighbours
2) Adjacency
3) Path
4) Connectivity
5) Region
6) Boundary
7) Distance.

① Neighbours

In any image $f(x,y)$. Let us consider a pixel p at co-ordinates (x,y)

$y \downarrow$

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

fig: co-ordinate convention used for digital image

This pixel can have 3 types of neighbours

1) 4 Neighbours ($N_4(P)$)
2) 8 Neighbours ($N_8(P)$)
3) Diognal Neighbours ($N_D(P)$)

4 Neighbours

	$x, y-1$	
$x-1, y$	P	$x+1, y$
	$x, y+1$	

The pixel p has 2 horizontal and 2 vertical neighbours as $(x, y-1)$, $(x-1, y)$, $(x, y+1)$, $(x+1, y)$. $N_4(P)$ denotes set of 4 neighbours, each having a distance of 1 pixel from point p.

D Neighbours ($N_D(P)$)

$x-1, y-1$		$x+1, y-1$
	P	
$x-1, y+1$		$x+1, y+1$

Pixel p has diaganal neighbours as shown in fig with co-coordinates $(x-1, y-1)$, $(x-1, y+1)$, $(x+1, y-1)$, $(x+1, y+1)$. $N_D(P)$ denotes set of 4 diagonal neighbours of pixel P. Each of these neighbours having a

8 Neighbours

$N_4(P)$ and $N_D(P)$ together is called $N_8(P)$

$$N_8(P) = N_4(P) \cup N_D(P)$$

x-1, y-1	x, y-1	x+1, y-1
x-1, y	P	x+1, y
x-1, y+1	x, y+1	x+1, y+1

$N_8(P)$ denotes set of 8 surrounding neighbours of pixel p with 1 pixel distance from p.

(2) Adjacency

Image boundary and regions are defined by set of connected pixels.

To determine 2 pixels are adjacent there are 2 conditions

* 2 pixels should be neighbours.
* Their grey level should be same.

Based on neighbours of pixel, 3 types of adjacency are defined.

i) 4 adjacency

ii) 8 adjacency

iii) Mixed adjacency (M adjacency)

4 Adjacency

2 Pixels p and q with values from V are 4 adjacent if q is in set $N_4(P)$

Ex: $V = \{0, 1, 2, 3, 4\}$

→ p and q_1 are 4 Adjacent because p and q_1 are 4 Neighbours and $p=0$, $q_1=4$ are in set V.

40	4 (q_1)	1 (q_2)
3 (q_3)	0 (p)	20
80	75 (q_4)	50

$V = \{0,1,2,3,4\}$

→ p and q_2 are Not 4 adjacent because q_2 is $N_D(p)$

→ p and q_3 are 4 adjacent because p and q_3 are 4 Neighbours and $p=0$ and $q_3=3$ are in set V.

→ p and q_4 are not 4 adjacent because $q_4=75$ not belongs to set V.

<u>8 Adjacency</u>

2 pixels p and q ~~are~~ with values from V are 8 adjacent, if q is in set $N_8(p)$

40	4 (q_1)	1 (q_2)
3 (q_3)	0 (p)	20
80	75 (q_4)	50

$V = \{0,1,2,3,4\}$

→ p and q_1 are 8 adjacent because p and q_1 are 8 neighbours and $p=0$ and $q_1=4$ are present in set V.

→ p and q_2 are 8 adjacent because p and q_2 are 8 neighbours and $p=0$, $q_2=1$ belongs to set V.

→ p and q_3 are 8 adjacent because p and q_3 are 8 neighbours and $p=0$, $q_3=3$ belong to set V.

→ p and q_4 are not 8 adjacent because $q_4=$ ~~7~~75 not belongs to set V.

M adjacency

Two pixels p and q are called m adjacent, if both have the values from set V and

(i) q is $N_4(P)$ (or)

(ii) q is $N_D(P)$ and $N_4(P) \cap N_4(q)$ has no pixels, whose value belongs to set V.

40	4 (q_1)	1 (q_2)
3 (q_3)	0 (p)	20
80	75 (q_4)	50

$V = \{0, 1, 2, 3, 4\}$

→ p and q_1 are m adjacent because q_1 is $N_4(P)$ and $p = 0$ and $q = 4$ belongs to set V.

→ p and q_2, $p = 0$, $q_2 = 1$

q_2 is $N_D(P)$

$N_4(P) \cap N_4(q)$

$\{4, 3, 20, 75\} \cap \{4, 20\}$

$= \{4, 20\}$ and $4 \in V$

∴ p and q_2 are not M adjacent

→ p and q_3 are M adjacent because $q_3 = 3$ belongs to set V and $q_3 = N_4(P)$

→ p and q_4 are Not M adjacent because $q_4 = 75$ not belongs to set V.

---

③ Path

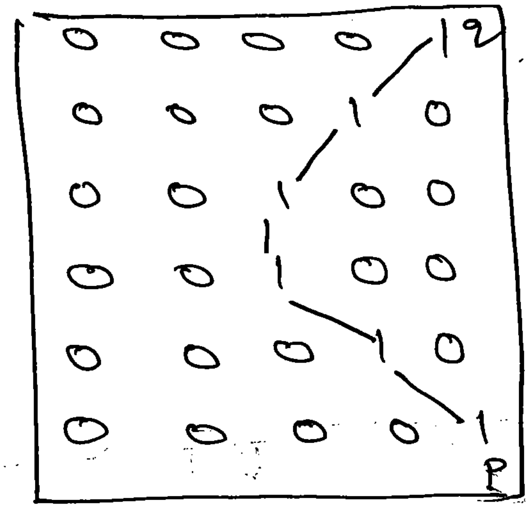
A digital path between pixel p having coordinates (x, y) to pixel q with (u, v) coordinates is a sequence of connected pixels $(x, y), (x_0, y_0), (x_1, y_1)$ ―― ―――― (u, v)

→ Length of the path is count of connected pixel

→ If first pixel is same as last pixel i.e

Ex:- path length between p and q is 5

fig: example showing path between p and q →



④ Connectivity

Two pixels are connected if they are adjacent. similarly 2 subsets are connected if some pixel in S_1 is adjacent to some pixel in S_2.

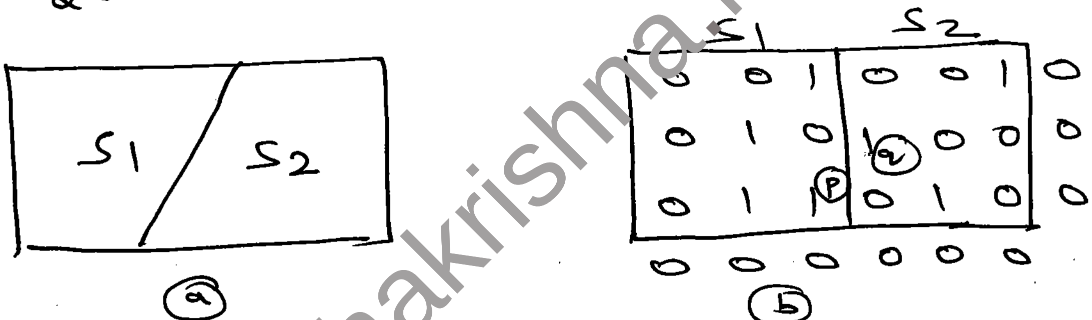


fig a and b :- 2 Image subsets

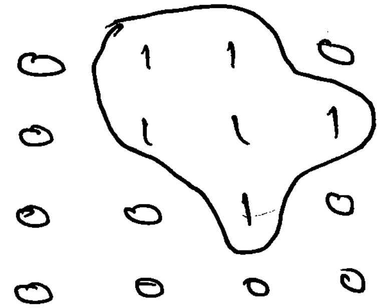
consider 2 image subsets S_1 and S_2 and $V = \{1\}$. As pixel p in sub image S_1 and pixel q in subimage S_2 have value 1 and are 8 adjacent, thus S_1 and S_2 are 8 adjacent but not 4 adjacent

⑤ Region

Let R be a subset of pixels in an image. we call R as a region of image if R is a connected set.

A group of connected pixel with ~~[illegible]~~ similar properties is called Region

Fig illustrates region in an image.



6) Boundary

Boundary of a region is defined as a set of pixels in the region that have one or more neighbours that are not in R

Boundary is edge of a region.

7) Distance

Let us consider 2 pixels having coordinates (x,y) and (s,t) respectively

Many distance measuring formula can be define in image processing.

For any formula to qualify as distance measure, following conditions should be met.

→ Distance should be non negative number i.e $D(p,q) \geq 0$

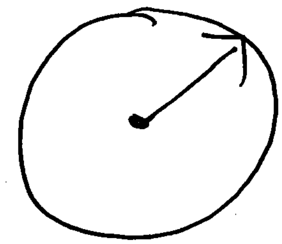
→ Distance between p and q should be same as distance between q and p

→ Distance between any 2 points p and q should be the sum of distance between ~~[illegible]~~ p and x and x and q

Most commonly used distance measures are

1) <u>Euclidean distance</u>

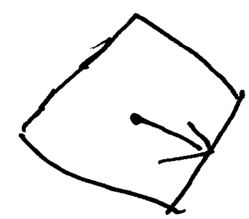
Euclidean distance between 2 points is defined as



$$D_{eq}(p,q) = \sqrt{(x-s)^2 + (y-t)^2}$$

2) <u>D4 Distance (city block distance)</u>

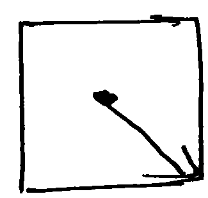
D4 Distance between 2 points p and q is defined as



$$D_4(p,q) = |x-s| + |y-t|$$

3) <u>D8 Distance (Chess board Distance)</u>

D8 Distance between 2 points p and q is defined as



$$D_8(p,q) = \max(|x-s|, |y-t|)$$

Ex:-

(-2,2)	(-1,2)	(0,2)	(1,2)	(2,2)
(-2,1)	(-1,1)	(0,1)	(1,1)	(2,1)
(-2,0)	(-1,0)	(0,0)	(1,0)	(2,0)
(-2,-1)	(-1,-1)	(0,-1)	(1,-1)	(2,-1)
(-2,-2)	(-1,-2)	(0,-2)	(1,-2)	(2,-2)

$\sqrt{8}$	$\sqrt{5}$	2	$\sqrt{5}$	$\sqrt{8}$
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$
2	1	0	1	2
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

4	3	2	3	4
3	2	1	2	3
2	1	0	1	2
3	2	1	2	3
4	3	2	3	4

2	2	2	2	2
2	1	1	1	2
2	1	0	1	2
2	1	1	1	2
2	2	2	2	2

4) Dm distance

The distance between 2 points is defined as shortest m path between the points.

consider following arrangement of pixels and assume $P, P_2, P_4 = 1$

P_3 P_4

P_1 P_2 $\quad\quad V = \{1\}$

P

<u>case (i) :- If P_1 and P_3 are zero</u>

Length of shortest m path between P & P_4 is 2 (P, P_2, P_4)

<u>case (ii) :- If $P_1 = 1$</u>

Length of shortest m path between P & P_4 is 3 (P, P_1, P_2, P_4)

<u>case (iii) :- If $P_3 = 1$</u>

Length of shortest m path between P & P_4 is 3 (P, P_2, P_3, P_4)

<u>case (iv) :- If $P_1 = P_3 = 1$</u>

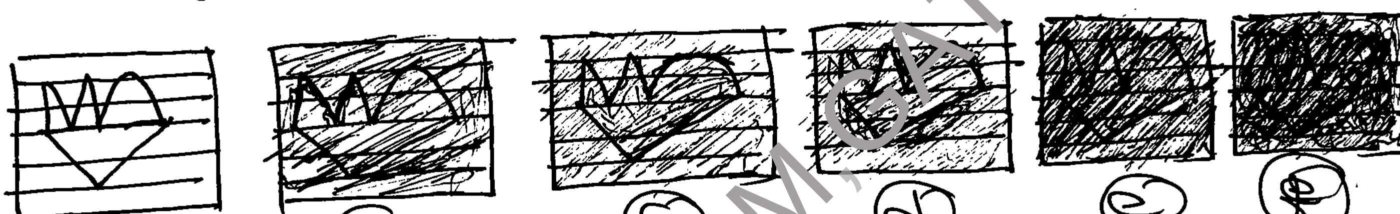
Length of shortest m path between P and P_4 is 4 i.e (P, P_1, P_2, P_3, P_4)

Spatial and Gray level Resolution

* Details in an image is determined by its resolution
* Resolution quality increases with the number of pixels.
* There are 2 types of Resolution

Spatial Resolution

* Smallest discernible detail is determined by spatial Resolution.
* Sampling is the principle factor determining the spatial resolution of an image.
* Consider a chart with vertical lines of width w, with the space between the lines also having the width w. Thus the width of the line pair is 2W. There are 1/2W line pair which are clearly visible.



(a) (b) (c) (d) (e) (f)

(a) 1024 X 1024 image whose gray levels are represented by 8 bit (256 gray levels)

(b) 512 X 512 image obtained by deleting every other Row and column

(c) 256 X 256 image generated by deleting row and column of 512 X 512

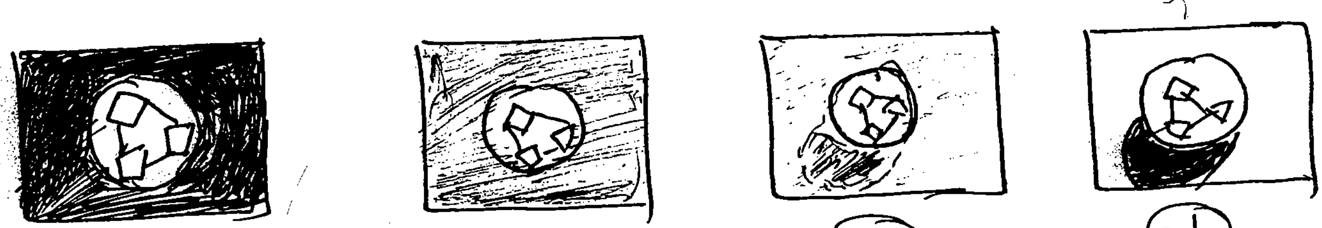
Similarly d, e and f images are created.

Gray level Resolution

* Gray level Resolution refers to the smallest discernible change in gray level.
* The number of Gray levels are usually an integer power of 2, i.e generally gray scale image are 8 bit image. If the nor of Gray levels are increased to 1024 (10 bits)

to distinguish between 4096 gray levels. Thus generally 8 bit images (256 gray levels) are used.

* If the number of gray levels reduce in image (5 or less than 5 bits). False contouring Effect can be seen. i.e very fine false edge are seen in areas of smooth gray levels.



(a) (b) (c) (d)

fig (a) :- 128 x 128 with 256 gray levels (2^8)

fig (b) :- 128 x 128 with 128 gray levels

fig (c) :- 64 gray levels

fig (d) :- 32 gray levels

* Bit representation of an image with different gray levels is given by

$$\boxed{L = 2^k}$$ Ex $256 = 2^8$

Ex :- dot per inch → Monitor

Line per inch → Printer

Pixel per inch → Mobile

Linear verses non linear operations

Consider a input image $f(x,y)$. Let the operator H, produce an output image $g(x,y)$, for a given input image $f(x,y)$.

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

H is said to be linear operator if

$$H[a_i f_i(x,y) + a_j f_j(x,y)] = a_i H[f_i(x,y)] + a_j H[f_j(x,y)] \quad (1)$$

$$= a_i g_i(x,y) + a_j g_j(x,y) \quad (2)$$

Where a_i, a_j are arbitary constants and $f_i(x,y)$ and $f_j(x,y)$ are images (of same size)

Equation indicates that, the output of a linear operation due to the sum of 2 inputs is the same as performing the operation on the inputs individually and then summing the result. This property is called additivity

also The output of linear operation to a constant times an input is the same as output of the operation due to the original input multiplied by that constant. This property is called homogeneity

Ex:-

Suppose H is the sum operator, Σ. To Test for linearity consider Left side of equation (1) and prove that it is equal to Right side

$$\Sigma[a_i f_i(x,y) + a_j f_j(x,y)] = \Sigma a_i f_i(x,y) + \Sigma a_j f_j(x,y)$$

$$= a_i \Sigma f_i(x,y) + a_j \Sigma f_j(x,y)$$

$$= a_i g_i(x,y) + a_j g_j(x,y)$$

In the above equations LHS = RHS and we conclude that sum operator is linear.

Consider the max operation, whose function is to find the maximum value of the pixels in an image.

Consider the following 2 images

$f_1 = \begin{bmatrix} 0 & 2 \\ 2 & 3 \end{bmatrix}$ and $f_2 = \begin{bmatrix} 6 & 5 \\ 4 & 7 \end{bmatrix}$

and let $a_1 = 1$ and $a_2 = -1$. To Test for linearity, we start with LHS of equation ①

$$\max\left\{ (1)\begin{bmatrix} 0 & 2 \\ 2 & 3 \end{bmatrix} + (-1)\begin{bmatrix} 6 & 5 \\ 4 & 7 \end{bmatrix} \right\} = \max\left\{\begin{bmatrix} -6 & -3 \\ -2 & -4 \end{bmatrix}\right\}$$

$$= \underline{\underline{-2}}$$

According to RHS of equation ①

$$(1)\max\left\{\begin{bmatrix} 0 & 2 \\ 2 & 3 \end{bmatrix}\right\} + (-1)\max\left\{\begin{bmatrix} 6 & 5 \\ 4 & 7 \end{bmatrix}\right\}$$

$$= 3 + (-1)7$$

$$= \underline{\underline{-4}}$$

LHS $\neq$ RHS $\therefore$ max operator is non linear

Image Interpolation

Interpolation is a basic tool used extensively in task such as zooming, shrinking, rotating and geometric corrections

Interpolation is the process of using known data to estimate values at unknown locations.

suppose that an image of size 500 x 500 pixels has to be enlarged to 750 x 750 pixels (1.5 times) then several methods can be used. If nearest neighbor interpolation method is used, it has a tendency to produce undesirable artifacts, such as severe distortion of straight edges, hence this method is used infrequently. A more suitable approach is bilinear interpolation. In this method we use 4 nearest neighbors to estimate the intensity at a given location. For Bilinear interpolation the intensity value $v(x,y)$ is obtained using the equation

$$v(x,y) = ax + by + cxy + d$$

where the 4 coefficients are determined from the 4 equations.

In bicubic interpolation it involves sixteen nearest neighbors of a point. The intensity value assigned to point (x,y) is obtained using equation

$$v(x,y) = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij}\, x^i y^j$$

16 equations in 16 unknowns. Bicubic interpolation does a better job of preserving fine detail than bilinear interpolation.

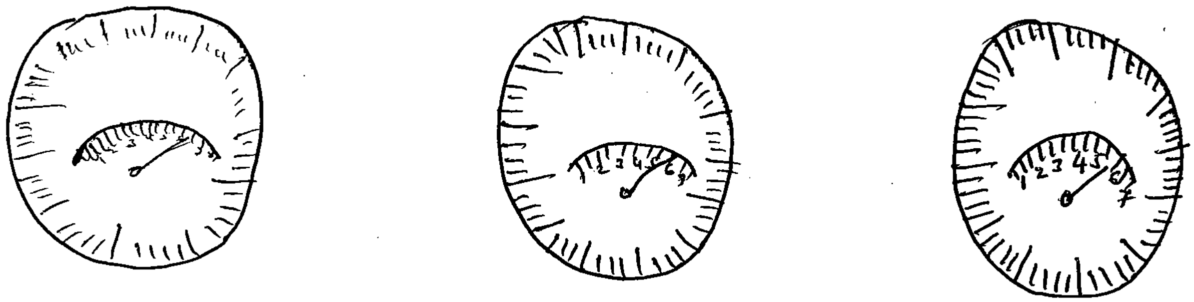


fig (a) fig (b) fig (c)

Fig (a) → Image reduced to 72 dpi and zoomed back to its original size using nearest neighbor interpolation

Fig (b) → output image after bilinear interpolation.

Fig (c) → output image after bicubic interpolation.

Problems

① An image of size 630×480 has 24 bit colour. Calculate the memory required by the image

Soln:
$$b = M \times N \times k$$
$$= 630 \times 480 \times 24$$
$$= \underline{7.257 \text{ M bits}}$$

---

② Calculate the number of bits required to store a digital image of size 1024 × 1024 and the number of grey levels are 128.

Soln
$$L = 2^k$$
$$128 = 2^k \Rightarrow \boxed{k = 7}$$
$$b = 1024 \times 1024 \times 7 = 7.34 \text{ mb}$$

---

③ Image transmission is done in packets. A packet consist of start bit, a byte of data and a stop bit. Answer the following

a) How many minutes it would take to transmit a 512 × 512 image with 256 gray levels at 300 baud rate

b) What would be the time at 9600 baud.

Soln: Data (including start & stop bit) $= 512 \times 512 \times (8+2)$
$$= 512 \times 512 \times 10$$

At 300 baud rate $T = \dfrac{512 \times 512 \times 10}{300}$
$$= 8738.133 \text{ sec}$$
$$= 145.63 \text{ min}$$

At 9600 baud rate $T = \dfrac{512 \times 512 \times 10}{9600}$
$$= 273.067 \text{ sec}$$

(4) Transmission is accomplished in packets consisting of start bit, a byte of information and stop bit. find

a) How many minutes it would take to transmit a 2048 X 2048 image with 256 intensity levels with 33.6 K baud modem.

b) What would be the time be at 3000 K baud.

Sol^n: Size of image = 2048×2048

No of bits Required for image = $2048 \times 2048 \times (8+2)$

$= 2048 \times 2048 \times 10$

a) Time $= \dfrac{2048 \times 2048 \times 10}{33.6 \times 10^3}$

$= 1248.3$ sec

$= \underline{20.8 \text{ min}}$

b) Time $= \dfrac{2048 \times 2048 \times 10}{3000 \times 10^3}$

$= \underline{13.9 \text{ sec}}$

---

(5) Consider two image subsets S1 & S2 shown in fig. For $V = \{1\}$, Find if 2 subsets are a) 4 adjacent b) 8 - Adjacent c) M Adjacent

	S1				S2				
0	0	0	0	0	0	0	1	1	0
1	0	0	1	0	0	1	0	0	1
1	0	0	1	0	1 q	1	0	0	0
0	0	1	1	1 p	0	0	0	0	0
0	0	1	1	1	0	0	1	1	1

Sol: a) p and q are not 4 Adjacent. (24)
because q is not $N_4(p)$. Thus S_1 and S_2 are not connected

b) p and q are 8 Adjacent because q is $N_8(p)$. Thus S_1 and S_2 are connected

c) $N_4(p) = \{0,1\}$, $N_4(q) = \{0,1\}$

$N_4(p) \cap N_4(q) = \{0,1\} \Rightarrow 1 \in V$

$\therefore$ p and q are not m adjacent

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⑥ Let p and q are pixels at co-ordinates (10,12) and (15,20) respectively. Find out which distance measure gives minimum distance between between them

Sol^n: (i) Euclidean distance

$(x,y) = 10,12$
$(s,t) = 15,20$

$$d_e(p,q) = \sqrt{(x-s)^2 + (y-t)^2}$$

$$= \sqrt{(10-15)^2 + (12-20)^2}$$

$$= \sqrt{89}$$

(ii) D4 Distance

$$D_4(p,q) = |x-s| + |y-t|$$

$$= |10-15| + |12-20|$$

$$= 5 + 8 = \underline{\underline{13}}$$

(iii) D8 Distance

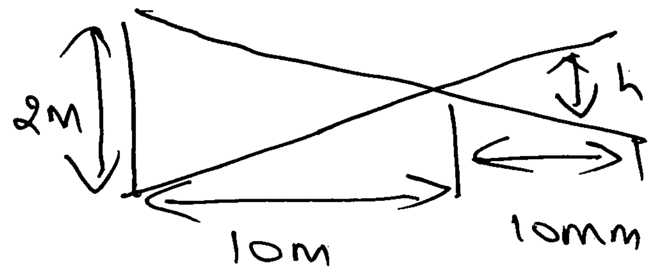
$$D_8(p,q) = \text{Max}(|x-s|, |y-t|)$$

$$= \text{Max}(|10-15|, |12-20|)$$

7) Suppose a camera is focused at pillar of height 2m and situated of distance 10 meter. If focal length of camera is 10mm. What would be the height of image produced in camera.

24

Soln



Let h be the height of the image

$$\frac{2}{10m} = \frac{h}{10mm}$$

$$\boxed{h = 2mm}$$

8) Consider an image segment

	3	4	1	2	0
	0	1	0	4	2 q
	2	2	3	1	4
p	3	0	4	2	1

Let $V = \{0, 1, 2\}$. compute the length for shortest 4, 8 and m path between p and q. Repeat for $V = \{2, 3, 4\}$

Soln: (i) $V = \{0, 1, 2\}$

No 4, 8, m path exist between p and q as the value $p = 3$ is not in set V.

(ii) V = [2, 3, 4]

4 path

$$\begin{array}{cccccc} & 3 & 4 & 1 & 2 & 0 \\ & 0 & 1 & 0 & 4 & 2 \; q \\ & 2 & 2 & 3 & 1 & 4 \\ p & 3 & 0 & 4 & 2 & 1 \end{array}$$

No 4 path between p & q

8 path

$$\begin{array}{cccccc} & 3 & 4 & 1 & 2 & 0 \\ & 0 & 1 & 0 & 4 & 2 \; q \\ & 2 & 2 & 3 & 1 & 4 \\ p & 3 & 0 & 4 & 2 & 1 \end{array}$$

4 path length = 4

M path

$$\begin{array}{cccccc} & 3 & 4 & 1 & 2 & 0 \\ & 0 & 1 & 0 & 4 & 2 \; q \\ & 2 & 2 & 3 & 1 & 4 \\ p & 3 & 0 & 4 & 2 & 1 \end{array}$$

m path length = 7

When p = 2 and q = 4

$N_4(P) \Rightarrow \{1, 1, 4\}$

$N_4(q) \Rightarrow \{ 1, 1 \}$

$N_4(P) \cap N_4(q) = \{1, 1\} \notin V \therefore$ 2 & 4 are m adjacent

(9) Consider the image segment

$$\begin{array}{ccccc} & 3 & 1 & 2 & 1\ q \\ & 2 & 2 & 0 & 2 \\ & 1 & 2 & 1 & 1 \\ p & 1 & 0 & 1 & 1 \end{array}$$

a) Let $V = \{0, 1\}$ compute the length of 4, 8 and m path between p and q. If a particular path dosen't exist between ~~these~~ p & q ~~points~~ Explain why?

b) Repeat for $V = \{1, 2\}$

Sol^n:- (i) $V = \{0, 1\}$

4 adjacency (4 path)

$$\begin{array}{ccccc} & 3 & 1 & 2 & 1\ q \\ & 2 & 2 & 0 & 2 \\ & 1 & 2 & 1 & 1 \\ p & 1 & 0 & 1 & 1 \end{array}$$

When $V = \{0, 1\}$, 4 path does not exist because it is impossible to connect p to q travelling along points that are 4 adjacent

8 adjacency (8 path)

$$\begin{array}{cccc} 3 & 1 & 2 & 1 \\ 2 & 2 & 0 & 2 \\ 1 & 2 & 1 & 1 \\ 1 & 0 & 1 & 1 \end{array}$$

Path length = 4

$$\begin{array}{cccc} 3 & 1 & 2 & 1 \\ 2 & 2 & 0 & 2 \\ 1 & 2 & 1 & 1 \\ 1 & 0 & 1 & 1 \end{array}$$

Path length = 5

M adjacency (m path)

$$\begin{array}{ccccc} & 3 & 1 & 2 & 1 \\ q & 2 & 2 & 0 & 2 \\ & 1 & 2 & 1 & 1 \\ & 1 & 0 & 1 & 1 \end{array}$$

Path length = 5

(ii) V = {1, 2}

4 adjacency (4 path)

	3	1	2	1	q
	2	2	0	2	
	1	2	1	1	
p	1	0	1	1	

Path length = 6

	3	1	2	1	q
	2	2	0	2	
	1	2	1	1	
p	1	0	1	1	

Path length = 6

8 adjacency (8 path)

	3	1	2	1	q
	2	2	0	2	
	1	2	1	1	
p	1	0	1	1	

Path length = 4

	3	1	2	1	q
	2	2	0	2	
	1	2	1	1	
p	1	0	1	1	

Path length = 4

M adjacency (M path)

	3	1	2	1	q
	2	2	0	2	
	1	2	1	1	
p	1	0	1	1	

Path length = 6

3	1	2	1
2	2	0	2
1	2	1	1
1	0	1	1

(10) Find the time required in seconds for transmitting a monochrome image of size 2.5 x 2 scanned at 150 DPI (Dot per inch) and to be sent at 28 kbps speed.

Sol: Size of image $= (2.5 \times 150)$ rows $\times (2 \times 150)$ columns

$= \underline{\underline{112500}}$ pixels

Generally gray scale image is 8 bits

$\Rightarrow k = 8$

Memory required for this image

$b = 112500 \times 8$

$= \underline{\underline{0.1125 \text{ M byte}}}$

Transmission time $= \dfrac{0.1125 \text{ M byte}}{28 \text{ K}}$

$= \underline{\underline{32.142 \text{ sec}}}$

Shrinking:

Spatial Resolution can be reduced by removing appropriate rows and columns from original image.
Shrinking refers to reducing the size of an image, which is called as sub sampling or under sampling.

Ex: 1024 x 1024 image to 512 x 512 image

0	1	2	4	5	6
1	2	8	9	10	2
4	1	8	6	3	9

$\xrightarrow{\text{Shrinking}}$

0	2	5
4	8	3