MODULE - I

INTRODUCTION

Fundamentals of Digital Image processing

* Image processing refers to the processing of visual information sources, such as image for some specific task, as per the application requirements.
* pattern recognition is used for identifying & recognizing the objects that is present in the image, using the features generated & classification or clustering is pattern recognition.
* Computer vision associated with scene understanding. Most image processing algorithms produce results that can serve as the first input for m/c vision algorithm.
* computer graphics & image processing are very closely related areas. Image processing deals with raster data or bitmaps, whereas computer graphics primarily deals with vector data.
* DIP focuses on 2 major tasks:
  - improvement of pictorial info^n for human interpretation.
  - processing of image data for storage, transmission & representation for autonomous m/c perception.
* The continuation from image processing to c/m vision can be broken up into low level, mid level & high-level processes.

What is Digital image processing?

Digital Image processing refers to processing digital images by means of digital computer.

→ DIP focuses on 2 major tasks:

* Improvement of pictorial info^n for human inter-pretation.
* processing of image data for storage, transmission & representation for autonomous m/c perception.

→ There is no boundary as to where image processing stops at one End & c/m vision starts at the other End.

→ The Continum from image processing to c/m vision can be broken up into low, mid- and high-level processes.

Low-level process	Mid-level process	High-level process
I/p : image o/p : image Eg: Noise removal, image sharpening	I/p : image o/p : Attributes Eg : object recognition, Segmentation	I/p : Attributes o/p : understanding Eg : Scene understanding, autonomous navigation

Low-level process : low level methods usually very little knowledge about the content of images. Low level process involve primitive operations such as image processing to reduce noise, Contrast Enhancement & image Sharpening. A low-level process is characterized by the fact that both it's inputs & o/p are images.

Mid-level processing: on images involves tasks such as segmentation (partitioning an image into regions or objects), description of those objects to reduce them to a form suitable for c/m processing & classification (recognition) of individual objects. It's characterized by the fact that it's i/p's generally are images but it's o/p's are attributes extracted from those images (Eg: Edges, Contours).

High-level processing: is based on knowledge, goals & plans of how to achieve those goals. Artificial intelligence (AI) methods are used in many cases. High level c/m vision tries to imitate human cognition the ability to make decisions according to the infoⁿ contained in the image. Higher-level processing involves "making sense" of an ensemble of recognized objects, as in image analysis & in addition, encompasses processes that extract attributes from images, upto & including the recognition of individual objects.

* Note: DIP deals with low/middle level image processing.

A simple illustration to clarify these concepts,

Consider the area of automated analysis of text. The process of acquiring an image of the are containing the text, preprocessing that image, extracting (segmenting) the individual characters, describing the characters in a form suitable for c/m processing & recognizing those individual characters are in the

Scope of what we call digital image processing.

⟨Q: Explain 3 levels of Image processing⟩

Origins of DIP:

① Early 1920's: one of the 1st appn of digital image was in the news paper industry.

* The Bart Lane cable picture transmission Service
* An image was transferred by submarine cable b/w London & Newyork in 3 hours.
* picture were Coded for cable transfer & reconstructed at the receiving End on a telegraph printer with half toning.

Mid to late 1920's: Improvements to the Bart lane System resulted in higher Quality images.

* New reproduction processes based on photographic techniques.
* Increased number of tones in reproduced images.

② 1960's: Improvement in Computing technology & the onset of the Space race led to a Surge of work in digital image processing.

③ 1964: clm used to improve the Quality of images of the moon taken by the Ranger 7 probe.

* Such techniques were used in other Space missions including the Apollo landings.

④ 1970s: Digital image processing begins to be used in medical applications.

⑤ 1979: Sir Godfrey N. Hounsfield & prof. Allan M. Cormack Share the Nobel prize in medicine for the invention of tomography, the technology behind computerized Axial Tomography (CAT) Scans.

⑥ 1980'S : The use of digital image processing techniques has Exploded & they are now used for all kinds of tasks in all kinds of areas.

* Image Enhancement/restoration
* Artistic Effects
* Medical Visualization
* Industrial inspection
* Law Enforcement
* Human c/m interfaces

What is an Image?

An image is a two-dimensional function that represents a measure of some characteristic such as brightness or color of a viewed scence.

(or) * An image is a projection of a 3D scene into a 2D projection plane. It can be defined as a two-variable function $f(x,y)$ where for each position (x,y) in the projection plane, $f(x,y)$ defines the light intensity at this point.

(or) where x & y are spatial coordinates & the amplitude of f at any pair of coordinates (x,y) is called the intensity or gray level of the image at that point.

What is Digital Image?

An image is called digital image when x, y & the intensity values of f are all finite discrete quantities. Digital image processing refers to processing digital images by means of digital computer.

A digital image is composed of finite numbers of elements called pixels, each of which has a particular location & Value.

pixels are also called picture Elements or pels.

* pixel values typically represent gray levels, colors, heights, opacities etc.
* Remember digitization implies that a digital image is an approximation of a real scene after Sampling & Quantization.

Digital image Representation:

$$f(x,y) = \begin{array}{c|c} & \begin{matrix} 0 & 1 & 2 & & N-1 \end{matrix} \\ \hline \begin{matrix} 0 \\ 1 \\ \vdots \\ \vdots \\ N-1 \end{matrix} & \begin{bmatrix} f(0,0) & f(0,1) & f(0,2) & \ldots\ldots & f(0,N-1) \\ f(1,0) & f(1,1) & f(1,2) & \ldots\ldots & f(1,N-1) \\ \vdots & & & & \\ \vdots & & & & \\ f(M-1,0) & f(M-1,1) & f(M-1,2) & \ldots & f(M-1,N-1) \end{bmatrix} \end{array} \quad \underline{\&} \quad \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Matrix Dimension = $M \times N$

digital image representation

A digital image is a two-dimensional discrete Signal. It is also an $N \times N$ array of Elements. Each Element in the array is a number which represents the Sampled intensity.

Q: Define digital image processing.
Q: Briefly Explain digital image & it's representation.

Important ***

Fundamental Steps in Digital Image processing:

The fundamental Steps involved in DIP is as Shown in the block diagram:

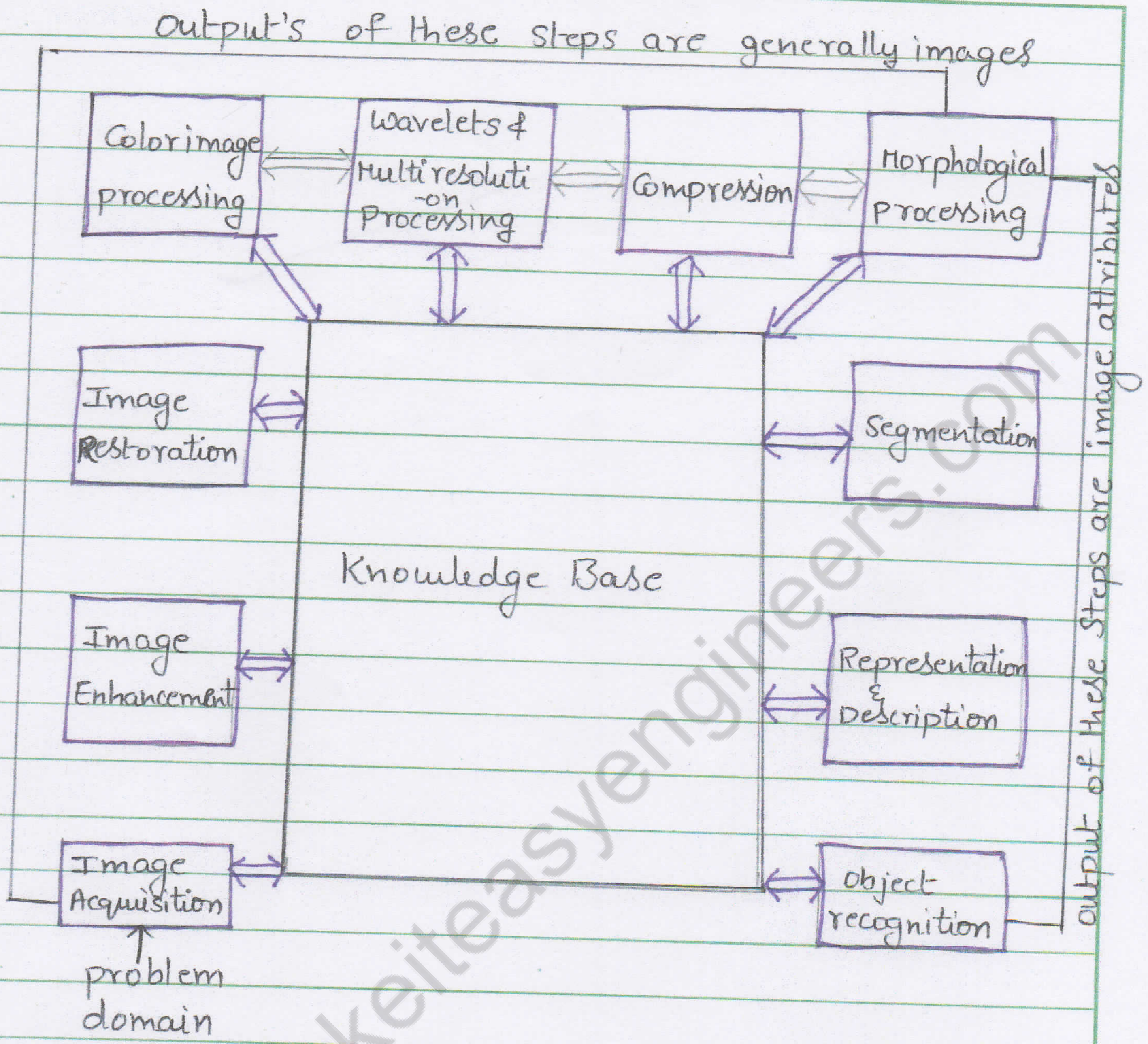


Fig: Fundamental Steps in DIP.

The diagram depicts all the methodologies that can be applied to images for different purpose & with different objectives.

Image Acquisition: 1st Step in DIP. An image is captured by a sensor (such as digital camera) & digitized. The image that is acquired is completely unprocessed & is the result of whatever sensor was used to generate it.

Image Enhancement : The idea behind Enhancement technique is to bring out detail that is hidden & Simply to highlight Certain features of interest in an image; Such as, changing brightness & Contrast etc.

→ It is the process of Manipulating an image so that the result is more Suitable for a Specific application.

→ The method used for Enhancing a particular appⁿ (Eg: X-Ray image) may not Suitable for another application (Eg: Satellite images taken in Emspectrum).

Image Restoration : It is an area that also deals with improving the appearance of an image.

→ However unlike Enhancement which is subjective, image restoration is objective, it's techniques tend to be based on mathematical or probabilistic models of image degradation.

→ It's aim is at reversing the degradation undergone by an image to recover the true image.

Color image processing : It's processing of Color images & is gaining a lot of importance because of the Significant increase in the use of digital images over the internet.

Wavelets & Multiresolution processing : wavelets are the foundation for respresenting images in various degrees of resolution.

Compression : It Deals with techniques for reducing the Storage required to Save an image or the band-width to transmit it.

→ Storage technology has improved significantly & hence Compression is significantly important for transmission.
Eg: JPEG (Joint photographic Experts Group) is a image Compression Standard.

Morphological processing: It deals with tools for Extracting image Components that are useful in the representation & description of shapes.

Segmentation: It refers to the process of partioning an image into it's Constituent part's or objects. It Extracts required portion of the image.
(or) process of partioning of an image into groups of pixels which are homogeneous with respect to some Criteria.
→ It's one of the most difficult tasks in digital image processing. It's based on the property of discon-tinuity & similarity.

[Feature Extraction]
Representation & Description: Almost always follows the output of a segmentation stage, which is usually raw pixel data, which is either the boundary of a region [i.e the set of pixels separating one image region from another] or all the point's in the region itself.
→ The decision is to be made whether the image data is to be represented as boundary or as Complete region.
→ Boundary representation is required when focus is an External shape Characteristics such as corners & Edges.
→ Regional Representation is appropriate when focus is an internal properties such as texture or skeletal

properties.

→ Representation is only part of solution of transforming raw data into a form suitable for subsequent computer processing.

→ Description also called feature selection deals with extracting attributes that result's in some quantitative info^n of interest required for differentiating one class of objects from another.

Object Recognition: [Image pattern classification] is the process that assigns a label (Eg. "Vehicle") to an object based on it's feature descriptors.

Knowledge Base: Knowledge about a problem domain is coded into an image processing system in the form of knowledge database.

→ Knowledge may be simple as detailing regions of an image where the info^n of interest is known to be located, thus limiting the search that has to be conducted in seeking information.

Q: With a neat block diagram describe the various phases of fundamental steps of Digital image processing.

Imp***

Components of An Image processing system:

Numerous models of image processing systems were sold till mid 1980's that were peripheral devices attached to equally substantial host computer's.

In Early 1990's Image processing hardware was brought in the form of single board's compatiable with standard buses to fit into Engg workstations, Cabinets & personal

Computers. Several s/w were specifically designed for image processing.

The trend is towards miniaturizing & blending of general purpose small c/m with specialized image processing h/w.

The Block diagram of Components of a general purpose Image processing system is as shown below,

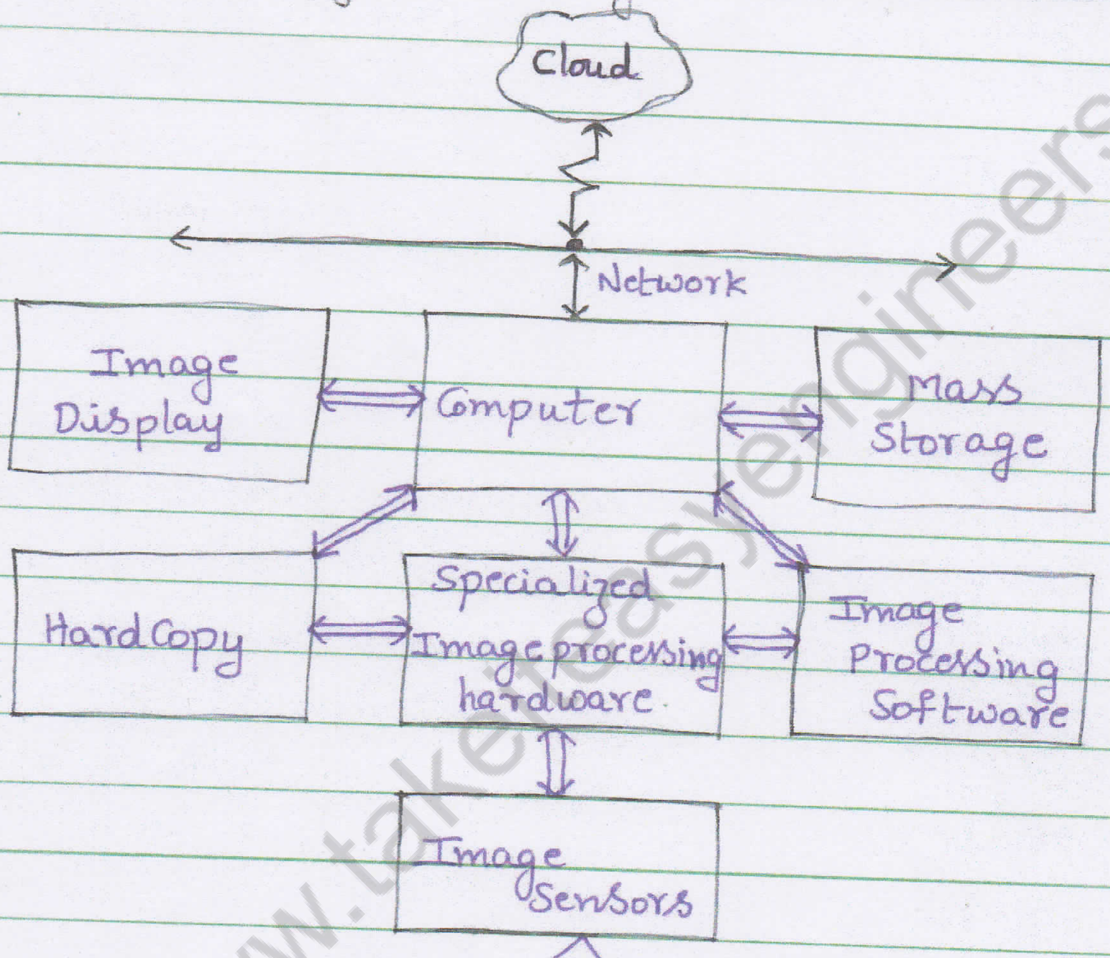


Fig: Components of a general purpose Image processing System

Image Sensor's: Images are acquired using Image sensor's. It has 2 Element's:

→ The first is a physical sensor that responds to the Energy radiated by the object to be captured.

→ The 2^{nd}, called a digitizer, is a device for converting the o/p of the physical sensing device into digital form.

[For Eg, in a digital video camera, the sensors (CCD chips) produce an Electrical o/p proportional to light intensity. The digitizer Convert's these output's to digital data.

Specialized Image processing hardware: Usually Consists of a digitizer & hardware that performs other primitive operations, Such as an arithmetic logic unit (ALU), that performs arithmetic & logical operations in parallel on Entire images. This type of hardware sometimes is called a "front-End Subsystem" & it's most distinguis-hing characteristic's is speed.

Eg of how an ALU is used in averaging images as quickly as they are digitized, for the purpose of noise reduction.

Computer: is an image processing system is a general-purpose c/m & can range from a pc to a supercl/m. Customized c/m are used to achieve a required level of performance. Any well-Equipped pc-type m/c is suitable for off-line image processing tasks.

Software: for image processing Consist's of specialized modules that perform specific tasks. A well-designed package also includes the capability for the user to write code that, as a minimum, utilizes the specialized modules. Sophisticated s/w packages allow the integration of those modules & general purpose s/w Commands from at least one c/m language.

Mass Storage: is a must in image processing applications. An image of size 1024×1024 pixels, in which the intensity of each pixel is an 8-bit quantity, requires one megabyte of storage space if the image is not compressed.

Thus providing adequate storage in an image processing system can be a challenge. Digital storage for image processing app^n falls into 3 principal categories:

1. Short-term storage for use during processing
2. on-line storage for relatively fast recall.
3. Archival storage, characterized by infrequent access.

Short-term Storage: Can be provided using c/m memory, 2nd by specialized boards called frame buffer's, that store one or more images & can be accessed rapidly at video rates (30 images/sec). This method allows virtually instantaneous image zoom, as well as scroll (vertical shifts) & pan (horizontal shifts). Frame buffers usually are housed in the specialized image processing hardware unit.

On-line Storage: It takes the form of magnetic disks & optical media storage. The key factor characterizing on-line storage is frequent access to the stored data.

Archival Storage: It's characterized by massive storage requirement's but infrequent need for access.

Image displays: are mainly color, flat screen monitors. Monitors are driven by the o/p's of image & graphics display cards that are an integral part of the c/m system.

→ Display cards may not be used for some image display applications.

→ Some appⁿ require stereodisplays that are implemented in the form of headgear containing 2 small displays embedded in goggles worn by the user.

Hardcopy: Hardcopy devices for recording images include laser printers, film cameras, heat sensitive devices, ink-jet units & digital unit's such as optical & CD-ROM disks.

→ Highest resolution is provided by films, but paper is the preferable choice of medium for written material

→ For presentation, images displayed on film transparencies or in a digital medium (if projection equipment used).

Networking & Cloud: Communication are almost default funⁿ in any c/m system in use. Coz of the large amount of data inherent in image processing appⁿ, the key consideration in image transmission is bandwidth. This is not an issue when a dedicated network is used but the challenging is communications with remote site, which are not always efficient. Use of optical fiber & other broadband technologies is improving quickly bandwidth transmission.

Q: with neat diagram, describe the components of a general purpose Image processing system

(or) Q: Describe or Explain with diagram components of Digital image processing system.

Element's of visual perception:

Understanding the basic characteristics of human visual perception is the first step in DIP. Our Interest here is, the Elementary mechanics of how images are formed & perceived by humans.

Structure of the Human Eye

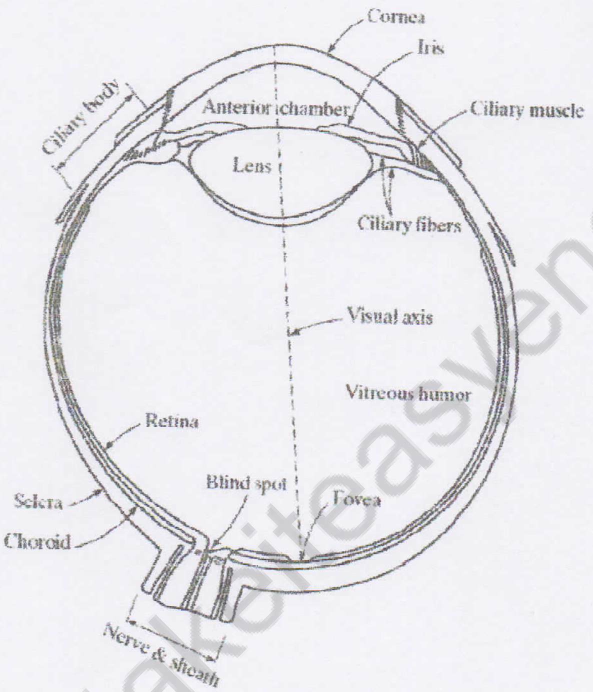


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

Figure 2.1 Simplified diagram of a cross section of the human Eye

Figure 2.1 Shows a Simplified cross Section of the human Eye. The Eye is nearly a sphere (with a diameter of about 20mm) Enclosed by 3 membranes: the Cornea & Sclera outer Cover; the choroid; & the retina. The Cornea is a tough, transparent tissue that Covers the anterior surface of the Eye. Continuous with the cornea, the sclera is an opaque membrane that Encloses the remainder of the optic globe.

The choroid lies directly below the sclera. This membrane contains a network of blood vessels that serves as the major source of nutrition to the Eye.

→ At it's anterior Extreme, the choroid is divided into the ciliary body & the iris.

→ The latter contract's or Expands to control the amt of light that Enters the Eye.

→ The central opening of the iris (the pupil) varies in diameter from approximately 2 to 8mm. The front of the iris contains the visible pigment of the Eye, whereas the back contains a black pigment

→ The lens consists of concentric layers of fibrous cells & is suspended by fibres that attach to the ciliary body. It is composed of 60% & 70% water about 6% fat, & more protein than any other tissue in the Eye.

→ The innermost membrane of the Eye is the retina, which lines the inside of the wall's Entire posterior portion. when the Eye is focused, light from an object is imaged on the retina.

* pattern vision is afforded by discrete light receptors distributed over the surface of the retina.
* There are two types of receptor's : cones & rods.
* There are between 6 & 7 million cones in Each Eye.
* They are located primarily in the central portion of the retina, called the fovea, & are highly sensitive to color.

→ Humans can resolve fine details because Each cone is Connected to it's own nerve End.

→ Muscles rotate the Eye until the image of a region of interest falls on the fovea.

* Cone vision is called photopic & bright-light vision.
* Rods are giving a general, overall picture of the field of view & are not involved in color vision.
* Several rods are connected to a single nerve & are sensitive to low levels of illumination.

For Eg: objects that appear brightly colored in daylight, when seen by moonlight appear as colorless forms because only the rods are stimulated. This phenomenon is known as scotopic vision & dim-light vision.

* The distribution of receptors is radially symmetric about the fovea.
* Cones are most dense in the center of the fovea while rods increase in density from the center out to approximately 20% off axis & then decrease.

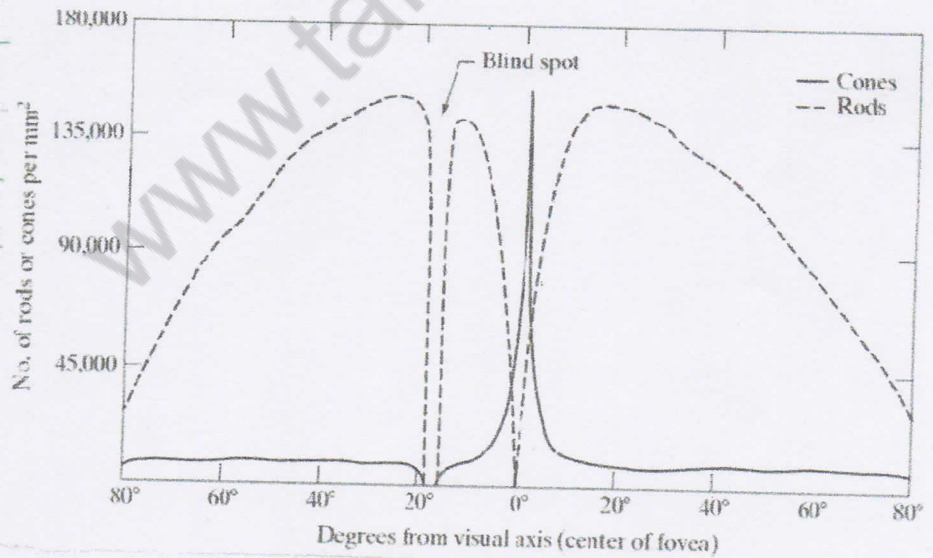


FIGURE 2.2 Distribution of rods and cones in the retina.

Fig: Distribution of rods & cones in the retina

Image Formation in the Eye :

In the human Eye, the Converse is true; the distance between the Center of the lens & the imaging Sensor (the retina) is fixed, & the focal length needed to achieve proper focus is obtained by Varying the Shape of the lens.

→ Muscles within the Eye can be used to change the Shape of the lens allowing us focus on objects that are near or far away.

→ An image is focused onto the retina causing rods & Cones to become Excicted which ultimately Send Signals to the brain.

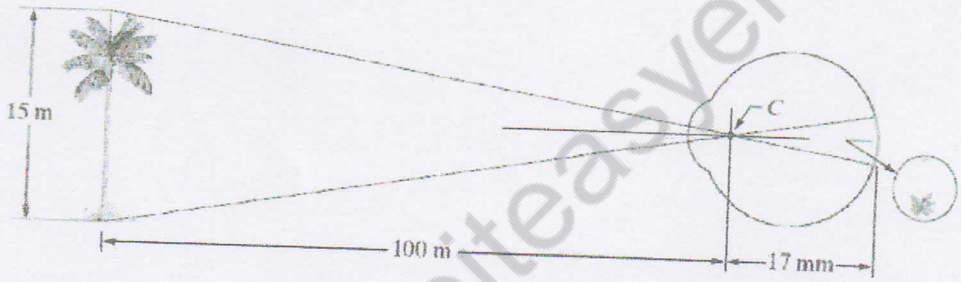


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point C is the optical center of the lens.

Fig: Graphical representation of the Eye looking at a palm tree.

point 'c' is the optical Center of the lens

Q: Explain Simple Image Formation Model with Example.

→ The Eye lens (if Compared to an optical lens) is flexible.

→ The Shape of the lens is Controlled by the tension in the fibers of the Cilliary body.

→ To focus on distant objects, lens to be relatively flattened.

→ Distance between the center of the lens & the retina (focal length): varies from 17mm to 14mm (refractive power of the lens goes from minimum to maximum).

→ objects farther than 3m use minimum refractive lens powers (& vice versa).

For Eg: Suppose that a person is looking at a tree 15m high at a distance of 100m.

* Let "h" denote the height of that object in the retinal image,

$$\frac{15}{100} = \frac{h}{17}$$

$$h = \frac{17 \times 15}{100} = \frac{255}{100} = 2.55\,mm$$

Figure illustrates how to obtain the dimensions of an image formed on the retina.

Image Sensing & Acquisition

Images are typically generated by illuminating a scene & absorbing the energy reflected by the objects in that scene.

* Typical notions of illumination & scene can be seen in:
  - → X-Rays of a skeleton
  - → Ultrasound of an unborn baby
  - → Electro-microscopic images of molecules.

Fig shows the three principal sensor arrangements used to transform incident energy into digital images.

Idea is: Incoming energy lands on a sensor material responsive to that type of energy & this generates a voltage (or) Incoming Energy is transformed into a voltage by a Combination of the i/p Electrical power & Sensor material that is responsive to the type of Energy being detected.

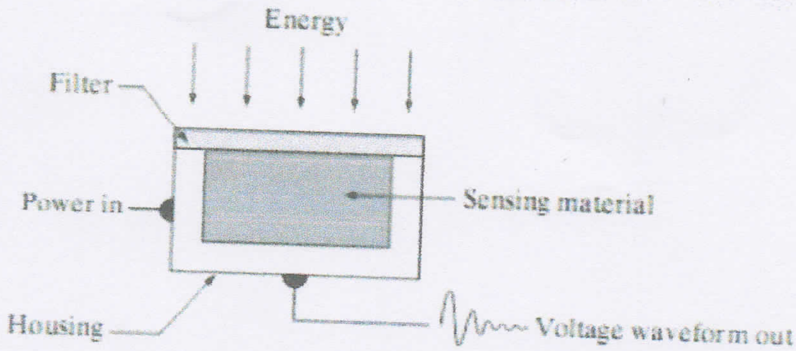


Fig : (a)

Fig : (b)

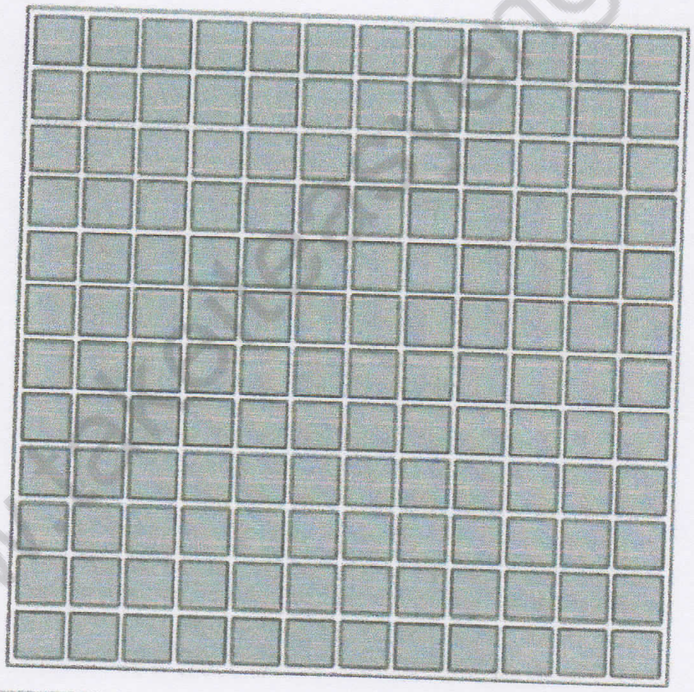


Fig : (c)

Figure 2.12 (a) Single Image Sensor
(b) Line Sensor
(c) Array Sensor.

→ An image can be captured using multiple sensors using line sensor or an array of horizontal & vertical sensor as shown in fig (b) & (c).

Image Acquisition using Sensor strips:

The strip provides imaging elements in one direction.

→ Linear Motion perpendicular to the strip provides imaging in the other direction, as shown in fig.

→ This arrangement is used in most flat bed scanners. Sensing devices with 4000 & more in-line sensors are possible.

→ In-line sensors are used routinely in airborne imaging applications, in which the imaging system is mounted on an aircraft that flies at a constant altitude & speed over the geographical area to be imaged.

→ An imaging strips give one line of an image at a time, & the motion of the strip relative to the scene completes the other dimensions of a 2D-images.

→ Lenses & other focusing schemes are used to project the area to be scanned onto the sensors.

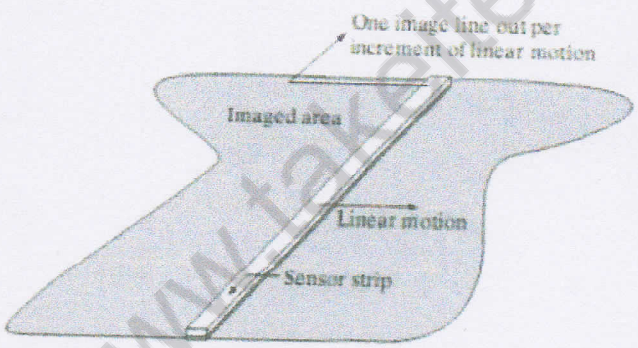


Fig (a): Linear Sensor Strip

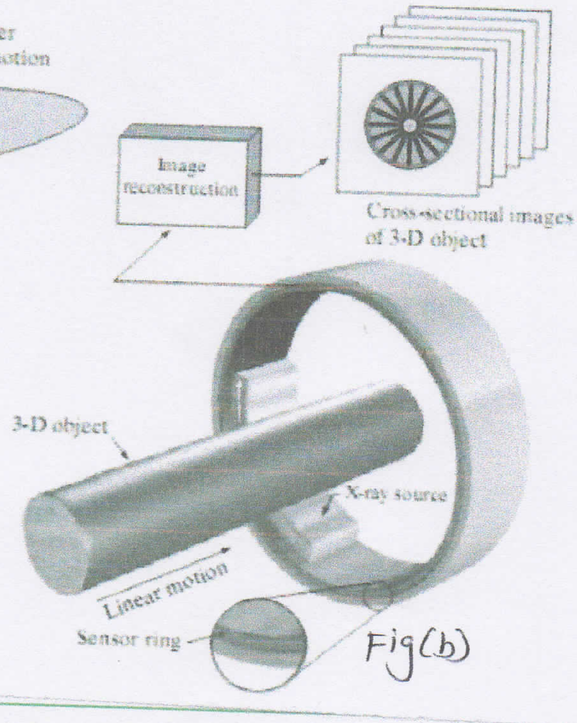


Fig (b)

Figure: (a) Image Acquistion using a linear sensor strip
(b) using a circular sensor strip.

Sensor strips in a ring configuration are used in medical & industrial imaging to obtain cross-sectional ("slice") images of 3-D objects, as Fig shows.

→ A rotating x-ray source provides illumination, & X-Ray sensitive sensors opposite the source collect the Energy that passes through the object. This is the basis for medical & industrial computerized axial tomography (CAT) imaging.,

→ The o/p of the sensor's is processed by reconstruction algorithms whose objective is to transform the sensed data into meaningful cross-sectional images.

→ A 3-D digital volume consisting of stacked images is generated as the object is moved in a direction perpendicular to the sensor ring.

→ other modalities of imaging based on the CAT principle include magnetic resonance imaging (MRI) & positron Emission tomographly (PET).

Image Acquisition using Sensor Arrays.

Fig 2.12(c) Shows individual Sensing Elements arranged in the form of a 2D-array.

→ Electromagnetic & ultrasonic Sensing devices frequently are arranged in this manner.

→ This is found in digital Cameras. A typical Sensor for these Camera is a CCD (charge-coupled device) array, manufactured with a range of Sensing properties & can be packaged in rugged arrays of 4000×4000 Elements or more.

→ The response of Each Sensor is proportional to the integral of the light Energy projected onto the Surface of the Sensor

→ Noise reduction is achieved by letting the Sensor integrate the input light Signal over minutes & Even hours.

→ Because the Sensor array in fig is 2-dimensional, it's advantage is that a Complete image can be obtained by focusing the Energy pattern onto the Surface of the array.

Fig 2.15 Shows the manner in which array sensors are used. This figure Shows the Energy from an illumination Source being reflected from a Scene.

→ The first function performed by the imaging system in fig (c) is to Collect the incoming Energy & focus it onto an image plane.

→ If the illumination is light, the front End of the imaging System is an optical lens that projects the viewed Scene onto the focal plane of the lens, as fig (d) Shows.

→ The sensor array, which is coincident with the focal plane, produces o/p's proportional to the integral of the light received at each sensor.
→ Digital & analog circuitry sweep these o/p's & convert them to an analog signal, which is then digitized by another section of the imaging system.
→ The o/p is a digital image, as shown in fig (c).

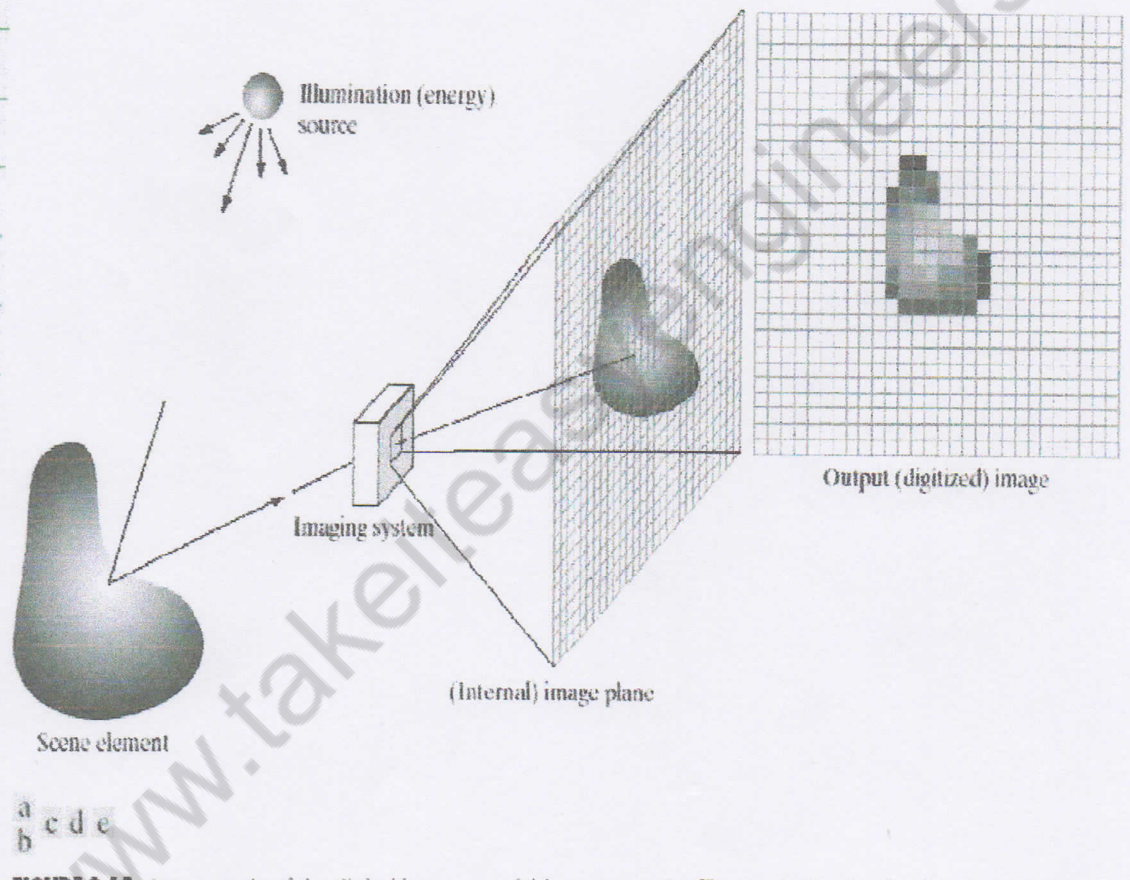


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Q: Explain with neat diagram, how image is acquired using sensor strips?
Q: Discuss the image acquisition using a single sensor, sensor strips & sensor arrays.

A Simple Image Formation Model:

Image denoted by 2-dimensional functions of the form f(x, y). The Value of f at spatial coordinat-es (x, y) is a scalar quantity whose meaning is determined by the source of the image & whose values are proportional to Energy radiated by a physical source (Eg. Electromagnetic waves).

* f(x, y) must be nonnegative & finite

i.e, $0 \leq f(x,y) < \infty$ → Eqⁿ ①

Function f(x, y) is characterized by 2 components:

(1) the amount of source illumination incident on the scene being viewed &

(2) the amount of illumination reflected by the objects in the scene.

These are called the illumination & reflectance components & are denoted by i(x, y) & r(x, y) respectively.

Therefore, 2 functions combine as a product to form f(x, y);

$$f(x,y) = i(x,y)\, r(x,y) \quad \rightarrow \text{Eq}^n \; ②$$

where

$$0 \leq i(x,y) < \infty \quad \rightarrow \text{Eq}^n \; ③$$

&

$$0 \leq r(x,y) \leq 1 \quad \rightarrow \text{Eq}^n \; ④$$

Thus, reflectance is bounded by 0 (total absorption) & 1 (total reflectance).

→ i(x, y) is determined by the illumination source & r(x, y) by the characteristics of the imaged objects.

Let the intensity (grey level) of a monochrome (one color) image at any coordinates (x,y) denoted by,

$$l = f(x,y) \qquad \rightarrow Eq^n \ 5$$

From Eq^n 2 & 3, it is evident that l lies in the range

$$L_{min} \leq l \leq L_{max} \qquad \rightarrow Eq^n \ 6$$

Theortically, L_{min} is to be nonnegative & L_{max} be finite.

& $L_{min} = i_{min} r_{min}$ & $L_{max} = i_{max} r_{max}$.

→ The interval $[L_{min}, L_{max}]$ is called the intensity (or gray) scale.

→ Common practice is to shift this interval numerically to the interval $[0,1]$ or $[0, C]$, where $l = 0$ is considered as black & $l = 1$ [or C] considered white on the scale.

→ All intermediate values are shades of gray varying from black to white.

*** V.Imp

Image Sampling & Quantization:

There are numerous ways to acquire images but objective is to generate digital images from sensed data.

→ To create a digital image, we need to convert the continuous sensed data into a digital format. This requires 2 processes: Sampling & Quantization.

Basic Concept's in Sampling & Quantization.

Fig shows a continuous image "$\underline{f}$" that we want to

Convert to digital form.

→ An image may be Continuous with respect to the x- and y- Coordinates, & also in amplitude.

→ To Convert it to digital form, we have to Sample the function in both Coordinates & in amplitude.

Digitizing the Coordinate values is called "Sampling"

Digitizing the amplitude values is called "Quantization"

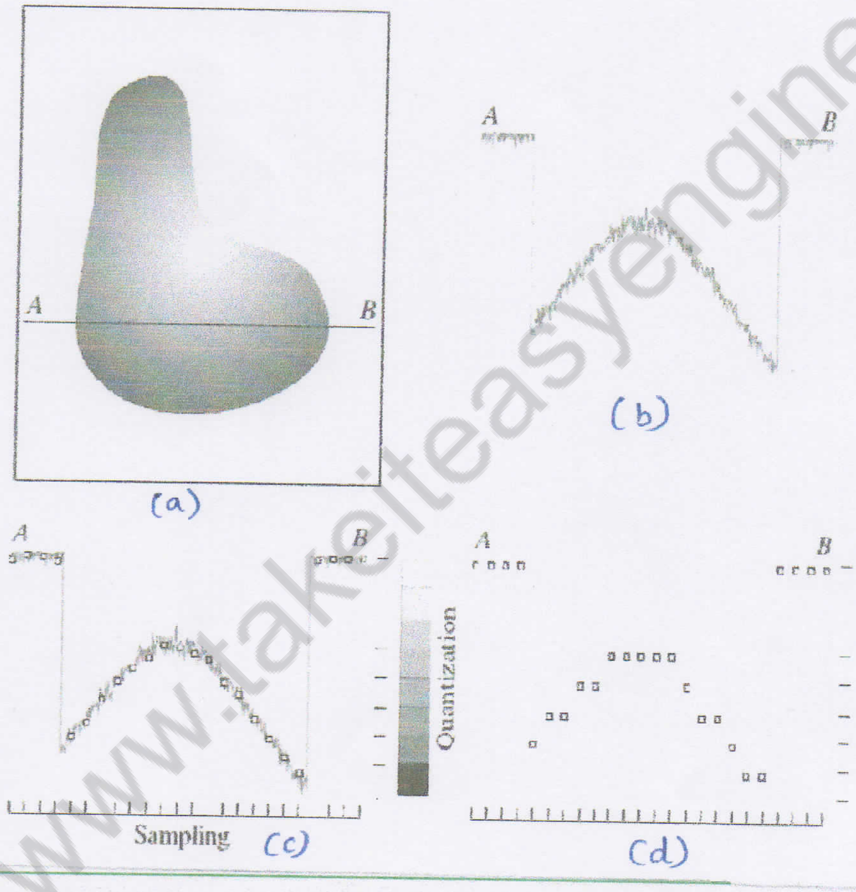


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Figure: Generating a digital image

(a) Continuous image

(b) A Scan line from A to B in the Continuous image, used to illustrate the Concepts of Sampling & Quantization.

(c) Sampling & Quantization (d) Digital Scan line.

→ The Fig (b) is a plot of amplitude (intensity level) Values of the Continuous image along the line segment AB in Fig (a). The random Variations are due to image noise.

→ To Sample this function, Equally Spaced Samples are taken along line AB, as in fig (c).

→ The Samples are Shown as Small dark Squares Super-imposed on the function & their (discrete) Spatial locⁿ are indicated by Corresponding tick marks in the bottom of figure.

→ The Set of dark Squares Constitute the "Sampled" function.

→ The "Values" of the Samples Still Span (vertically) a Continuous range of intensity values.

→ To get a digital function, the intensity or greylevel Values must be Converted (Quantized) into discrete Quantities.

→ The vertical gray bar in fig (c) Shows the intensity Scale divided into Eight discrete intervals, ranging from black to white. The vertical tick marks indicates the Specific value assigned to Each of the Eight intensity intervals.

→ The digital Samples resulting from both Sampling & Quantization are Shown as white Squares in fig (d).

The method of Sampling is determined by the Sensor arrangement used to generate the image.

→ when an image is generated by a Single Sensing Element Combined with mechanical motion, the o/p of the Sensor is quantized in the manner as above described.

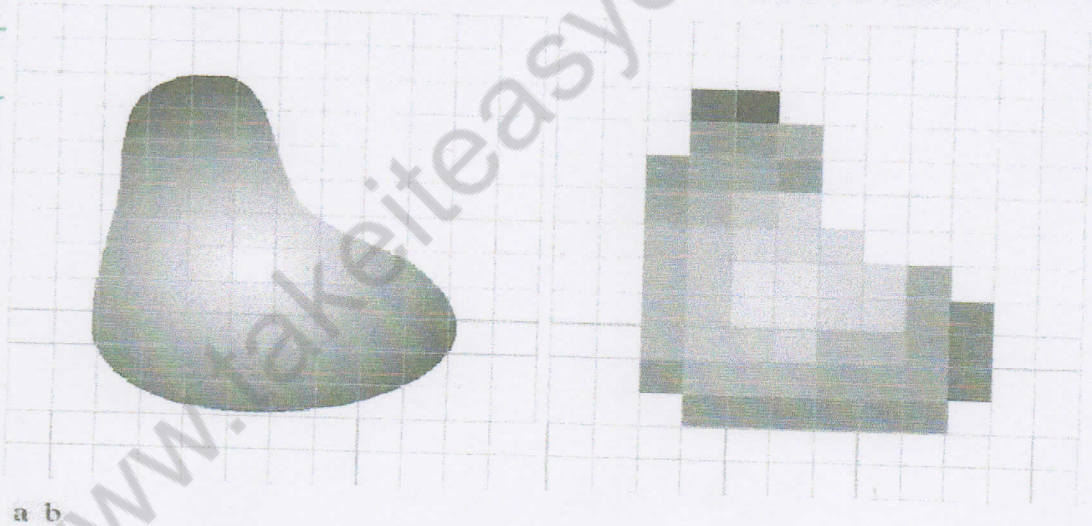
→ when a Sensing Strip is used for image acquisition, the number of Sensors in the Strip Establishes the Sampling limitation in one direction & mechanical motion Establishes the number of Samples in the other. Quantization of the Sensor o/p's Completes the process of generating a digital image.

→ when a Sensing array is used for image acquisition, there is no motion. The number of Sensors in the array Establishes the limit of Sampling in both directions. Digitization is done by Quantization of Sensor outputs.

Fig (a) Shows a Continuous image projected onto the plane of a 2-D Sensor & an array Sensor.

Fig (b) Shows image after Sampling & Quantization.

* The Quality of a digital image is determined by no of Samples & discrete intensity levels used in Sampling & Quantization.



a b

FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Q: Discuss the procedure of Sampling & Quantization

(or) Q: Explain the Steps involved in image digitization.

(or) Q: Explain the Concept of Sampling & Quantization of an image.

Representing Digital Images :

The result of Sampling & Quantization is a matrix of real numbers. Consider an image $f(x,y)$ which is Sampled Such that resulting digital image has M rows & N columns, where (x,y) are discrete Coordinates.

For notational clarity & Convenience, we use integer values for these discrete Coordinates: $x = 0,1,2,\ldots,M-1$ & $y = 0,1,2,\ldots,N-1$.

→ The value of the digital image at the origin is $f(0,0)$.
Fig 2.18 Shows, coordinate convention used to represent digital images.

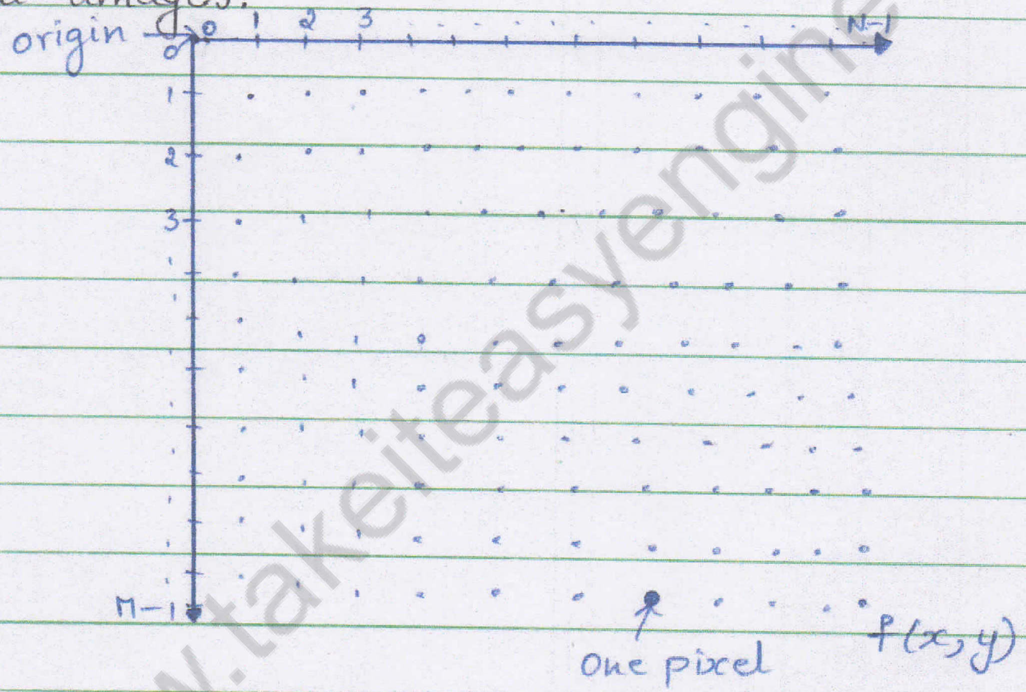


Fig 2.18 Conventional Coordinate system for Image Representation

we write the representation of an MxN numerical array as

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

→ This Eq^n is a digital image represented as an array of real numbers.

* Each Element of this array is called an image Element, picture Element, pixel or pel.

→ Traditional matrix form can also be used to represent a digital image:

$$A = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\ \vdots & \vdots & & \vdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix}$$

when we refer Specific Coordinates (i, j) we use $f(i,j)$ where the arguments are integers.

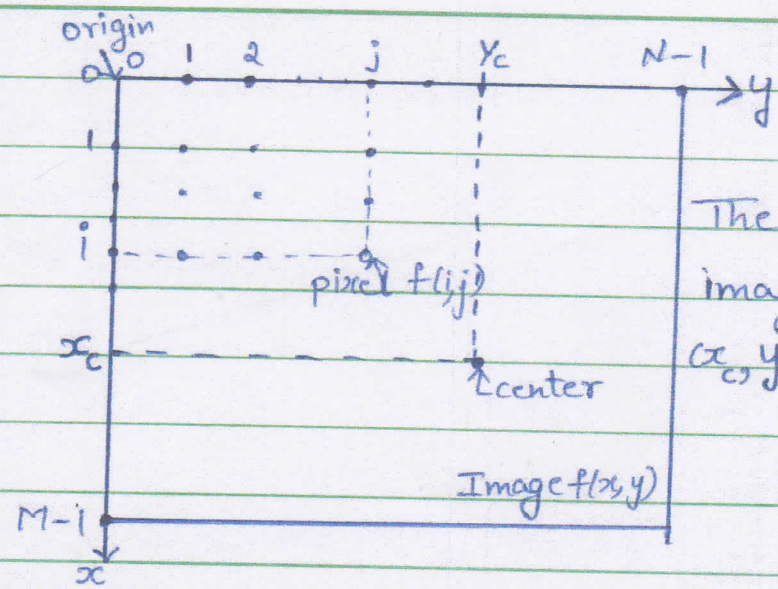
clearly, $a_{ij} = f(i,j)$ & $f(x=i, y=j)$

→ The center of an $M \times N$ digital image with origin at $(0,0)$ & Range to $(M-1, N-1)$ is obtained by dividing M & N by 2 & rounding down to the nearest integer. This operation Sometimes is denoted using the floor operator, $\lfloor \cdot \rfloor$ as shown in fig 2.19

→ This holds true for M & N Even or odd.

For Eg:, Center of an image of Size 1023×1024 is at $(511, 512)$. So, In matlab, start indexing at 1 Instead of at 0. The center of an image in that case is found at $(x_c, y_c) = (\text{floor}(M/2)+1, \text{floor}(N/2)+1)$.

→ Image digitization requires decisions about the values for M, N & for the number "L" of grey Intensity levels



The coordinates of the image center are $(x_c, y_c) = (\text{floor}(M/2), \text{floor}(N/2))$

Fig2.19: Coordinate Convention used to represent digital images. Because coordinate values are integers, there is a One-to-one Correspondence b/w x & y & the rows(r) & Columns (c) of a Matrix.

→ "M" & "N" have to be positive integers, & no of intensity levels 'L' an integer power of 2.

i.e $L = 2^K$

where K is an integer.

→ we assume that the discrete levels are Equally spaced & they are integers in the range $[0, L-1]$.

→ Thus, number "b" of bits required to store a digital image is

$$b = M \times N \times K$$, when $M = N$

this Eqn becomes,

$$b = N^2 K$$

So, when an image has 2^K gray/Intensity levels, it is referred to as "K-bit image",

For Eg: An image with 256 gray/intensity levels is called an 8-bit image i.e $2^8 = 256$.

Q: Explain the data Structure of representing digital image.

Spatial & Intensity Resolution :

The Spatial Resolution of an image is determined by how Sampling was Carried out.

→ Spatial resolution is a measure of the Smallest discernible detail in an image.

→ Spatial resolution can be Stated with line pairs per unit distance, & dots (pixels) per unit distance.

* Vision specialists will talk about pixel size.
* Graphic designers will talk about dots per inch (DPI).

Intensity Level Resolution refers to the no of gray or Intensity levels used to represent the image.

→ Intensity resolution refers to the Smallest discernible change in intensity level.

* The more intensity levels used, the finer the level of detail discernable in an image.
* Intensity level resolution is usually given in terms of the number of bit's used to store Each intensity level.

Digital Image Types :

① Intensity or Monochrome image

* Each pixel Corresponds to light intensity normally represented in gray Scale (gray level).

② Binary image or black & white image

* Each pixel Contains one bit : 1 represent white
  0 represents black

③ Index image

* Each pixel Contains index number pointing to a color in a Color table.

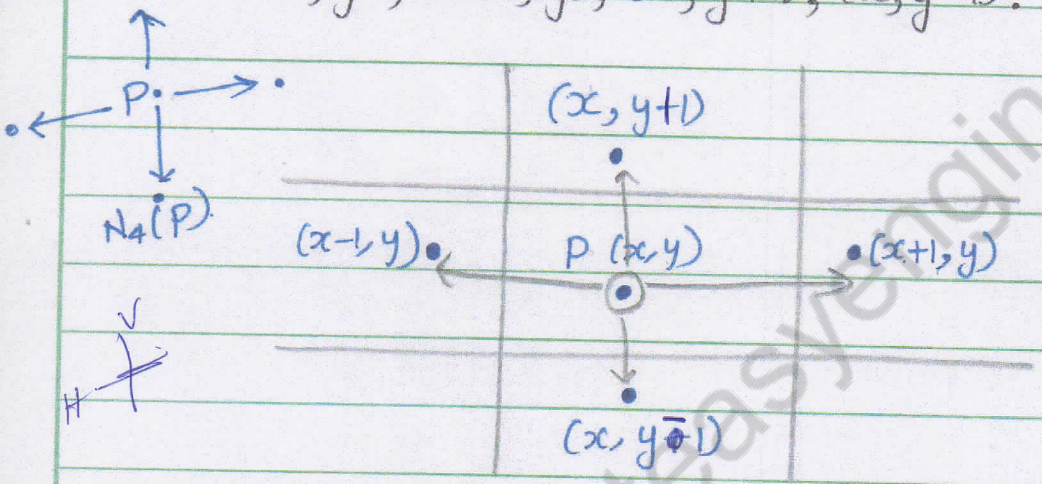
Some Basic Relationship Between pixels:

An analog image is digitized to be represented as a digital image with M rows & N columns. Each Element of 2D matrix is termed as pixel & is denoted using a lower case letter, Such as p or q

1) Neighbors of a pixel:

A pixel p at coordinates (x, y) has two horizontal & two vertical neighbors, whose coordinates are given by,

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



4-neighbors of P:

$$N_4(P) = \begin{bmatrix} (x-1, y) \\ (x+1, y) \\ (x, y-1) \\ (x, y+1) \end{bmatrix}$$

* 4 Neighborhood relation considers only vertical & horizontal neighbors

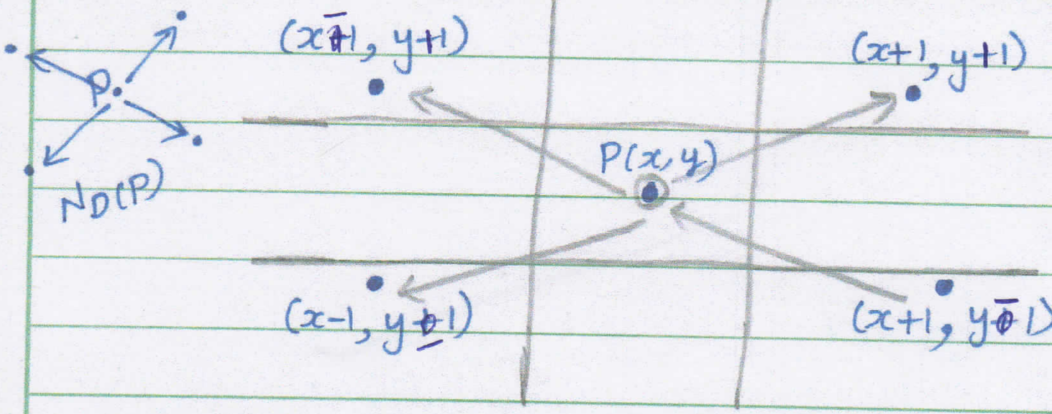
→ This set of pixels are called the 4-neighbors of P, is denoted by $N_4(P)$.

→ Each pixel is a unit distance from (x, y)

→ if (x, y) is on the border of the image then some of the neighbor locations of p lie outside the digital image.

⇒ The four diagonal neighbors of $p(x, y)$ are given by,
$(x+1, y+1)$ $(x+1, y-1)$, $(x-1, y+1)$, $(x-1, y-1)$ & denoted by $N_D(p)$.

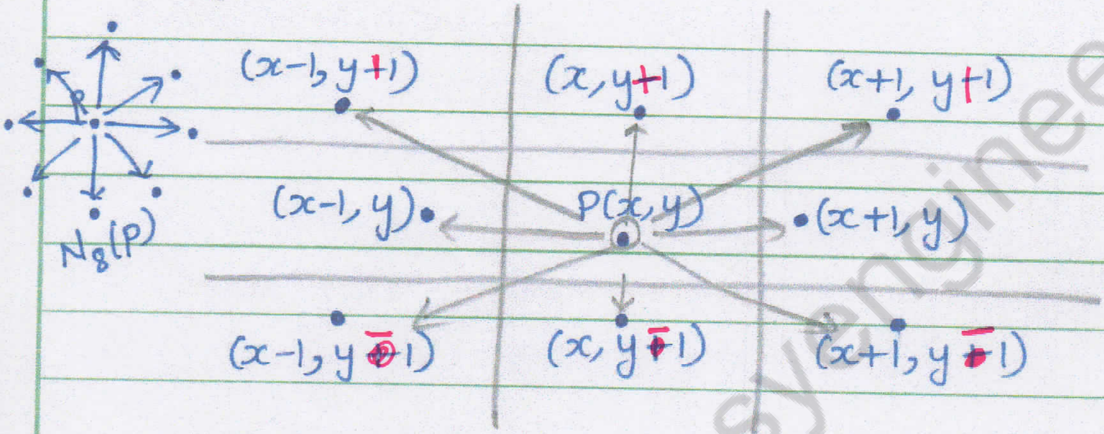
→ The 4 Neighbors along with diagonal neighbors are called 8 neighbors of $p(x, y)$ & denoted by $N_8(P)$.



Diagonal neighbors of P :

$$N_D(P) = \begin{bmatrix} (x-1, y-1) \\ (x+1, y-1) \\ (x+1, y+1) \\ (x-1, y+1) \end{bmatrix}$$

* diagonal neighborood relation Considers only diagonal neighbor pixel.



8 neighbors of is union of 4-neighbors & diagonal neighbors of p i.e $N_8(P) = N_4(P) \cup N_D(P)$.

8 neighbors of P = $N_4(P)$ & $N_D(P)$.

2) Adjacency: Two pixels are Connected if they are neigh-bors & their gray levels Satisfy Some Specified Criterian of Similarity.

For Eg, In a binary image 2 pixels are Connected if they are 4-neighbors & have Same value (0/1).

→ Let $\underline{V}$ be Set of gray levels used to define adjacency

→ In a binary image, V = {1}, if we are referring to adjacency of pixels with value $\underline{1}$.

→ for a grayscale image, V contains more elements.
Eg: if gray value ranges from 0 to 255, V could be any subset of 256 values.

Three types of Adjacency:

1) 4-Adjacency: Two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$.

2) 8-Adjacency: Two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(P)$.

3) m-Adjacency: Two pixels p and q with values from V are m-adjacent if, (i) q is in $N_4(P)$

(ii) q is in $N_D(P)$ & the set $[N_4(P) \cap N_4(q)]$ is Empty [has no pixels whose values are from V].

i.e $N_4(P) \cap N_4(q) = \phi$.

m-Adjacency → Mixed Adjacency.

→ Mixed adjacency is a modification of 8-adjacency. It eliminates the ambiguities that often arise when 8-adjacency is used.

Eg: Consider the pixel arrangment shown in fig (a). for $V = \{1\}$.

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

fig (a)
An arrangement of pixels

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

fig (b)
pixels that are 8-adjacent to center pixel (adjacency is shown by dashed lines note the ambiguity)

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

fig (c)
m-adjacency.

→ The 3 pixels at the top of fig (b) shows multiple (ambiguous) 8-adjacency, as shown by the dashed lines.
→ This ambiguity is removed by using m-adjacency as shown in fig (c).

path: A (digital) path (or curve) from pixel p with coordinates (x, y) to pixel q with coordinates (s, t) is a sequence of distinct pixels with coordinates,

$$(x_0, y_0), (x_1, y_1), \ldots, (x_n, y_n).$$

where,

$$(x_0, y_0) = (x, y) \; \& \; (x_n, y_n) = (s, t).$$

& pixels (x_i, y_i) & (x_{i-1}, y_{i-1}) are adjacent for $1 \leq i \leq n$, where $\underline{n}$ is the length of the path.
if $(x_0, y_0) = (x_n, y_n)$

Connectivity [Connected Component]: Let "S" represent a subset of pixels in an image. Two pixels p & q are said to be connected in 'S' if there exists a path between them consisting entirely of pixels in S.
Eg: for any pixel p in S, the set of pixels that are connected to it in S is called a connected component of S.
If it is only has one connected component, then set S is called a connect set.

Connectivity:
Let 'V' be the set of gray-level values used to define connectivity the 2 pixels p, q that have values from the set V are:

* 4 connected, if q is the set $N_4(p)$.

$$\begin{bmatrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

* 8 Connected, if q is in the set $N_8(P)$.

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

* m-Connected, if q is in $N_4(P)$ or q is in $N_D(P)$ & the set $[N_4(P) \cap N_4(q)]$ is Empty.

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

Regions & Boundaries:

Let 'R' be a subset of pixels in an image, R is Called a Region of the image if 'R' is a Connected set.

The boundary (border or Contour) of the region R is the set of pixels in the region that have one or more neighb-ors that are not in R.

(or)

The border of a region is the set of pixels in the region that have one or more neighbors that are not in R.

→ If R happens to be an Entire image, then it's boundary is defined as the set of pixels in the first & last rows & columns of the image.

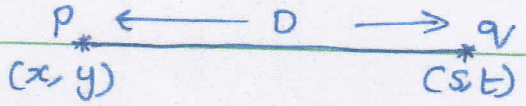
Distance Measures:

Consider three pixels p, q & z with Coordinates (x, y) (s, t) & (v, w) respectively, the distance function D has following properties;

a) $D(p,q) \geq 0$ $[D(p,q) = 0, \text{ if } p = q]$

b) $D(p,q) = D(q,p)$

c) $D(p,z) \leq D(p,q) + D(q,z)$



The following are the different Distance measures:

1) Euclidean Distance: b/w p & q defined as

$$\langle D_e(p,q) = [(x-s)^2 + (y-t)^2]^{1/2} \rangle$$

2) City-Block Distance [D_4 distance]: b/w p & q defined as

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

⇔ Sum values traversed along x-axis + values traversed along y-axis

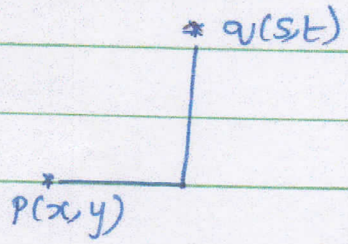
→ The pixels having distance less than or Equal to some value r from (x,y) are the points contained in a disk of radius r centered at (x,y).

→ The pixels having a D_4 distance from (x,y) less than or Equal to some value r form a diamond centered at (x,y).

For Eg: the pixels with D_4 distance ≤ 2 from (x,y) (center point) form the following contours of constant distance:

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

center p(x,y)



The pixels with $D_4 = 1$ are the 4-neighbors of (x,y).

3) Chess Board Distance [D_8 distance]: b/w p & q defined as

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

$\Leftrightarrow$ is max of distance covered along x direction & y direction.

→ The pixels with D_8 distance from (x,y) less than or Equal to some value r from a square centered at (x,y).

Eg: The pixels with D_8 distance ≤ 2 from (x,y) (center point) form the following contours of constant distance:

$$\begin{matrix} 2 & 2 & 2 & 2 & 2 \\ 2 & 1 & 1 & 1 & 2 \\ 2 & 1 & 0 & 1 & 2 \\ 2 & 1 & 1 & 1 & 2 \\ 2 & 2 & 2 & 2 & 2 \end{matrix}$$

→ The pixels with $D_8 = 1$ are the 8-neighbors of (x,y).

Eg: Consider a sample image shown below:

	0	1	2	3	
0	0	1	1	1	
1	1	0	0	1	
2	1	1	1	1	(q)
3	1	1	1	1	
	(p)				

Let $V = \{0,1\}$ & the pixel coordinates of p & q be $(3,0)$ & $(2,3)$ respectively. Compute D_e, D_4 & D_8 distances b/w 2 pixels p & q.

Given: $(x,y) = (3,0)$ & $(p,q) = (2,3)$ i.e $(s,t) = 2,3$

Sol^n: The Euclidean distance is $D_e = \sqrt{(x-s)^2 + (y-t)^2}$

$$D_e = \sqrt{(3-2)^2 + (0-3)^2}$$
$$= \sqrt{1+9}$$
$$= \sqrt{10}$$

The city block Distance is $D_4 = |x-s| + |y-t|$

$$= |3-2| + |0-3|$$
$$= 1 + 3 = \underline{4}$$

The chess Board distance is : $D_8 = \max(|x-s|, |y-t|)$

$= \max(|3-2|, |0-3|)$

$= \max(1, 3)$

$= \underline{3}$

Q: Define 4-, 8- & m- adjacency.

Q: Compute the length of the Shortest 4-, 8- & m- path between p & q in the image Segment in fig Q.b by Considering V={2,3,4}

	3	4	1	2	0	
	0	1	0	4	2	(q)
	2	2	3	1	4	
(p)	3	0	4	2	1	
	1	2	0	3	4	

Fig Q.b

Q: Explain following terms:

(i) Neighbors (ii) Connectivity of pixels (iii) Euclidean distance (iv) Cityblock distance (v) path (vi) chess Board distance (vii) Region & Boundaries.

Q: Consider the 2 image Subset S1 & S2 as shown in Q. for V={1}. Determine whether these 2 subsets are (i) 4-adjacent (ii) 8-adjacent (iii) 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	q 1	1	0	0	0
0	0	1	1	p 1	0	0	0	0	0
0	0	1	1	1	0	0	1	1	1

Q: Explain different distance metrics used in image processing with Example.

important

Applications of Image processing:

Digital image processing is widely used in diffe-rent fields including Medical Imaging, Forensics, Robot vision, character Recognition, Remote Sensing, Communicati-ons, Automotives & so on.

i) Medical Imaging: There are various ways in which image processing can be applied to the field of medicine

(a) Gamma-Ray Imaging: Major application of Gamma Ray imaging is nuclear medicine. The approaches to inject a patient with a radioactive isotope that Emits gamma rays as it decays.

* Images are produced from the Emissions collected by gamma rays detectors. Images produced so can be used to locate bone pathology such as infections or tumors.
* PET (position Emission Tomography) also works on same principle. It's similar to X-Ray Except that instead of External source, patient is given a radioactive isotrope that Emits positrons as it decays.
* A Tomographic image is created which can be used to diagonise tumors.

(b) X-Ray Imaging: X-Ray imaging is Extensively used in medical diagnostics. X-Rays for medical imaging are generated using X-Ray tube which is a vaccum tube with a cathode and anode.

* The cathode is heated to generate free Electron to be released & these flow at high speed to the positively charged anode.
* when the Electrons strike a nucleus, Energy is released in

form of X-Ray radiations.

* The Energy (penetrating power) of x-rays is Controlled by a voltage applied to anode & few x-rays are Controlled by a current applied to filament in the cathode.
* The intensity of the X-Rays is modified by absorption as they pass through the patient & Resulting Energy falling on the film sensitive to x-ray Energy.

In digital radiography, digital images are obtained by one of 2 methods: (1) By digitizing x-ray films &
(2) By having the x-Rays that pass through the patient fall directly onto devices (such as phosphor screen) that Convert X-rays to light.

* Angiography is another major application used to obtain images Called angiograms of blood vessels.

→ A Catheter (Small, flexible, hollow tube) is inserted into an artery or vein in the groin. The catheter is threaded into the blood vessel & guided to the area to be studied. when the Catheter reaches the Site under investigation, an x-ray Contrast medium is injected through the tube. This Enhances Contrast of the blood Vessels & Enables the radiologist to see any irregularities or blockages.

* Another application of X-Ray imaging is Computerized Axial Tomography (CAT) or CT Scan (computer tomography) Each CAT image is a "slice" taken perpendicularly through the patient. Numerous slices are generated as the patient is moved in longitudinal direction. The Ensemble of such images Consititutes a 3-D image of the inside of patient body.

(c) Imaging in RadioBand: In Medicine, radio waves are used in magnetic resonance imaging (MRI).

→ This technique places a patient in a powerful magnet & passes radio waves through patient body in short pulses. Each pulse causes a responding pulse of radio waves to be emitted by the patient's tissues. The location from which these signals originate & their strength are determined by a c/m, which produces a 2-dimensional picture of a section of the patient.

[A MRI scan uses harmful ionizing radiation].

(d) Ultrasound Imaging: In medicine, especially in obstetrics, where unborn babies are imaged to determine the health of their development.

Ultrasound images are generated using following procedure:

1) The ultrasound system (a c/m, ultrasound probe consisting of a source & receiver & a display) transmits high frequency (1 to 5MHz) sound pulses into the body.

2) The sound waves travel into the body & hit a boundary b/w tissues (b/w fluid & soft tissue, soft tissue & bone). Some of the sound waves are reflected back to the probe, while some travel on further until they reach another boundary & get reflected.

3) The reflected waves are picked up by the probe & relayed or transmitted to the computer.

4) The machine calculates the distance from the probe to the tissue or organ boundaries using the speed of sound in tissue (1540 m/s) & the time of each echo's return.

5) The system displays the distances & intensities of the echoes on the screen, forming a 2-d image.

2) Robot Vision: is process of Extracting, characterizing & interpreting information from images. Robot vision is primarily targeted at manipulation & interpretation of image & use of this information in robot operation Control

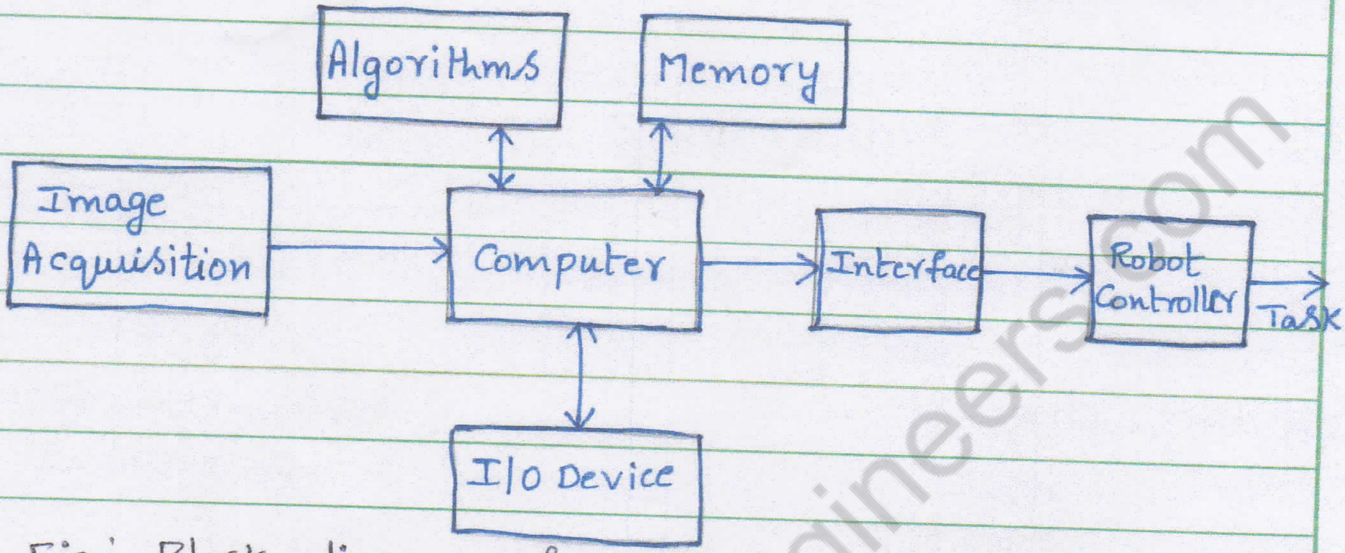


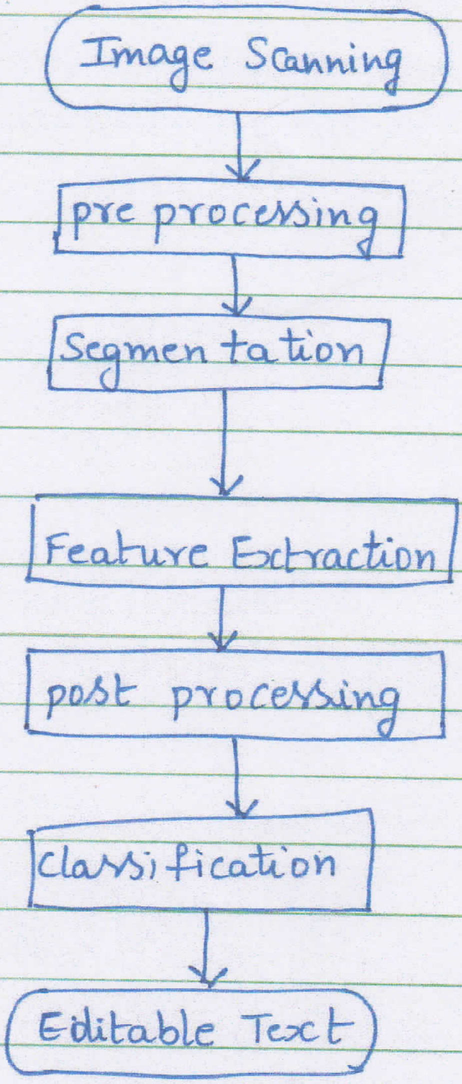
Fig: Block diagram of a simple robot vision

→ The image acquired is processed using various algorithms & the processed o/p is processed onto a robot Controller through an interface. The various applications of robotic vision includes inspection, part identification, location & orientation, security & surveillance, autonomous vehicles, mobile robots for navigation used to remove parts with defects.

3) Character Recognition:

optical character recognition is process of Converting images of typed, handwritten or printed text into machine Encoded text (Editable). It is a Common method of digitising printed texts so that they can be Electronically Edited, Search, Stored & so on.

The process of character recognition is shown in flow-chart below:



An image scanner is used to scan images, pictures or printed text & converts it into digital images.
The preprocessing is done to produce a binary image that contains text only.
Segmentation : Digital image is partioned into multiple segments used to locate objects & boundaries.
Feature Extraction: Features are extracted & is passed through post processing stage.
A suitable classifier is used to classify the extracted character.
The extracted character is converted to editable text.

4) Remote Sensing: is defined as any process where information about object, area as phenomenon is gathered without being in contact with it. It includes several bands in visual & infrared regions.

NASA'S LANDSAT Satellite is used to obtain & transmit images of the Earth from space for purpose of monitoring Environmental Conditions on the planet.

* Major applications of multispectral imaging from satellites includes weather observation & prediction. It is used to assess population growth, & shift patterns, pollution & other factors harmful to the Environment.

The images generated by National oceanographic & Atmospheric Administration (NOAA) can be used for oceanic observations of hurricanes & storms.

Similarly NOAA DMSP (defens Meterological satellite program) Satellite pictures can be used for global invent-ory of human settlements, these images are part of the Nighttime Lights of the world data set.

* A computer program can be written that would use these images to estimate the percent of total Electrical Energy used.

Q: Mention any four fields that use digital image processing.

Q: Explain any 2 application of digital image processing with Example.

Ranjit KN

[Dr. RANJIT K.N]

MITT