Code:- R22EC713PE

R22

CMR ENGINEERING COLLEGE - HYDERABAD

IV B.TECH I SEMESTER END EXAMINATIONS - Dec-2025

DIGITAL IMAGE PROCESSING

(ECE)

PART-A

1a	Image Sampling definition	(1M)
b)	Define pixel and its importance	(1M)
c)	Image Enhancement - Improves the visual apperance	(1M)
d	Relation Spatial domain and frequency domain filters	(1M)
e	write the causes of Image degradation	(1M)
f	Satellite Images, medical Images	(1M)
g	$A \oplus B = \{ z \mid (\hat{B})_z \cap A \neq \emptyset \}$	(1M)
h	write two methods:- Sobel, Prewitts	(1M)
i)	advantages of JPEG 2000 over standard JPEG	(1M)
j	Image Compression definition	(1M)

PART-B

2	Image transforms - 2m, Significance Image Transforms in Enhancement, morphology, Restoration	(8m)

3) 2D DCT Expression derivation — (6m)
advantages of 2-D DCT compression over Comp (4m)

4 Image Enhancement — 2m, Design procedure — (4m), Explanation of Image Enhancement in Freq. (4m)

5) Definition of histogram Technique — (2m)
histogram Equalization with Ex:- (4m)
histogram stretching with Example:- 4m
10m

6 Inverse filtering in restoration — (2m)
Block diagram — 2m
Derivation and Explanation — 6m
10m

7) Constrained Least Square — (2m)
Block diagram — (3m)
Derivation Explanation — 5m
10m

8) morphology opening — 5m
Morphology closing — 5m
10 M

9) Detection of Discontinuities — 4m, Edge detection — 4m
Boundary Detection — 2M

10 Block diagram of JPEG — 2m,
DCT — 3m, quantization — 3m, Entropy Encoding — 2m

11) Image compression models — (2m)
lossy — 4m, lossless — 4m

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PART-A.

1(a)	Image Sampling is the process of selecting discrete points (pixels) from a continuous image in the spatial domain to form a digital Image.
b)	A pixel is the smallest picture element in a digital image; it represents the intensity at a specific location. Importance:- pixels collectively form a entire digital image and determine its resolution and detail.
(c)	Image Enhancement is the process of improving an image's visual apperance or making its features more suitable for analysis
d)	A spatial domain corresponds to a frequency domain filters through the Fourier Transform i.e Convolution in spatial domain $\longleftrightarrow$ Multiplication in frequency domain
(e)	Causes of Image degradation noise, blur, sensor defects, Atmospheric turbulance, motion,

f)	Removing motion blur or noise from satellite images medical images to recover original details.
g)	For an Image A, structuring Element B Dilation $A \oplus B = \{ z \mid (B)_z \cap A \neq \phi \}$
h)	methods of Edge detection → Sobel operator → prewitt operator
i)	(1) provides better image quality at higher compression ratios due to wavelet based compre-ssion (2) lossless compression capability
j)	Image Compression is the process of reducing the amount of data required to represent a digital image by removing redundant or irrelevent information.
	PART-B
2)	<u>Significance of Image Transforms in Image Processing</u>:- → Image Transforms Fourier, DCT, wavelet, KL) Convert the image from Spatial to frequency domain → Enhancement, Compression, restoration Wavelet

Image Enhancement :- (i) Simplifies Image Analysis

Transforms like the fourier Transform FT seperate an image into its frequency components.

low frequencies → Smooth | Intensity } Enable Efficient Ehancement
High frequencies → Edge, fine

Image Restoration :- Many image Enhancement and restoration operations are easier in the frequency domain

→ Noise removal
→ Edge sharpening
→ Smoothing | blur operations

— A applying a low pass | high pass filter is mathematically simpler and more efficient in the transform domain.

Image Compression :- Transforms help remove redundancy and represent images compactly.

→ DCT is the basis of JPEG compression
→ Wavelet Transform is used JPEG 2000.

Transforms concentrate most of the image energy in fewer coefficients, allowing effective compression without significant quality loss.

Pattern Recognition :-

Transform like Hough Transform → line
Walsh → texture

Image transforms are Significant

→ Simplify image representation
→ Enable Efficient filtering and enhancement
→ Improve compression and restoration
→ provide multi resolution analysis
→ Reduce computational complexity.

(3) 2D Discrete cosine Transform (2-D DCT)

The N×N Cosine transform matrix

For 1-D Sequence $x[n], n=0, \ldots, N-1$, the forward DCT-II Coefficients $X[k]$ are.

$$X[k] = \alpha[k] \sum_{n=0}^{N-1} x[n] \cos\left(\frac{\pi(2n+1)k}{2N}\right)$$

$$\alpha[k] = \sqrt{\frac{1}{N}}, \; k=0$$
$$\sqrt{\frac{2}{N}}, \; k = 1, 2, \ldots N-1$$

The inverse 1-D DCT

$$x[n] = \sum_{k=0}^{N-1} \alpha(k) X[k] \cos\left(\frac{\pi(2n+1)k}{2N}\right), n=0 \ldots N-1$$

Extend to 2-D by seperability

2D DCT N×M image block $f(x,y)$ $x=0, \ldots N-1$

Forward 2-D DCT

$$F(u,v) = \alpha(u)\alpha(v) \sum_{x=0}^{N-1} \sum_{y=0}^{M-1} f(x,y) \cos\left(\frac{\pi(2x+1)u}{2N}\right) \cos\left(\frac{\pi(2y+1)v}{2M}\right)$$

for $u=0 \ldots N-1$, $v=0,1,\ldots M-1$

$$\alpha(u)=\begin{cases}\sqrt{1/N}, & u=0\\ \sqrt{2/N}, & u\geq 1\end{cases} \qquad \alpha(v)=\begin{cases}\sqrt{1/M} & v=0\\ \sqrt{2/M} & v\geq 1\end{cases}$$

Inverse DCT :-

$$f(x,y)=\sum_{u=0}^{N-1}\sum_{v=0}^{M-1}\alpha(u)\alpha(v)F(u,v)\cos\left(\frac{\pi(2x+1)u}{2N}\right)\cos\left(\frac{\pi(2y+1)v}{2M}\right)$$

Advantages of 2-D DCT for image compression

DCT Excels over DFT/Fourier by using real valued cosines, avoiding imaginery components and periodic discontinuities that cause artifacts like ringing in truncated signals.

DFT :- Complex Coefficients, less efficient energy compaction for real images, DCT is real and usually better for compression

Wavelets :- provide multi resolution representation and often produce fewer blocking artifacts and better compression at low bitrates

KLT :- data dependent and Expensive, DCT is fixed, fast and close to optimal for many images.

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4) Enhance an image by modifying its frequency Content : remove periodic noise, smooth (low pass) sharpen(high pass) or correct illuminaton

Frequency domain filtering works by transforming the image to the frequency domain, applying a filter transfer function $H(u,v)$, then transforming

Let $f(x,y)$ be an $M \times N$ image, 2D-DFT and inverse DFT

$$F(u,v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y)\, e^{-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)}, \quad u=0 \ldots M-1, \; v=0 \ldots N-1$$

$$f(x,y) = \frac{1}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u,v)\, e^{j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)}$$

Filtering in frequency domain

$$\boxed{G(u,v) = H(u,v)\, F(u,v)}$$

Algorithm for implementing Enhancement

(i) preprocessing & padding $P \geq 2M$, $Q \geq 2N$

Create padded image $f_p(x,y)$ of size $P \times Q$ with zeros place f in the top left or centre.

(ii) Compute DFT

$F(u,v) = DFT\{f_c\}$ using 2D-FFT for speed.

(iii) Design filter $H(u,v) \rightarrow H$ must be $P \times Q$ size.

$\rightarrow$ low pass Gaussian $H_{LP}(u,v) = e^{-\frac{D(u,v)^2}{2D_0^2}}$

$\rightarrow$ High pass : $H_{HP} = 1 - H_{LP}$ or high boost

$$H_{HB} = A + (1-A)\, H_{HP}$$

Butterworth $H_B(u,v) = \dfrac{1}{1+\left(\dfrac{D(u,v)}{D_0}\right)^{2n}}$

$$D(u,v) = \sqrt{(u-P/2)^2 + (v-Q/2)^2}$$

4

Apply filter
multiply $G(u,x) = H(u,v) \cdot F(u,v)$

Inverse filter DFT $\Rightarrow g_c(x,y) = IDFT\{G(u,v)\}$

Crop:- multiply by $(-1)^{x+y}$ again: $g_p(x,y) = g_c(x,y) \cdot (-1)^{x+y}$

Low pass filtering (Smoothing)

Apply an ideal filter $H(u,v) = 1$ if $\sqrt{u^2+v^2} \le D_0$

D_0 cutoff frequency

The cutoff frequency determines the amount of frequency Components passed by the filter. The Smaller the value of D_0 greater the No of images Components Eliminated by the filter.

High pass filter in frequency filter

$$H(u,v) = \begin{cases} 0, & \text{if } D(u,v) \le D_0 \\ 1, & \text{if } D(u,v) > D_0 \end{cases}$$

5) Histogram processing Techniques:- Histogram of an image is a plot graph between drawn between gray level values (0 to 255) in X-axis & no. of pixels having the corresponding gray level in Y-axis

$\boxed{h(r_k) = n_k}$ r_k - k^{th} gray level

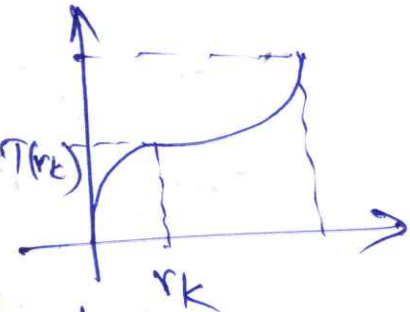
n_k - Number of pixels in the image

Histogram Equalization :- Is a process of automatically determing a transformation function which produces an output image with a uniform histogram. This is transformation function is different for continuous and discrete.

let 'r' represents the gray levels of the image to be Enhanced Interval [0,1]

Transfer function $s = T(r) \quad 0 \leq r \leq 1$

Inverse Transform $r = T^{-1}(s)$



Histogram Stretching (contrast stretching)

→ Is a simpler technique that expands the range of intensity levels to fill the available dynamic range (0 to 255 for 8 bit images)

The transformation function is

$$s = \left(\frac{r - r_{min}}{r_{max} - r_{min}} \right) \times (L-1)$$

Procedure to perform Histogram Equalization

→ find the running sum of the histogram values.

→ Normalize the values from step(1) by dividing by the total no of pixels

→ multiply the values from step (2) by the minimum gray level value and round.

→ Map the gray level values to the values from step (3) using a one to one correspondance.

Ex:

$$\begin{bmatrix} 4 & 4 & 4 & 4 & 4 \\ 3 & 4 & 5 & 4 & 3 \\ 3 & 5 & 3 & 5 & 3 \\ 3 & 4 & 5 & 4 & 3 \\ 4 & 4 & 4 & 4 & 4 \end{bmatrix}$$

6) <u>Inverse filtering</u> :- Inverse filtering is the process of <u>recovering</u> the input of a system from its output.
Inverse filters are used for precorrecting an i/p signal in anticipation of the degradation caused by the system.

— An estimate $\hat{F}(u,v)$ of the transform of the original image is obtained by dividing the transform of the degraded image $G(u,v)$ by the degradation function.

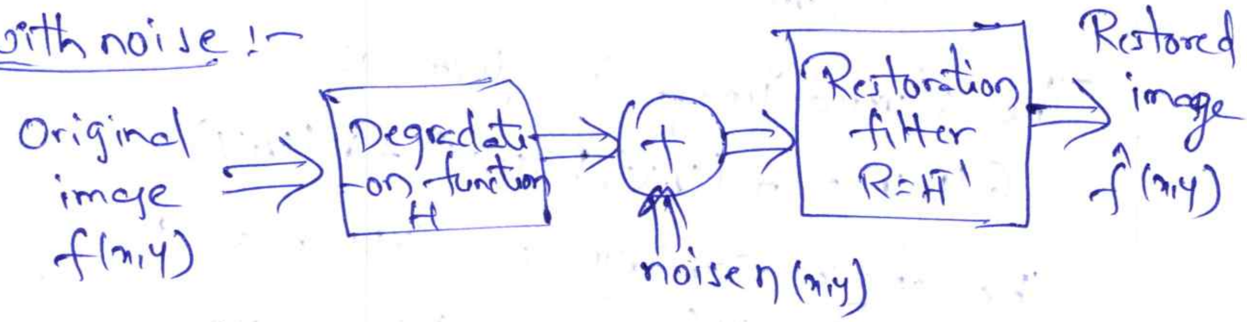
$$\hat{F}(u,v) = \frac{G(u,v)}{H(u,v)}$$

→ Image function $f(x,y)$ and blurring function $h(x,y)$ we need recover $f(x,y)$ from the convolution $g(x,y) = f(x,y) *$

$$\boxed{g(x,y) = f(x,y) * h(x,y)}$$

Same Explanation without noise ⇒ $\hat{F}(u,v) = F(u,v)$

<u>with noise</u> :-



$$\hat{F}(u,v) = R(u,v)\,G(u,v) = H^{-1}(u,v)\,G(u,v) = \frac{G(u,v)}{H(u,v)}$$

$$G(u,v) = F(u,v) * H(u,v) + \eta(u,v)$$

$$\hat{F}(u,v) = \frac{G(u,v)}{H(u,v)} = \frac{F(u,v)\,H(u,v) + \eta(u,v)}{H(u,v)}$$

Simplify the Expression

$$\boxed{\hat{F}(u,v) = F(u,v) + \frac{\eta(u,v)}{H(u,v)}}$$

Here along with the original image, noise is also added. Hence restored consist of noise.

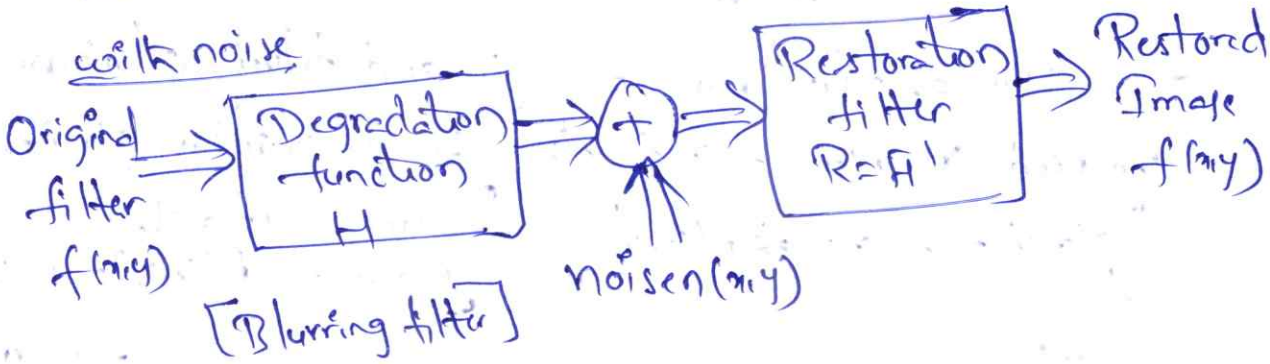
Draw backs :-

1. Doesnot perform well when used on noisy images.
2. In the absense of noise if $H(u,v)=0$, then

$$R(u,v) = H^{-1}(u,v) = \frac{1}{H(u,v)} = \frac{1}{0} = \text{Infinite}$$

7) ## Constrained Least Square restoration technique

In weiner filter, the power spectra of the undergraded image and noise must be known. Constrained least square (CLS) filtering just require the mean and variance of the noise.



The Blurred image is given as

$$G(u,v) = H(u,v)F(u,v) + \eta(u,v)$$

The above Equation is expressed as

$$\boxed{g = Hf + \eta} \Rightarrow \eta = g - Hf \quad \text{--- (1)}$$

To find the minimum criterion function C

$$C = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left[\nabla^2 f(x,y)\right]^2$$

$$\Rightarrow \|g - H\hat{f}\|^2 = \|\eta\|^2 \quad \text{--- (2)}$$

$\nabla^2 f$ = laplacian

$\|\eta\|^2$ = Euclidean vector.

Solution to the problem :- The frequency domain solution to this optimization problem is given by

$$\hat{F}(u,v) = \left[\frac{H^*(u,v)}{|H(u,v)|^2 + \gamma |P(u,v)|^2} \right] G(u,v)$$

$$\Rightarrow \|n\|^2 = \|g - H\hat{f}\|$$

$$p(x,y) = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \Rightarrow \boxed{C(u,v) = 4 - 2\cos\left(\frac{2\pi u}{M}\right) - 2\cos\left(\frac{2\pi v}{N}\right)}$$

Advantages CLS Technique :-

- Controls the noise amplification
- provides a smooth and visually pleasing restored image.

→ Computable using FFT.

Limitations :- (i) Requires knowledge of PSF $H(u,v)$
(ii) Choosing γ is not straightforward

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8) Morphology is a set of image processing operations that process images, based on shapes. Morphological operations apply a structuring element to an i/p image, creating an output image of the same size.

- Morphological techniques probe an image with a small shape or template called a structuring element. — Small matrix of pixels.

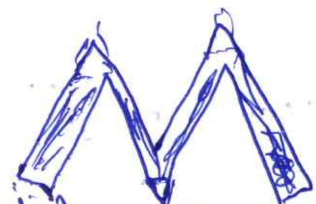
1	1	1
1	1	1
1	1	1

morphological Image processing the original image can be reconstructed by using Dilation, Erosion, Opening and closing operations for an finite no. of times

→ Erosion operation is defined as follows.

$E(A,B) = A \ominus B$ where A is the image. B is the structuring Element of the Order 3X3

many S.E are required for eroding the Entire image.



OPENING :- structred removal of image region boundary pixels.

It is a combining Erosion and dilation. "Opening seperates the objects". As we know, Dilation Expands an image and Erosion shrinks it. Opening generally smoothes the countour of an image, breaks narrow Isthamuses and Eliminates thin protrusions.

$$A \circ B = (A \ominus B) \oplus B$$

→ Opening operation is obtained by doing Dilation and Eroded image. It is to smoothen the curves of the image. Opening spaces objects that are too close together, detaches objects that are touching and should not be and enlarges holes inside objects.

CLOSING :-

Structuctured filling in of image region of boundary pixels.

Combining Erosion and Dilation. "closing join the objects"

closing also tends to smooth sections of contours of but as opposed to Opening.

— The closing of an image 'A' by a S.E "B" is denoted as A• B and defined as a Dilation followed by an Erosion

$A \cdot B = (A \oplus B) \ominus B$. closing is obtained by doing Erosion on Dilated image. closing joins broken objects and fills in unwanted holes in objects. closing involves one or more Dilations followed by one Erosion.

(9) Detection of Discontinuities :- "Abrupt changes in intensity"

→ Points — isoated intensity change at single pixel

→ line — thin Intensity

→ Edge — Significates change in intensity across a boundary.

Discontinuities detected using mask operations

point detection mask

$$R = \sum_{i=1}^{9} z_k \cdot f_k .$$

-1	-1	-1
-1	8	-1
-1	-1	-1

Line Detection

Horizontal
$$\begin{bmatrix} -1 & -1 & -1 \\ 2 & 2 & 2 \\ -1 & -1 & -1 \end{bmatrix}$$

Vertical
$$\begin{bmatrix} -1 & 2 & -1 \\ -1 & 2 & -1 \\ -1 & 2 & -1 \end{bmatrix}$$

Edge detection:- It is used for detecting discontinuities in gray levels, First and Second order digital derivatives are implemented to detect the Edges in an image.

→ Edge is defined as the boundary between two regions distinst gray level properties. They provide outline of an objects. An Edge is typically extracted by computing the derivative of the image function.

→ step Edge
→ Ramp Edge
→ Spike Edge
→ Roof Edge.

First order Derivative operators

(a) Roberts operator $G_x = f(x+1, y+1) - f(x,y)$
$G_y = f(x+1, y) - f(x, y+1)$

(b) Prewitt operator :-
$$\begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

(c) Sobel operator
$$\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

Second order :

Laplacian operator
$$\nabla^2 f = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 4 & -1 \\ 0 & 1 & 0 \end{bmatrix}$$

Boundary detection

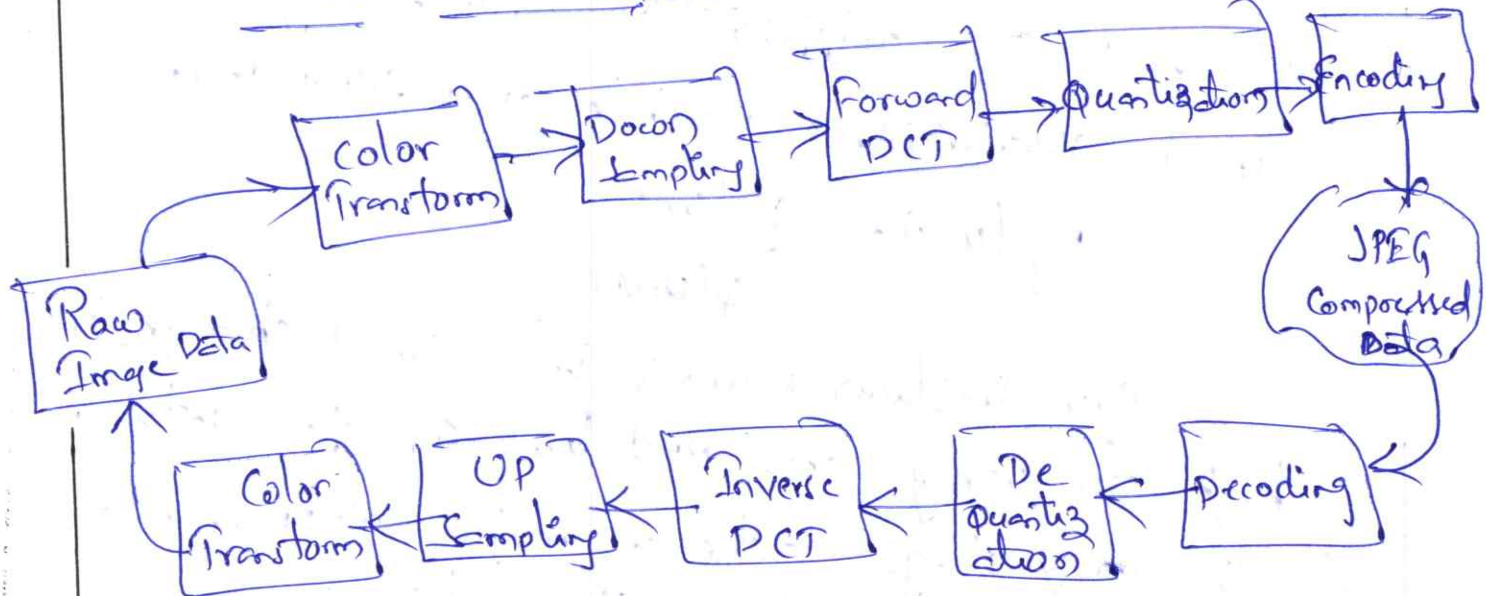
Boundary detection focuses on identify the outline of objects present in the image.

→ Edge detection + contour linking
→ morphological operations
→ Active contour models
→ Region based methods.

It follows Edge detection using like edge linking to connect Pixels based on similarity in direction or position.

10)

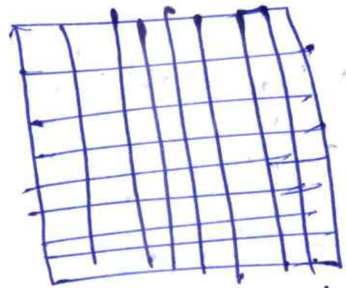
JPEG COMPRESSION



(i) DCT :- JPEG begins by dividing the image into 8X8 pixel block after color space Conversion from RGB to YCbCr. DCT then transforms each block from domain to frequency domain concentrating energy in low frequency coefficients while high frequency ones hold fine details.

DCT used for Energy compaction: most important becomes concentrated in a few low frequency coeffi

- High frequencies become small values → easier to discard.

DCT ⇒ 

8x8 Block DCT

ii) Quantization :- Reduce precision of DCT coeffi to main source of compression and loss in JPEG.

Each DCT coefficient is divided by a value in a quantization table and rounded.

$$F_q(u,v) = \frac{F(u,v)}{Q(u,v)}$$

- Quantization works in small changes in high frequency areas and loss of fine detail.

- This lossy stages acheives major compression as human vision overlooks these changes,

iii) Entropy Encoding :- Compress quantized values losslessly using statistical encoding.

after quantization :- most high-frequency coefficients become zero. JPEG arranges the 8x8 block in Zigzag order to group zeros.

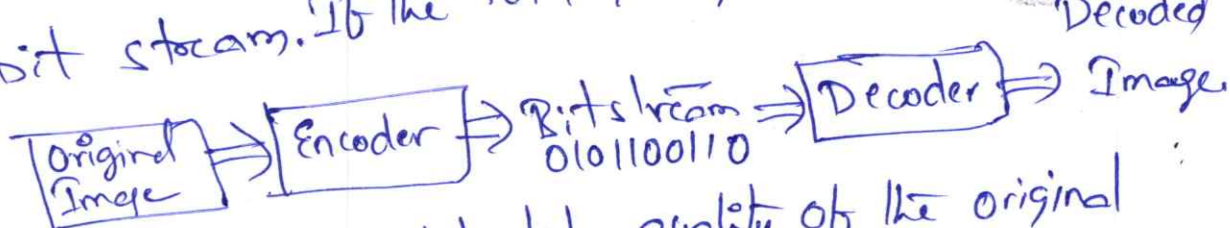
Stages of entropy encoding
→ Runlength Encoding
→ Huffman coding

Entropy Encoding works — Compress Extremely well with Runlength & Huffman coding.

11 Various Image Compression models :-

Image compression models reduce the size of Image data by Exploiting statical, structured, perceptual redundancies. Compression model are broadly classified into lossless and lossy models. The major image compression model include Run length coding, Huffman coding, LZW, predictive coding, Transform Coding, wavelet based coding

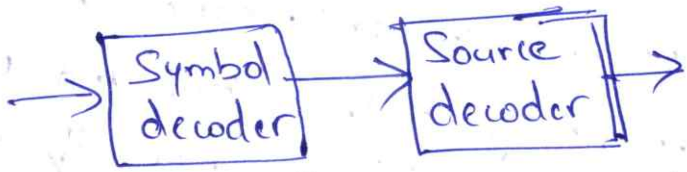
Compression consists of Encoder, decoder. when the Encoder receives the original image file, the image file Converted into a Series of binary data which is Called bit stream. If the total quality of the bit stream



is lessthan the total data quality of the original image., then this is called image compression.

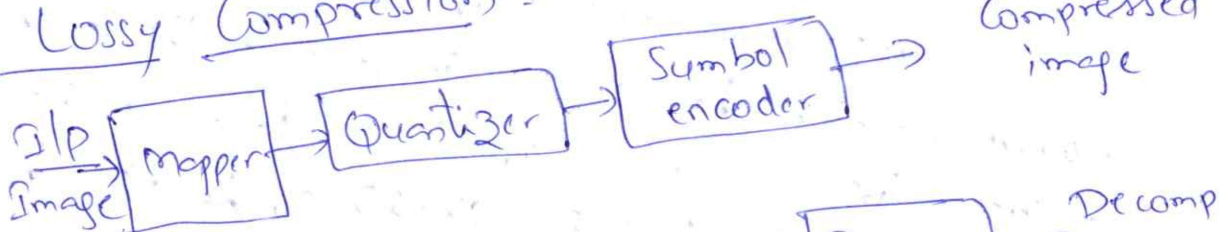
Two Types :- Lossless compression
lossy Compression.

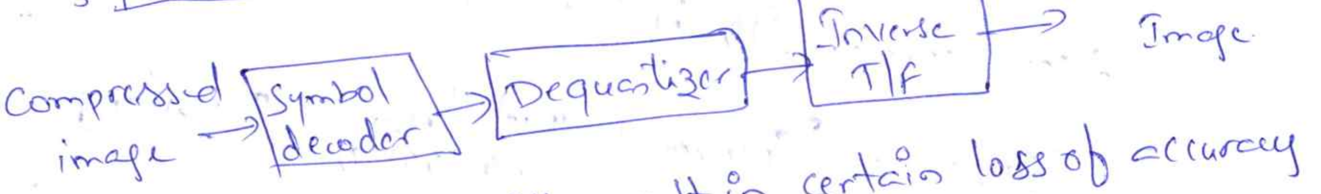
Lossless compression can recover the exact original data after compression. It is used mainly for compressing database records, spreadsheets or word processing files.
→ There is no information loss, and the image can be reconstructed exactly the same as the original.



1. Source encoder is responsible for removing the coding and interpixel redundancy and Psycho visual redundancy.
→ Source decoder :- Symbol decoder, Inverse mapping.
Lossless Compression technique :- Runlength coding, LZW coding, Huffman coding.

Lossy Compression :-





Lossy Compression will result in certain loss of accuracy in exchange for a substantial ↑ in compression.
Encoder:- i) mapper ii) Quantizer (iii) Symbol encoder
Source decoder — (a) Symbol decoder (b) Inverse mapping.
Lossy technique compression :- Transform coding, wavelet coding, DPCM, Delta modulation.