NAME : VEDANT A. Panari Subject: ~~ANN~~ IPPR

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MODULE 1

Image - spatial arrangement of 2D or 3D space.

Function of intensity values over 2D plane $I(r,s)$

Samples = pixels

Quantization = no. of bits per pixel

Image Representation

a) Black and White - 2 bits
b) Grey scale - 8 bits
c) Colour image - 3 colour panel — 8 bit each
   eg. RGB, CMY, YIQ
d) Indexed color image
e) Compressed images
   TIFF, JPEG, BMP

Digital Image Processing

A Discipline in which both input & output of a process are images.

Intensity - Amplitude of function of any pair of coordinates.

PIL
CV2

Full forms:

JPEG
GIF
PNG
BMP
TIFF

OpenCV

1) Brightness - cv2.add(+)

2) Contrast - cv2.convertScaleAbs

Types of Color Models

1) RGB } Theory
2) CMY }
3) HSI
4) YIQ

HSI - Hue, Saturation, Intensity

Saturation : Intensity of color
Colors appear sharper
Purity of color
Distance from grey color
Excitation property - percentage of brightness

Regions and Boundaries
Subset R of pixels in an image is called a Region of the image if R is a connected set.
Boundary of region R is a set of pixels

Color image — 1) Brightness
2) Hue
3) Saturation

Reason of color

Hue : — More theory
- Dominant wavelength in a mixture of light waves
- Colors
- Mean wavelength of spectrum

Brightness :
- Intensity
- Perceived luminance
- Depends on surrounding luminance

Cyan (green plus blue)
Yellow (green plus red)
Magenta (red plus blue)

(CYM) → (RGB)

Radiance :
Total amount of energy that flows from a light source
(measured in watts)

Luminance :
Amout of energy an observer perceives from light source
(measured in lumen)

Brightness
Subjective notion for intensity of light.

Pixel - Picture Element
- Smallest part of computer picture
- Color, brightness and position

Resolution - No. of pixels per unit of length
PNG - no change in resolution on zoom
JPEG - Quality decreases on zoom

Measurement of resolution : PPI (pixels per inch)
PPCM (pixels per centimeter)

Digital storage
Short term storage
On-line storage
Archival storage

Application Areas of DIP
1) Gamma Ray Imaging
2) X Ray Imaging
3) Ultraviolet band imaging
4) Visible & Infrared band imaging
5) Microwave band imaging
6) Radio band imaging
7) Biometrics
8) Object recognition / Target detection

Adjacency (theory)

4-Adjacency : p & q with intensity from V and q is in $N_4(p)$

8-Adjacency : q is in $N_8(p)$

M-Adjacency (mixed adjacency)

Path (theory)

Distance measure

p : (x,y) q : (s,t)

Euclidean distance

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

D_4 distance

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

D_8 distance

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

Aspect Ratio

Proportional relationship between height and width of an image.

Affects visual appearance

Applications - printing, display, analysis

OpenCV → imread()

imshow()

Representing digital image

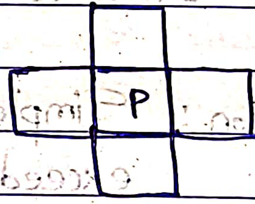
$L = 2^k$ gray levels, gray scales $[0, \dots, L-1]$

The dynamic range of an image
[min(image)   max(image)]

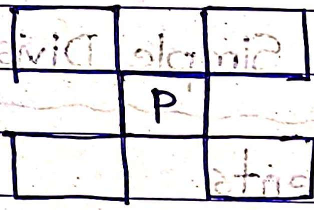
If dynamic range of image spans significant portion of dyn.
$\longrightarrow$ high contrast.

Neighbors of a pixel

4-neighbors of p : $N_4(p)$



Diagonal neighbors of p : $N_D(p)$



8 neighbors = 4 neighbors + diagonal neighbors

: $N_8(p)$

Adjacency, connectivity, regions & boundaries

Connectivity of pixels

- They are neighbors
- They grey levels satisfy a specified criterion of similarity
- Concept about regions and boundaries

Arithmetic Operation Between Images

Array operations corresponding pixel pairs.

$$A(x,y) = f(x,y) + g(x,y)$$
$$S(x,y) = f(x,y) - g(x,y)$$
$$P(x,y) = f(x,y) * g(x,y)$$
$$D(x,y) = f(x,y) / g(x,y)$$

Addition : Matrix Addition

Subtraction : Matrix Subtraction except for negative answers converted to 0.

Multiplication : Simple Multiplication, except numbers can't exceed 255

Division : Simple Division except 0 for division by 0

Assignments

1) Use library to convert color image to greyscale image
2) Find (R, G, B) value of original image.

Translation

Rotation

$$R = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$$

$$P = \begin{bmatrix} x \\ y \end{bmatrix}$$

$P(4,3)$ $\theta = 45$

$$P' = \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} x \\ y \end{bmatrix} t$$

$$[4, 3] \times \begin{bmatrix} \cos 45 & \sin 45 \\ -\sin 45 & \cos 45 \end{bmatrix}$$

$x' = x + tx$

$y' = y + ty$

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} tx \\ ty \end{bmatrix}$$

4. Deep learning based denoising :

Recent technique uses deep neural networks

Large dataset of noisy & clean images

Using network to remove noise from new images

e.g. (Tensorflow - ~~P~~ PyTorch)

5. Wavelet Filtering

Fourier transform

image wavelet coefficients.

6. Bilateral Filtering

Combining median and gaussian filtering

Importance of image manipulation and enhancement (Theory)

Defining the importance of removing noise

Process of reducing or removing irrelevant information from image.

Noise - random variation in an image.

Factors : low-light conditions
camera sensor limitations
interference in data transmission

Common techniques for noise reduction

1. Gaussian filtering
   Low pass filtering
   Remove high-frequency noise from an image.
   Convolving the image with Gaussian kernel
   OpenCV → cv2.GaussianBlur()
   e.g. filtered = cv2.GaussianBlur(img, (5,5), 0)

2. Median filtering
   Non-linear filtering
   Remove salt & pepper noise from an image.
   Replacing each pixel in the image with the median value of the neighboring pixels.
   cv2.medianBlur()

3. Wavelet denoising
   Wavelet transform to decompose an image into multiple frequency bands.
   Remove each bands' noise separately.
   Both high-frequency & low frequency noise from an image.

pywt library → pywt.wavedec2() pywt.waverec2()

-ve +ve	+ve +ve
-ve -ve	+ve -ve

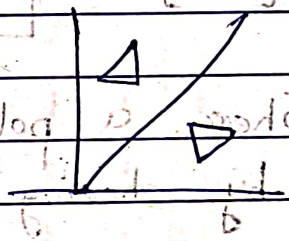
Other transformations

Reflection : Transformation that produces mirror image of an object. It is obtained by rotating the object by 180 deg about the reflection axis

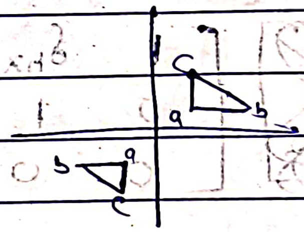
$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \Longleftarrow \text{for } y = 0 \text{ i.e. } X\text{-axis}$$

$$\begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \Longleftarrow \text{for } x = 0 \text{ i.e. } Y\text{-axis}$$

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \Longleftarrow \text{for } y = x$$



$$\begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \Longleftarrow \text{for origin}$$



Example: $A(4,1)$ $B(5,2)$ $C(4,3)$ $x=0$

$$[4 \ 1 \ 1]\begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = [-4 \ 1 \ 1]$$

$A' = (-4, 1)$

$$[5 \ 2 \ 1]\begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = [-5 \ 2 \ 1]$$

$B' = (-5, 2)$

$$[4 \ 3 \ 1]\begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = [-4 \ 3 \ 1]$$

$C' = (-4, 3)$

Homogeneous co-ordinates for Rotation

$$R = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$[x' \; y' \; 1] = [x \; y \; 1] \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= [x\cos\theta - y\sin\theta \quad x\sin\theta + y\cos\theta \quad 1]$$

Example of translation

a (2,2) b (10,2) c (5,5) translate the triangle

$dx = 5$ $dy = 6$

$a' = a + t$ t = change.

$a' = (2,2) + (5,6) = (7,8)$ $\begin{bmatrix} 2 \\ 2 \end{bmatrix} + \begin{bmatrix} 5 \\ 6 \end{bmatrix} = \begin{bmatrix} 7 \\ 8 \end{bmatrix}$

$b' = (10,2) + (5,6) = (15,8)$ $\begin{bmatrix} 10 \\ 2 \end{bmatrix} + \begin{bmatrix} 5 \\ 6 \end{bmatrix} = \begin{bmatrix} 15 \\ 8 \end{bmatrix}$

$c' = (5,5) + (5,6) = (10,11)$ $\begin{bmatrix} 5 \\ 5 \end{bmatrix} + \begin{bmatrix} 5 \\ 6 \end{bmatrix} = \begin{bmatrix} 10 \\ 11 \end{bmatrix}$

Homogeneous co-ordinates for Scaling

$$S = \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$[x' \; y' \; 1] = [x \; y \; 1] \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & 1 \end{bmatrix} = [x \cdot S_x \quad y \cdot S_y \quad 1]$$

Homogeneous co-ordinates

$P(x, y) \Rightarrow P'(x', y', h)$

h = homogeneous factor

- To display 3d object on 2d plane

Example: convert (3,4) into homogeneous coordinate if $h = 2$

1) Convert $P(5,7)$ into homogeneous coordinate if $h = 3$

$P' = (x*h, y*h, h)$

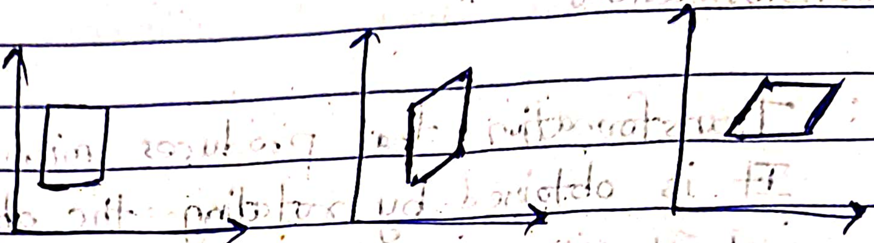
$= (5\times3, 7\times3, 3)$
$= (15, 21, 3)$

Homogeneous co-ordinates for Traslation

$$T = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ tx & ty & 1 \end{bmatrix}$$

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} + \begin{bmatrix} tx \\ ty \\ 1 \end{bmatrix}$$

Shears



$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & sh_x & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \leftarrow X \text{ shearing}$$

$$\begin{bmatrix} x + (sh_x \cdot y) & y & 1 \end{bmatrix}$$

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ sh_y & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \leftarrow Y \text{ shearing}$$

$$\begin{bmatrix} x & (sh_y \cdot x) + y & 1 \end{bmatrix}$$

Q. Shear a polygon A(0, 0), B(1, 0), C(1, 1) & D(0, 1) by shearing vector $sh_x = 2$ & determine new co-ordinates

$$\begin{bmatrix} 1 & sh_x & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix} \quad A'(0, 0)$$

$$\begin{bmatrix} 1 & sh_x & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \end{bmatrix} \quad B'(1, 0)$$

$$\begin{bmatrix} 1 & sh_x & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 3 & 1 & 1 \end{bmatrix} \quad C'(3, 1)$$

$$\begin{bmatrix} 1 & sh_x & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 2 & 1 & 1 \end{bmatrix} \quad D'(2, 1)$$

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2) Non-Linear Filters
- Do not rely on weighted sums
- Use operations like median or maximum values
- Noise removal
- e.g.: max
  min
  median

Max-filter = max(7, 9, 5, 4, 6, 8, 2, 0, 1)
= 9

Min filter = min(7, 9, 5, 4, 6, 8, 2, 0, 1)
= 0

Median filter = median(0, 1, 2, 4, 5, 6, 7, 8, 9) ascending sort
= 5

SMOOTHING Linear Filters

Difference betn Spatial Filtering & Image Smoothing

Use Cases of Image Smoothing
1) Noise Removal
Gaussian & Salt and pepper
2) Pre-processing for Edge Detection
Sobel or Canny
3) Visual Enhancement
Blur effect

Spatial Filtering (Theory)

Image Smoothing are two techniques used in image processing to enhance the quality of an image.

Types of Spatial Filters

1) Linear Filters
   - Work by computing weighted sum of pixel values in the neighborhood
   - E.g. Averaging Filter, Gaussian Filter.

Box Filtering (Averaging Filter)

$$\frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \cdot \times \begin{bmatrix} 7 & 9 & 5 \\ 4 & \boxed{6} & 8 \\ 2 & 0 & 1 \end{bmatrix} \rightarrow \text{Replace with } 5$$

input

$$\frac{1}{9}[7+9+5+4+6+8+2+0+1]$$

$$\frac{1}{9}[42] = 4.66$$

$$\simeq \boxed{5}$$

Gaussian Blur

$$G_\sigma(x,y) = \frac{1}{2\pi\sigma^2} e^{\left(-\frac{(x^2+y^2)}{2\sigma^2}\right)}$$

$$= \frac{1}{16}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix} \cdot \begin{bmatrix} 7 & 9 & 5 \\ 4 & 6 & 8 \\ 2 & 0 & 1 \end{bmatrix}$$

$$= \frac{1}{16}[7+18+5+8+24+16+2+0+1] = \frac{1}{16}[81]$$

$$= 5.062 \approx \boxed{5}$$

Q. A(0,0) B(1,0) C(1,1) D(0,1) $d_{xy} = 2$

$A' = [0 \quad (2\cdot0)+0 \quad 1] = [0 \quad 0 \quad 1]$ $A' = (0,0)$

$B' = [1 \quad (2\cdot1)+0 \quad 1] = [1 \quad 2 \quad 1]$ $B' = (1,2)$

$C' = [1 \quad (2\cdot1)+1 \quad 1] = [1 \quad 3 \quad 1]$ $C' = (1,3)$

$D' = [0 \quad (2\cdot0)+1 \quad 1] = [0 \quad 1 \quad 1]$ $D' = (0,1)$

Geometric Operations

1) Scale - change image content size
2) Rotate - change image content orientation
3) Reflect - flip over image contents
4) Translate - change image content position
5) Affine Transformation - general image content linear geometric transformation.

Image Interpolation

Technique used to estimate pixel values at non-sampled using known pixel values.

a) Nearest Neighbour
b) Linear Interpolation
c) Cubic Interpolation
d) Affine Transform : Geometric transform which preserves collinearity and ratios of distances between points on a line.

Module 3:

Image Enhancement in Frequency Domain

Introduction to Frequency Domain Transforms

Spatial Domain : Pixel values (intensity values at each coordinate)
Frequency Domain : Frequency components (sinusoidal waves of varying frequency and amplitude)

Transformation

A signal can be converted from spatial domain to frequency domain

Frequency components

- High frequency
  edges in an image
- Low frequency
  smooth spots in image

Steps

1) cv2.imread()
2) cv2.cvtColor()
3) cv2.dft()
4) numpy.fft.fftshift()
5) numpy.abs()
6) cv2.normalize
7) cv2.imshow()

Why Frequency Domain?

- smoothing
- edge detection
- image compression
- noise filtering
- separate & manipulate different frequency components

Key frequency Domain Transforms

1) Fourier Transform (FT)
   Transform image into frequency domain
2) Discrete Cosine Transform (DCT)
   Image Compression
   JPEG encoding
3) Discrete Wavelet Transform (DWT)
   Allows multi-resolution analysis compression and noise resolution

Case 2

$$A' = \begin{bmatrix} 1 & 0 & 0 \\ 3 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 3 & 1 \end{bmatrix} \quad (1,3)$$

$$B' = \begin{bmatrix} 1 & 0 & 0 \\ 3 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 2 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 2 & 6 & 1 \end{bmatrix} \quad (2,6)$$

$$C' = \begin{bmatrix} 1 & 0 & 0 \\ 3 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 2 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 2 & 7 & 1 \end{bmatrix} \quad (2,7)$$

$$D' = \begin{bmatrix} 1 & 0 & 0 \\ 3 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 4 & 1 \end{bmatrix} \quad (1,4)$$

Q. Reflect about origin $A(1,1)$ $B(3,2)$ $C(2,4)$

$$A' = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} -1 & -1 & 1 \end{bmatrix} \quad (-1,-1)$$

$$C' = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 2 \\ 4 \\ 1 \end{bmatrix} = \begin{bmatrix} -2 & -4 & 1 \end{bmatrix} \quad (-2,-4)$$

$$B' = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 3 \\ 2 \\ 1 \end{bmatrix} = \begin{bmatrix} -3 & -2 & 1 \end{bmatrix} \quad (-3,-2)$$

Q. Determine translation matrix of triangle A(3,1) B(5,4) C(3,3) about the line $x = 0$.

Shifting of axis
Reflection

$$\begin{bmatrix}3 & 1 & 1\end{bmatrix}\begin{bmatrix}-1 & 0 & 0\\0 & 1 & 0\\0 & 0 & 1\end{bmatrix} = \begin{bmatrix}-3 & 1 & 1\end{bmatrix}$$

$$\begin{bmatrix}5 & 4 & 1\end{bmatrix}\begin{bmatrix}-1 & 0 & 0\\0 & 1 & 0\\0 & 0 & 1\end{bmatrix} = \begin{bmatrix}-5 & 4\end{bmatrix}$$

$$\begin{bmatrix}3 & 3 & 1\end{bmatrix}\begin{bmatrix}-1 & 0 & 0\\0 & 1 & 0\\0 & 0 & 1\end{bmatrix} = \begin{bmatrix}-3 & 3 & 1\end{bmatrix}$$

$A' = (-3, 1)$ $B'(-5, 4)$ $C'(-3, 3)$

Q. Translate P(6, 7) where $T[-1\ 5]$ $T_x = -1$ $T_y = 5$

$$P' = \begin{bmatrix}6\\7\end{bmatrix} + \begin{bmatrix}-1\\5\end{bmatrix} = \begin{bmatrix}5\\12\end{bmatrix}$$

Q. Shear a polygon A(1,0) B(2,0) C(2,1) D(1,1)
$Sh_x = 2$ $Sh_y = 3$

Case 1

$$A' = \begin{bmatrix}1 & 0 & 1\end{bmatrix}\begin{bmatrix}1 & Sh_x & 0\\0 & 1 & 0\\0 & 0 & 1\end{bmatrix} = \begin{bmatrix}1+(2\cdot 0) & 0 & 1\end{bmatrix} = \begin{bmatrix}1 & 0 & 1\end{bmatrix} = (1,0)$$

$$B' = \begin{bmatrix}1 & Sh_x & 0\\0 & 1 & 0\\0 & 0 & 1\end{bmatrix}\begin{bmatrix}2\\0\\1\end{bmatrix} = \begin{bmatrix}2 & 0 & 1\end{bmatrix} = (2,0)$$

$$C' = \begin{bmatrix}1 & 2 & 0\\0 & 1 & 0\\0 & 0 & 1\end{bmatrix}\begin{bmatrix}2\\1\\1\end{bmatrix} = \begin{bmatrix}4 & 1 & 1\end{bmatrix} = (4,1)$$

$$D' = \begin{bmatrix}1 & 2 & 0\\0 & 1 & 0\\0 & 0 & 1\end{bmatrix}\begin{bmatrix}1\\1\\1\end{bmatrix} = \begin{bmatrix}3 & 1 & 1\end{bmatrix} = (3,1)$$

2) Butterworth Low-Pass Filter

1) Smoother version of ideal filter
2) More gradual transition
3) Less ringing
4) Provides a smoother transition between pass & stop bands defined by an order parameter (n).
5) Higher the order, steeper the transition

3) Gaussian Low Pass Filter

1) Smoothiest

Sharpening (High-Pass Filtering)

1) Emphasize high frequency components (edges & fine details)
2) Suppressing low frequency components

1) Ideal High Pass Filter (IHPF)

Practical Considerations in Filter Design

1) Filter Size :
2) Cutoff Frequency: 30 Hz
3) Edge Effects:
4) Computational Efficiency :

Discreet Cosine Transform (DCT)

- JPEG encoding
- Image in terms of cosine functions with different frequencies
- separate an image into parts of differing importance based on frequency.

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

$f(x,y)$ = input 2D signal
$X(u,v)$ = 2D DCT output

Application

a) Image compression (JPEG)
b) Video Compression (MPEG)
c) Audio Compression (MP3, AAC)

Filters: Used to enhance or suppress certain frequencies.

Smoothing: (Low-Pass Filtering)

1) Reduce high-frequency noise
2) Low frequency components are passed.

Types

1) Ideal Low Pass Filter (ILPF)
Blocks all frequencies higher than cutoff frequency.

Discrete Fourier Transform (DFT)

- Spatial domain to frequency domain
- Magnitude spectrum :- strength of different frequencies
- Phase Spectrum :- spatial information
- Centre :- low frequencies

  Edges :- High frequencies

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

$f(x,y)$ = spatial domain function

$X(u,v)$ = frequency domain representation

Filters

- Low Pass (smoothing)
  - Ideal
  - Butterworth
  - Gaussian
- High Pass (Sharping)

Inverse Discrete Fourier Transform (IDFT)

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

Applications

1) Image Compression : Removing less significant frequencies

2) Image Filtering : Modifying specific frequency components

3) Signal Analysis : Identifying and analysing frequency components.