Code No: 155BT

R18

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD
B. Tech III Year I Semester Examinations, August - 2022
IMAGE PROCESSING
(Common to CSE, IT)

Time: 3 Hours **Max. Marks: 7**

Answer any five questions
All questions carry equal marks

1.a) What is a digital image? Explain the fundamental steps in digital image processing.
b) Explain the Concept of Gray Levels and its conversion to Binary Image. [8+7]

2. Explain in detail about DFT, DCT, KLT and SVD techniques. [15]

3. Differentiate and xplain the concept of Image Enhancement in Spatial Domain and Frequency Domain. [15]

4.a) Explain histogram processing.
b) Distinguish between image smoothing and sharpening. [7+8]

5.a) Discuss about the Image Restoration Degradation Model with a neat diagram.
b) Explain how Image Restoration can be done using various filters? [7+8]

6. Explain how image degradation is estimat d using observation and mathematical modelling. [15]

7.a) Explain basic global thresholding with an iterative algorithm.
b) Discuss the various techniques used in image segmentation. [7+8]

8.a) Explain the image compression model with a neat diagram.
b) Differentiate and explain the various compression techniques. [7+8]

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ANSWER KEY

1.a) What is a digital image? Explain the fundamental steps in digital image processing.

1. Digital Image Definition: A digital image is a representation of a two-dimensional image using binary data, composed of pixels, each representing a specific color or intensity level.
2. Image Acquisition: The first step involves capturing an image using a sensor (like a camera) and converting it into a digital format.
3. Image Preprocessing: Enhancing the image by reducing noise and adjusting contrast to prepare it for further analysis.
4. Image Segmentation: Dividing the image into meaningful regions or objects to simplify analysis.
5. Feature Extraction and Representation: Identifying important features (like edges, textures) and transforming the image into a suitable format for processing.

1.b) Explain the Concept of Gray Levels and its conversion to Binary Image.

1. Gray Levels Concept: Gray levels refer to the different shades of gray in a grayscale image, with pixel values ranging from 0 (black) to 255 (white).
2. Thresholding: A technique to convert a grayscale image to a binary image by selecting a threshold value.
3. Binary Conversion: Pixels above the threshold are set to 1 (white), and pixels below are set to 0 (black).
4. Simplification: This conversion simplifies the image, making it easier to analyze specific features or objects.
5. Example Application: Binary images are commonly used in object detection, edge detection, and shape analysis.

2. Explain in detail about DFT, DCT, KLT and SVD techniques.

1. DFT (Discrete Fourier Transform): Transforms a signal from the time domain to the frequency domain, used for frequency analysis of signals and images. It decomposes an image into its sine and cosine components.
2. DCT (Discrete Cosine Transform): Similar to DFT but uses only cosine functions. It is widely used in image compression (e.g., JPEG) as it concentrates energy in the lower frequency components.
3. KLT (Karhunen-Loève Transform): An optimal transform for data decorrelation and dimensionality reduction. It finds the principal components of the data, similar to Principal Component Analysis (PCA).
4. SVD (Singular Value Decomposition): Decomposes a matrix into three other matrices (U, Σ, V). It is used in image compression, noise reduction, and solving linear inverse problems.

5. Applications and Comparisons: Each technique has its specific applications and strengths, such as DFT for frequency analysis, DCT for compression, KLT for decorrelation, and SVD for matrix factorization.
6. Mathematical Representation of DFT: The DFT is mathematically represented as $X(k) = \sum_{n=0}^{N-1} x(n) e^{-j2\pi kn/N}$, where $X(k)$ is the frequency component, $x(n)$ is the input signal, and N is the total number of samples.
7. Energy Compaction in DCT: DCT is known for its energy compaction properties, where most of the signal information is concentrated in a few low-frequency components, making it highly efficient for compression.
8. Principal Component Analysis in KLT: KLT is essentially PCA in signal processing, where it transforms the data into a set of uncorrelated variables called principal components, maximizing variance and reducing redundancy.
9. Applications of SVD in Image Processing: SVD is used in various image processing tasks such as image compression, where it approximates the image with fewer singular values, and in noise reduction by reconstructing the image with significant singular values.
10. Comparative Efficiency: While DFT and DCT are computationally efficient for regular grid data, KLT and SVD are more computationally intensive but provide better decorrelation and compression performance in certain applications.

3. Differentiate and explain the concept of Image Enhancement in Spatial Domain and Frequency Domain.

1. Spatial Domain Enhancement: Operates directly on pixel values of the image. Techniques like histogram equalization, contrast stretching, and spatial filtering (smoothing, sharpening) are applied directly to the image matrix in its original form.
2. Frequency Domain Enhancement: Operates on the transformed (frequency) domain of the image. Techniques involve modifying the Fourier transform of the image, allowing manipulation of specific frequency components such as low-pass and high-pass filtering.
3. Advantages of Spatial Domain:
   - Simplicity: Easier to implement and understand due to direct manipulation of pixel values.
   - Real-time Processing: Suitable for real-time applications where immediate feedback or processing is required.
   - Local Enhancements: Effective for enhancing specific regions or features within the image.
4. Advantages of Frequency Domain:
   - Global Enhancements: Enables modifications that affect the entire image uniformly, such as noise reduction or enhancing overall contrast.

- Noise Reduction: Effective in reducing noise by filtering out specific frequency components.
- Feature Extraction: Allows extraction and enhancement of specific image features represented in the frequency domain.

5. Examples:
   - Spatial Domain: Edge detection using gradient operators (Sobel, Prewitt), histogram equalization to enhance contrast locally.
   - Frequency Domain: Low-pass filtering to smooth the image and remove high-frequency noise, high-pass filtering to enhance edges and fine details.

6. Applications: Spatial domain techniques are often used for tasks requiring localized adjustments, such as medical image enhancement or object detection. Frequency domain techniques are preferred for tasks like image restoration and enhancement where global adjustments or noise reduction are necessary.

7. Implementation Complexity:
   - Spatial Domain: Techniques involve straightforward algorithms that manipulate pixel values directly, making them easier to implement.
   - Frequency Domain: Requires the computation of the Fourier transform and its inverse, adding computational complexity but offering powerful tools for image enhancement.

8. Flexibility in Enhancement:
   - Spatial Domain: Limited to operations that can be applied directly to pixel values, such as contrast adjustments or local filtering.
   - Frequency Domain: Provides flexibility in enhancing specific frequency components, enabling targeted improvements in image quality and noise reduction.

9. Combination of Domains:
   - Spatial-Frequency Hybrid Techniques: Some advanced image enhancement methods combine both domains to leverage their respective strengths. For example, hybrid approaches may use frequency domain filtering for noise reduction followed by spatial domain contrast enhancement.

10. Resource Utilization:
    - Spatial Domain: Generally consumes fewer computational resources compared to frequency domain techniques, making it suitable for applications with limited processing capabilities.
    - Frequency Domain: Requires more computational resources due to Fourier transform operations, which may be a consideration for real-time or embedded systems applications.

4.a) Explain histogram processing.

1. Histogram Definition: A histogram represents the frequency distribution of pixel intensity values in an image.

2. Histogram Equalization: A technique to improve contrast by redistributing the intensity values, resulting in a more uniform histogram.
3. Histogram Specification: Also known as histogram matching, it adjusts the histogram of an image to match a specified histogram.
4. Applications: Enhances image contrast, improves visibility of features, and prepares images for further processing.
5. Example: Applying histogram equalization to an underexposed image to enhance its contrast and detail.

4.b) Distinguish between image smoothing and sharpening.
1. Image Smoothing: Reduces noise and details by averaging pixel values with their neighbors. Techniques include Gaussian blur and median filtering.
2. Image Sharpening: Enhances edges and fine details by amplifying the intensity differences between adjacent pixels. Techniques include the Laplacian filter and unsharp masking.
3. Purpose of Smoothing: Used to reduce noise and create a cleaner image for analysis.
4. Purpose of Sharpening: Used to enhance features and make edges more distinct.
5. Examples: Smoothing an image with Gaussian blur to reduce noise, and sharpening an image with a high-pass filter to enhance edges.

5.a) Discuss the Image Restoration Degradation Model with a neat diagram.
1. Degradation Model: Describes how an image gets degraded by factors such as noise, blurring, and distortions.
2. Mathematical Model: Typically represented as $g(x,y) = f(x,y) * h(x,y) + \eta(x,y)$, where g is the degraded image, f is the original image, h is the degradation function, and η is the noise.
3. Diagram: Includes the original image, degradation function, noise addition, and the resulting degraded image.
4. Purpose: Understanding the degradation helps in designing restoration algorithms.
5. Applications: Used in fields like medical imaging, satellite imaging, and photography to restore degraded images.

5.b) Explain how Image Restoration can be done using various filters.
1. Inverse Filtering: Reverses the degradation process by applying the inverse of the degradation function. It is sensitive to noise.
2. Wiener Filtering: Minimizes the mean square error between the restored and original images. It balances noise reduction and inverse filtering.
3. Regularized Filtering: Incorporates prior information about the image or degradation process to stabilize the solution.

4. Adaptive Filtering: Adjusts the filtering process based on local image characteristics.
5. Examples: Using inverse filtering to restore a blurred image, Wiener filtering to restore a noisy image while preserving details.

6. Explain how image degradation is estimated using observation and mathematical modeling.
1. Observation-Based Estimation: Analyzes the degraded image to identify patterns and characteristics of degradation, such as noise level or blurring extent.
2. Mathematical Modeling: Constructs a model to represent the degradation process, often involving convolution with a point spread function (PSF) and adding noise.
3. Estimation Techniques: Includes blind deconvolution, where the degradation function is estimated simultaneously with image restoration, and parametric modeling, where parameters of the degradation model are estimated.
4. Noise Estimation: Techniques like analyzing the variance of pixel values or using edge detection to estimate noise characteristics.
5. Application Examples: Estimating motion blur parameters by analyzing the direction and length of blur streaks, or estimating Gaussian noise parameters by analyzing uniform regions of the image.
6. Blind Deconvolution: A method where both the image and the degradation function are estimated simultaneously without prior knowledge of the degradation.
7. Adaptive Filtering: Adjusts the filter parameters based on local image characteristics to improve the restoration quality.
8. Regularized Methods: Incorporates prior information or constraints into the estimation process to stabilize the solution and improve robustness.
9. Simulation-Based Estimation: Uses simulations to generate degraded images under different conditions, comparing them with the observed image to estimate the degradation model.
10. Performance Metrics: Evaluates the accuracy of degradation estimation using metrics like Mean Squared Error (MSE) or Peak Signal-to-Noise Ratio (PSNR) to compare the restored image with the original.

7.a) Explain basic global thresholding with an iterative algorithm.
1. Global Thresholding: A technique to convert a grayscale image to a binary image using a single threshold value.
2. Iterative Algorithm: Starts with an initial threshold value, segments the image, and computes the mean intensities of the foreground and background.
3. Threshold Update: Updates the threshold as the average of the foreground and background mean intensities.
4. Convergence: Repeats the process until the threshold value converges.

5. Example: Converting a grayscale image to a binary image by iteratively updating the threshold until stable separation of foreground and background is achieved.

7.b) Discuss the various techniques used in image segmentation.

1. Thresholding: Segments an image by comparing pixel values to a threshold. Variants include global, local, and adaptive thresholding.
2. Edge-Based Segmentation: Detects edges using operators like Sobel, Canny, or Laplacian, and segments the image based on detected edges.
3. Region-Based Segmentation: Groups pixels into regions based on similarity criteria. Methods include region growing, region splitting and merging.
4. Clustering-Based Segmentation: Uses algorithms like k-means or mean shift to partition the image into clusters.
5. Model-Based Segmentation: Uses models like active contours (snakes) or level sets to segment objects based on their shape and contour.

8.a) Explain the image compression model with a neat diagram.

1. Compression Model Definition: Represents the process of reducing the size of an image file by removing redundancies and irrelevant information.
2. Components of the Model: Includes the encoder (compresses the image), the compressed image, and the decoder (decompresses the image).
3. Encoder: Involves processes like transformation (DCT, wavelet), quantization, and entropy coding (Huffman, arithmetic coding).
4. Decoder: Reverses the compression steps to reconstruct the image.
5. Diagram: Typically shows the flow from the original image through the encoder, compressed image, decoder, and reconstructed image.

8.b) Differentiate and explain the various compression techniques.

1. Lossless Compression: Compresses the image without any loss of information. Techniques include Huffman coding, LZW, and PNG.
2. Lossy Compression: Compresses the image with some loss of information for higher compression rates. Techniques include JPEG, MPEG, and wavelet compression.
3. Transform Coding: Uses transformations like DCT or wavelet transform to represent the image in a compact form.
4. Predictive Coding: Predicts pixel values based on previous pixels and encodes the prediction error. Techniques include differential pulse-code modulation (DPCM).
5. Comparisons: Lossless compression is suitable for applications needing exact reconstruction (e.g., medical imaging), while lossy compression is used where some loss is acceptable for higher compression (e.g., web images).