UNIT -5

Image Compression Techniques

- Image compression techniques are essential for reducing the storage space and bandwidth requirements of digital images.
- Compression methods can be **lossy** (where some image data is discarded) or **lossless** (where no data is lost).

Here are some of the most widely used image compression techniques:

1. JPEG Compression (Joint Photographic Experts Group)

<u>**Type**</u> **: Lossy**

<u>**Approach**</u> **:** JPEG uses Discrete Cosine Transform (DCT) to transform image blocks into frequency components.

<u>**Process**</u> **:**

 1. **Color Conversion** : Converts the image to YCbCr color space (separating brightness from color information).

 2. **DCT Transformation** : Each 8x8 pixel block is transformed from the spatial to frequency domain.

 3. **Quantization** : High-frequency coefficients are more heavily quantized to reduce data size, often leading to loss of fine details.

 4. **Encoding** : Uses Huffman or arithmetic coding to further compress the quantized data.

<u>**Use Cases**</u> : Photographs and realistic images where file size needs to be reduced without strict fidelity.

<u>**Advantages**</u> : High compression ratio and widely supported.

<u>**Disadvantages**</u> : Artifacts like blocking and blurring at high compression rates.

2. **Wavelet-Based Compression**

Type : Primarily lossy but can also be lossless.

Approach : Uses **Wavelet Transform** (often the Discrete Wavelet Transform, DWT) to analyze the image at multiple resolutions.

Process :

1. Transformation : Wavelet transforms decompose the image into a set of coefficients representing different frequency sub-bands.

2. Thresholding : Smaller coefficients, typically representing fine details, can be set to zero or reduced to achieve compression.

3. Encoding : Similar to JPEG, wavelet coefficients are encoded for storage.

Use Cases : Applications needing scalable compression, such as medical imaging, digital cinema, and satellite imagery.

Advantages : Smooth representation of edges and fine detail; fewer artifacts at high compression.

Disadvantages : More computationally complex than JPEG, which can lead to slower encoding/decoding.

3. PNG Compression (Portable Network Graphics)

Type : Lossless

Approach : Uses **Deflate compression algorithm** (a combination of LZ77 and Huffman coding).

Process :

1. Filtering : Preprocesses data to identify patterns.

2. Deflate Compression : Losslessly compresses data without any loss in quality.

Use Cases : Images requiring high fidelity and transparency (e.g., logos, icons, graphics).

Advantages : Perfect quality retention, supports transparency.

Disadvantages : Larger file sizes compared to lossy methods.

4. HEIF/HEIC (High Efficiency Image Format)

Type : Lossy (but supports lossless)

Approach : Based on the HEVC/H.265 video compression standard.

Process :

  1. Image Coding : Encodes images in a format that uses predictive coding, similar to video frames.

  2. Compression : Efficient compression for reduced file sizes with high quality.

Use Cases : Mobile devices and cloud storage where small file size and high image quality are required.

Advantages : Better compression ratio than JPEG with higher visual quality.

Disadvantages : Limited support in software and browsers compared to JPEG.

5. GIF Compression (Graphics Interchange Format)

Type : Lossless (with 8-bit color limitation)

Approach : Uses **LZW (Lempel–Ziv–Welch)** compression for data reduction.

Process :

  1. Color Reduction : Limited to 256 colors, which is achieved through color quantization.

2. LZW Encoding : Compresses data by replacing repeated patterns.

Use Cases : Simple graphics, icons, and animations with limited colors.

Advantages : Small file size, supports animation.

Disadvantages : Limited to 256 colors, making it unsuitable for complex images.

6. WebP Compression

Type : Both lossy and lossless

Approach : Hybrid compression, using DCT (similar to JPEG) for lossy and prediction-based compression for lossless.

Process :

1. Prediction Encoding : Predicts pixel values from neighbors, achieving higher compression.

2. Encoding : Encodes the differences for more efficient data storage.

Use Cases : Web images where small file size and flexibility between lossy and lossless are needed.

Advantages : Higher compression efficiency than JPEG, transparency support.

Disadvantages : Not universally supported in all software.

Key Considerations in Choosing Compression Techniques:

1. **Image Quality Requirements :** Lossy methods like JPEG are suitable for photographs, while lossless methods like PNG work well for graphics and images requiring high fidelity.

2. **File Size :** Lossy methods achieve smaller file sizes, while lossless methods maintain quality at the expense of larger files.
3. **Compatibility :** JPEG and PNG are widely compatible, whereas WebP and HEIF are less universally supported.
4. **Compression Artifacts :** Techniques like wavelet-based compression reduce common artifacts such as blocking, making them better for high-quality applications.

Understanding these techniques allows for optimized image storage and transmission based on specific needs in quality, efficiency, and compatibility.

Image Registration and Fusion Methods

Image registration and **image fusion** are essential techniques in computer vision, remote sensing, medical imaging, and other fields where multiple images or data sources need to be aligned or combined. Below are key concepts, methods, and applications for each.

1. Image Registration

Image registration involves aligning two or more images of the same scene taken at different times, viewpoints, or by different sensors. Its goal is to overlay images so corresponding points match as closely as possible.

Key Applications

Medical Imaging : Aligning MRI, CT, and PET scans to compare or fuse information.

Remote Sensing : Aligning satellite images taken at different times or by different sensors.

Robotics and AR : Combining real-world camera input with digital models or maps.

Registration Steps

1. Feature Detection : Identify unique points, edges, or regions in the image (e.g., corners, blobs).

2. Feature Matching : Match features between images using similarity measures.

3. Transformation Estimation : Determine the transformation (e.g., translation, rotation, scaling) that aligns matched features.

4. Image Resampling and Transformation : Apply the transformation to overlay images accurately.

Techniques for Image Registration

1. **Intensity-Based Methods :** Match images based on pixel intensity values. Often used when features are not easily identifiable, as in medical imaging.
2. **Methods** : Cross-correlation, mutual information.
3. **Feature-Based Methods** : Match distinctive features like corners or edges between images.
4. **Feature Detection** : SIFT (Scale-Invariant Feature Transform), SURF (Speeded-Up Robust Features), ORB (Oriented FAST and Rotated BRIEF).
5. **Feature Matching**: Nearest-neighbor matching, RANSAC (Random Sample Consensus) for outlier removal.
6. **Frequency-Based Methods** : Use frequency domain transformations, like Fourier, to match images with similar textures.
7. **Machine Learning and Deep Learning :** Use convolutional neural networks (CNNs) for feature extraction, and deep learning models for direct transformation estimation.

2. Image Fusion

Image fusion combines multiple images (often of different types) into a single composite image that retains useful information from each source. It aims to enhance the image quality or information content.

Key Applications

1. **Medical Imaging :** Merging MRI and CT data to combine soft tissue and bone information.

2. **Remote Sensing :** Merging multispectral and panchromatic images to enhance spatial and spectral resolution.
3. **Surveillance :** Combining visible and infrared images for day-night monitoring.
4. **Photography and Imaging :** Combining images at different exposures (HDR) to create an image with a high dynamic range.

Fusion Techniques

1. <u>**Pixel-Level Fusion :**</u> Combines images by directly merging pixel values. Suitable for simple tasks but may introduce noise.

   <u>**Technique :**</u> Averaging, maximum and minimum value selection, principal component analysis (PCA).

2. <u>**Feature-Level Fusion :**</u> Extracts significant features from each image (edges, textures) and fuses them to emphasize relevant information.

   <u>**Techniques :**</u> Wavelet transform, pyramidal decomposition.

3. <u>**Decision-Level Fusion :**</u> Combines information after processing each image independently. Often used in applications where images are analyzed separately, and decisions or features are fused.

   Techniques: Majority voting, weighted decision schemes.

Common Fusion Methods

Pyramidal Fusion : Decomposes images into multiple levels using image pyramids, such as Gaussian or Laplacian pyramids. Corresponding levels are fused and then reconstructed into a single image.

Wavelet Transform Fusion : Decomposes images into wavelet coefficients, fuses them based on certain rules, and performs inverse wavelet transformation to form the composite image. Preserves both

spatial and frequency information, ideal for retaining edges and fine details.

Intensity-Hue-Saturation (IHS) Fusion : Used mainly in remote sensing, where multispectral and panchromatic images are combined. The panchromatic image is fused with the intensity component of the multispectral image to produce an enhanced color image.

Deep Learning-Based Fusion : Uses neural networks, especially CNNs, to learn how to combine features or pixel information across images, often yielding higher-quality fusion results.

Key Considerations in Registration and Fusion

1.Accuracy : Registration and fusion methods should minimize spatial misalignment and preserve relevant details.

2.Efficiency : High-speed algorithms are essential in time-sensitive applications (e.g., real-time video fusion).

3.Robustness : Methods should perform well even with noise, occlusions, and variations in lighting or viewpoint.

4.Preservation of Information : Fusion should maximize information retention without introducing artifacts or noise.

Summary

Image registration and fusion are foundational techniques to integrate data from different sources, enhancing clarity, detail, or interpretability in images. From simple pixel-based methods to complex machine learning algorithms, these techniques enable advanced applications in multiple fields, especially where high-quality, integrated images are critical.

Case Studies and Applications of Image Processing in Various Domains

Image processing has revolutionized multiple fields, from medical diagnostics to environmental monitoring. Below are case studies and applications across several key domains, illustrating how image processing is utilized for critical tasks.

1. Medical Imaging

Image processing is a cornerstone of modern medical diagnostics, enabling early detection, diagnosis, and monitoring of diseases.

Case Study: MRI and CT Scan Fusion for Tumor Detection

Description: For cancer diagnosis, combining MRI (high soft tissue contrast) and CT (detailed bone structure) images provides a comprehensive view of tumors.

Image Processing Techniques Used :

Image Registration : Aligning MRI and CT scans using mutual information for precise overlay.

Image Fusion : Fusing images at pixel or feature levels to enhance tumor visualization.

Segmentation : AI-based segmentation identifies the tumor area, allowing accurate tumor size and location measurement.

Impact : Improved accuracy in tumor detection, enabling better treatment planning and outcomes.

Additional Applications:

Disease Detection : Techniques like deep learning-based segmentation help detect lesions in brain MRIs and lung X-rays.

3D Reconstruction : CT and MRI data can be reconstructed into 3D models for surgical planning.

Functional Imaging : Functional MRI (fMRI) helps map brain activity, aiding in neurological studies.

2. Remote Sensing and Environmental Monitoring

Remote sensing enables monitoring of vast geographical areas using satellite and aerial imagery, essential for environmental science, agriculture, and urban planning.

Case Study: Forest Health Monitoring using Hyperspectral Imaging

Description : Hyperspectral images capture hundreds of narrow spectral bands, allowing detection of subtle changes in forest vegetation health.

Image Processing Techniques Used :

Spectral Unmixing : Differentiates healthy from diseased vegetation based on spectral signatures.

Change Detection : Analyzes images over time to detect forest degradation or disease spread.

Classification : Machine learning models classify regions of healthy and diseased vegetation.

Impact : Early detection of stress in vegetation, aiding in targeted interventions to prevent forest degradation.