Assignment Number: 05

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Title:

Image Compression using Discrete Cosine Transform (DCT)

Aim:

To implement a basic image compression technique using the Discrete Cosine Transform (DCT) by processing a grayscale image in 8×8 blocks, applying DCT and quantization, and then reconstructing the image using Inverse DCT (IDCT), while analyzing the visual quality and storage efficiency.

Objective:

- To load a grayscale image into the working environment using OpenCV and preprocess it for compression.
- To divide the input image into fixed-size 8×8 pixel blocks suitable for frequency transformation.
- To apply two-dimensional DCT on each image block to convert spatial pixel data into frequency domain coefficients.
- To compress each block by zeroing out less significant (high-frequency) DCT coefficients, preserving only essential low-frequency data (top-left 4×4 region).
- To reconstruct the image by applying the inverse DCT (IDCT) to each compressed block.
- To save the final reconstructed image and compare its visual quality and file size with the original image.

- To understand the practical relevance of DCT-based compression, particularly its role in JPEG compression standards and multimedia applications.

Theory:

The Discrete Cosine Transform (DCT) is one of the most widely used transformations in digital image processing. It is particularly known for its role in lossy image compression formats like JPEG, where it is used to efficiently represent image data by focusing on energy compaction.

DCT and Frequency Domain Analysis

The DCT works by transforming an image block from the spatial domain (where pixel values are represented directly) into the frequency domain (where data is represented in terms of cosine functions of varying frequencies). The transformation makes it easier to identify and remove components that have little visual impact, particularly those associated with high-frequency details and noise.

When the DCT is applied to an 8×8 block of image pixels, the resulting matrix consists of coefficients that reflect the significance of different frequency components. The top-left corner of this matrix represents low-frequency data, which captures the general structure and smooth variations in the image. As we move toward the bottom-right, the coefficients represent higher frequencies, capturing finer textures, edges, and noise.

For a 2D signal (image), the 2D DCT is defined as:

$$F(u,v) = \frac{1}{4}C(u)C(v)\sum_{x=0}^{7}\sum_{y=0}^{7} f(x,y)\cos\left[\frac{(2x+1)u\pi}{16}\right]\cos\left[\frac{(2y+1)v\pi}{16}\right]$$

Where $C(u) = \frac{1}{\sqrt{2}}$ if $u = 0$, and 1 otherwise.

Quantization in Compression

Compression is achieved by quantizing the DCT coefficients. In this project, quantization is performed by zeroing out all but the top-left 4×4 values of the DCT-transformed block. This means we keep the most important frequencies while discarding others. This form of hard quantization simplifies the compression process and greatly reduces the number of non-zero values stored for each block.

Quantization is a key part of **lossy compression**, where some image information is permanently removed. However, since the human visual system is more sensitive to low-frequency information, this loss often goes unnoticed in casual observation.

Reconstruction Using Inverse DCT

Once the DCT coefficients have been compressed, the image is reconstructed using the Inverse DCT (IDCT). This process converts the frequency data back into pixel values. Although some details are lost due to quantization, the resulting image closely resembles the original, especially in terms of structure and general appearance.

The reconstruction error is typically minimal when low-frequency information is preserved, making DCT a powerful tool for effective compression with minimal perceptual loss.

Role in Real-World Applications

DCT is at the core of many image and video compression standards, including JPEG, MPEG, and H.264. It enables efficient storage and transmission of visual data while maintaining acceptable visual quality. DCT's importance lies in its simplicity, efficiency, and alignment with human perception, making it one of the most used transformations in multimedia systems.

CODE:

https://colab.research.google.com/drive/1UT_mTLiPsNnjC0rPiggCRrwmZvgW2J75?usp=sharing

Conclusion:

The experiment demonstrates the effectiveness of Discrete Cosine Transform (DCT) in achieving image compression through frequency domain transformation and selective coefficient retention. By splitting a grayscale image into 8×8 blocks and preserving only the most relevant frequency components (top-left 4×4 of DCT output), significant data reduction was achieved without a major compromise in image quality.