



Department of Electronic & Telecommunication Engineering
University of Moratuwa

EN3551 - DIGITAL SIGNAL PROCESSING

APPLICATION OF 2D-DCT FOR IMAGE COMPRESSION

MANIMOHAN T.

200377M

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ABSTRACT

This assignment report focuses on the application of 2D-DCT for image compression, where the Discrete Cosine Transform is used to compress digital images. The report provides a theoretical background on 2D-DCT, explaining its properties, orthogonality, and energy preservation. It also discusses the quantization and coding process for compression and the subsequent decompression steps.

The assignment involves the compression of various images with different quality levels. The performance is evaluated in terms of the percentage of zeros, peak signal-to-noise ratio (PSNR), and visual quality. Through this assignment, students gain a practical understanding of the principles of image compression using 2D-DCT and the impact of different quality levels on compression results. This practical experience enhances their knowledge of digital signal processing and image compression techniques.

1 DETECTING HARMONICS IN NOISY DATA AND SIGNAL INTERPOLATION USING DFT

1.1 Procedure

1.1.1 2-D DCT - Application to Image Compression

Suppose the image to be compressed has size $M \times N$, where M and N are multiples of 8 and represented with 8 bits. The image is first divided into 8×8 blocks. The steps described below are applied to each of these blocks. Let B be a representative 8×8 data block.

Step 1: Level-Off and 2-D DCT

Since DCT gives a lower DC coefficient when pixel values are in the range -128 to 127 rather than in the range 0 to 255 , B is leveled off by subtracting 128 from each entry. For illustration purposes, we take the $(16, 18)$ -th block of the 256×256 image Lena as matrix B .

$$B = \begin{bmatrix} 125 & 134 & 137 & 139 & 138 & 138 & 141 & 142 \\ 113 & 119 & 126 & 134 & 139 & 141 & 144 & 149 \\ 80 & 95 & 103 & 106 & 114 & 127 & 141 & 147 \\ 63 & 65 & 53 & 62 & 75 & 86 & 108 & 130 \\ 93 & 80 & 60 & 33 & 35 & 35 & 52 & 69 \\ 126 & 108 & 88 & 74 & 53 & 45 & 35 & 32 \\ 130 & 116 & 90 & 96 & 62 & 63 & 55 & 49 \\ 115 & 80 & 61 & 65 & 68 & 88 & 68 & 75 \end{bmatrix}$$

The modified data block after subtracting 128 from B is given by,

$$\tilde{B} = \begin{bmatrix} -3 & 6 & 9 & 11 & 10 & 10 & 13 & 14 \\ -15 & -9 & -2 & 6 & 11 & 13 & 16 & 21 \\ -48 & -33 & -25 & -22 & -14 & -1 & 13 & 19 \\ -65 & -63 & -75 & -66 & -53 & -42 & -20 & 2 \\ -35 & -48 & -68 & -95 & -93 & -93 & -76 & -59 \\ -2 & -20 & -40 & -54 & -75 & -83 & -93 & -96 \\ 2 & -12 & -38 & -32 & -66 & -65 & -73 & -79 \\ -13 & -48 & -67 & -63 & -60 & -40 & -60 & -53 \end{bmatrix}$$

Applying 2-D DCT to \tilde{B} , we obtain,

$$C = T_8 B \tilde{T}_8 = \begin{bmatrix} -272.3750 & 17.1771 & 46.7784 & 4.2270 & 6.1250 & -0.5799 & 0.2421 & -8.4813 \\ 182.5146 & -109.5361 & -28.0398 & -25.1231 & -8.9567 & -7.0036 & -6.1703 & 10.3445 \\ 117.4897 & 19.1429 & -30.8911 & 15.7065 & 1.7309 & 6.7882 & 5.4116 & -8.5788 \\ -23.4612 & 97.7162 & -0.0872 & -7.0795 & -1.0461 & 2.6980 & -2.9351 & 2.5446 \\ -48.3750 & -35.2958 & 27.0407 & 6.4060 & 4.1250 & -7.3615 & 3.5470 & 4.3781 \\ 15.8386 & -7.1745 & -7.9234 & -6.7518 & -0.5166 & 3.8019 & -8.3849 & -7.4654 \\ 0.4477 & 1.3348 & -5.5884 & 3.4787 & -4.6404 & -0.7361 & 4.6411 & 2.6707 \\ -3.6673 & 9.8948 & 6.2377 & -7.3148 & -7.0342 & 1.0065 & -0.6727 & 2.3138 \end{bmatrix}$$

Alternatively, one may apply MATLAB function `dct2` to \tilde{B} to obtain C .

Step 2: Quantization

A critical step in image compression is quantization and coding of the DCT coefficients in C . The quantization may be achieved by converting matrix $C = \{c_{i,j}\}$ to matrix $S = \{s_{i,j}\}$ determined by,

$$s_{i,j} = \text{round} \left(\frac{c_{i,j}}{q_{i,j}} \right)$$

where $Q = \{q_{i,j}\}$ is a quantization matrix that may be selected according to a desired quality level of the compression. In the JPEG standard, subjective experiments involving the human visual system have produced their own quantization matrices. For example, with a quality level 50 (on a 1-to-100 scale) we have,

$$Q_{50} = \begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}$$

Quantization matrices of other quality levels can be obtained by multiplying the above standard quantization matrix by a scaling factor τ where,

$$\tau = \begin{cases} \frac{100 - \text{quality level}}{50}, & \text{quality level} > 50 \\ \frac{50}{\text{quality level}}, & \text{quality level} < 50 \end{cases}$$

The scaled quantization matrix is then rounded and clipped to integer values between 0 and 255. With C obtained in Step 1 and $Q = Q_{50}$, the matrix S in Eq. 10 is computed as

$$S = \begin{bmatrix} -17 & 2 & 5 & 0 & 0 & 0 & 0 & 0 \\ 15 & -9 & -2 & -1 & 0 & 0 & 0 & 0 \\ 8 & 1 & -2 & 1 & 0 & 0 & 0 & 0 \\ -2 & 6 & 0 & 0 & 0 & 0 & 0 & 0 \\ -3 & -2 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Evidently, if a quantization matrix with a reduced quality level is used, S will contain more zeros, thus a higher compression can be achieved at the cost of reduced image quality.

Step 3: Coding

The quantized matrix S is then converted by an encoder to a stream of binary data like $\{1001101, \dots\}$. Detailed coverage of the coding process is beyond the scope of this experiment. Instead, we mention the following.

- * The DC coefficients of the 8×8 blocks are encoded by a differential pulse-code modulation (DPCM) coding (also referred to as DC prediction).
- * Because the location of the retained coefficients varies from block to block, the quantized AC coefficients are zigzag scanned and ordered into (run, level) pairs, where "level" means the value of a nonzero coefficient, and "run" means the number of zero coefficients preceding it.
- * These (run, level) pairs are entropy coded, that is, longer codes for less frequent pairs and vice versa.

Step 4: Decompression

This is a step to be carried out at the receiver to reconstruct the image. It consists of the following three simple operations.

- * Pointwise multiplication of matrix S with the quantization matrix Q to get an image block $R = Q \circ S$. In our example, the Q matrix was taken to be Q_{50} that yields,

$$R = \begin{bmatrix} -272 & 22 & 50 & 0 & 0 & 0 & 0 & 0 \\ 180 & -108 & -28 & -19 & 0 & 0 & 0 & 0 \\ 112 & 13 & -32 & 24 & 0 & 0 & 0 & 0 \\ -28 & 102 & 0 & 0 & 0 & 0 & 0 & 0 \\ -54 & -44 & 37 & 0 & 0 & 0 & 0 & 0 \\ 24 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

* Apply 2-D inverse DCT to matrix R . Note that this can be done by using the MATLAB command `idct2`. Alternatively, it can be done using $D_8^T R D_8$. This gives

$$E = D_8^T R D_8 = \begin{bmatrix} 2.7181 & 2.1228 & 2.2693 & 4.2600 & 7.6484 & 10.8548 & 12.7203 & 13.3406 \\ -18.1034 & -10.6760 & -0.3337 & 7.7581 & 11.5839 & 12.5496 & 12.8140 & 13.1153 \\ -43.2294 & -34.5413 & -23.6264 & -15.8552 & -9.7946 & -0.4317 & 12.7343 & 23.0141 \\ -57.9809 & -58.9924 & -63.0283 & -67.8737 & -64.7907 & -46.4675 & -17.7381 & 4.4189 \\ -40.7650 & -50.9610 & -69.2674 & -88.8143 & -98.8380 & -92.2600 & -73.6202 & -57.6914 \\ 0.1073 & -12.7805 & -34.0432 & -57.0831 & -76.3805 & -89.4098 & -96.5154 & -99.3926 \\ 6.4904 & -8.6805 & -28.5866 & -43.2078 & -52.0062 & -61.1538 & -73.3190 & -83.0164 \\ -25.3942 & -44.5619 & -65.1582 & -70.4424 & -60.8203 & -50.0267 & -47.8854 & -50.9752 \end{bmatrix}$$

* Finally, the effect of the "level-off" operation in Step 1 is taken into account by adding 128 to the entries of the matrix E obtained above. This yields the reconstructed image block that mimics the image block B as,

$$B = E + 128 = \begin{bmatrix} 130.7181 & 130.1228 & 130.2693 & 132.2600 & 135.6484 & 138.8548 & 140.7203 & 141.3406 \\ 109.8966 & 117.3240 & 127.6663 & 135.7581 & 139.5839 & 140.5496 & 140.8140 & 141.1153 \\ 84.7706 & 93.4587 & 104.3736 & 112.1448 & 117.2054 & 127.5683 & 139.7343 & 151.0141 \\ 70.0191 & 69.0076 & 64.9717 & 60.1263 & 63.2093 & 81.5325 & 110.2619 & 132.4189 \\ 87.2350 & 77.0390 & 58.7326 & 39.1857 & 29.1620 & 35.7400 & 54.3798 & 70.3086 \\ 128.1073 & 115.2195 & 93.9568 & 70.9069 & 51.6195 & 38.5902 & 31.4846 & 28.6074 \\ 134.4904 & 119.3195 & 99.4134 & 84.7922 & 75.9938 & 66.8462 & 54.6810 & 44.9836 \\ 102.6058 & 83.4381 & 62.8418 & 57.5576 & 67.1797 & 77.9733 & 80.1146 & 77.0248 \end{bmatrix}$$

On comparing the block B^\sim with block B (given in Step 1), we see B^\sim approximates B quite well. For an image of size $M \times N$, the number of blocks is $M/8 \times N/8$, and the steps described above are applied to each of these blocks for a selected quality level. We count the number of zeros contained in the S matrices (see Step 2) in order to compute the compression factor because the total number of zeros indicates how the image has been compressed. As expected, the use of reduced quality levels leads to a higher percentage of total zeros at the cost of a degraded image.

1.1.2 Peak Signal to Noise Ratio (PSNR)

The PSNR is defined as:

$$\text{PSNR} = 20 \log_{10} \left(\frac{\psi_{\max}}{\sigma_e} \right)$$

where ψ_{\max} denotes the maximum light intensity of the original image and σ_e^2 denotes the mean squared error. For an 8-bit digital image, $\psi_{\max} = 255$. Furthermore, σ_e^2 can be computed in MATLAB applying the command `mean` twice (over the two dimensions) on a

squared error matrix. The error matrix is given by $I_{\text{rec}} - I_{\text{original}}$, where I_{rec} and I_{original} are the reconstructed and original images.

1.1.3 Tasks

1. Download 3 images assigned to your index number. Select one additional image of your choice, which is not in the provided set of images.

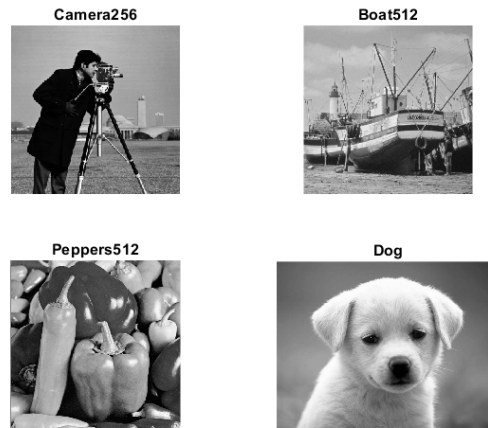


Figure 1 — Load the image

2. Compress each of these images using the DCT-based method described above with three quality levels. The quality levels are also assigned based on your index number.

Compress and observe image 1

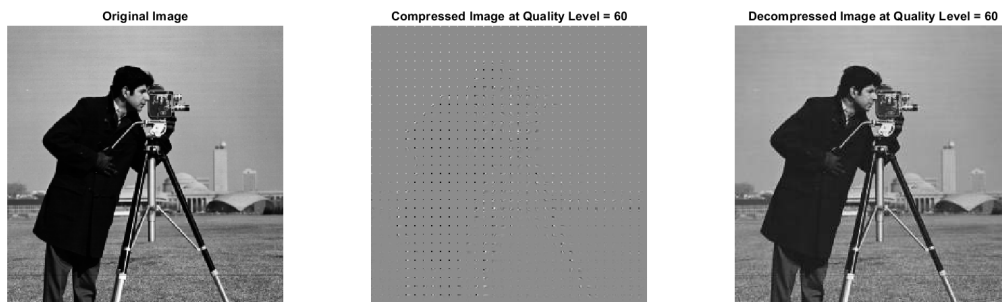


Figure 2 — Compress and observe image 1 at quality level 60

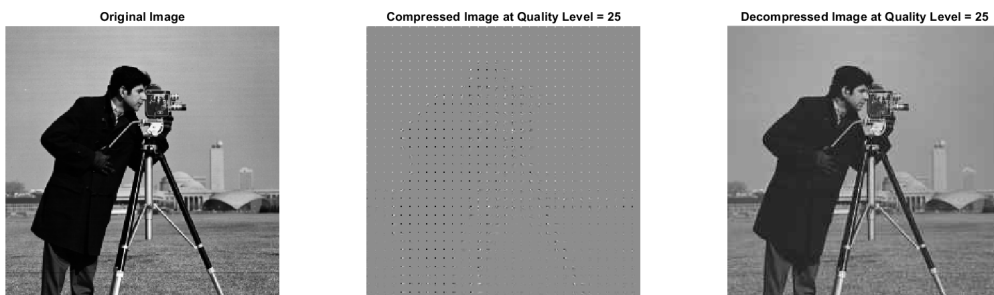


Figure 3 — Compress and observe image 1 at quality level 25

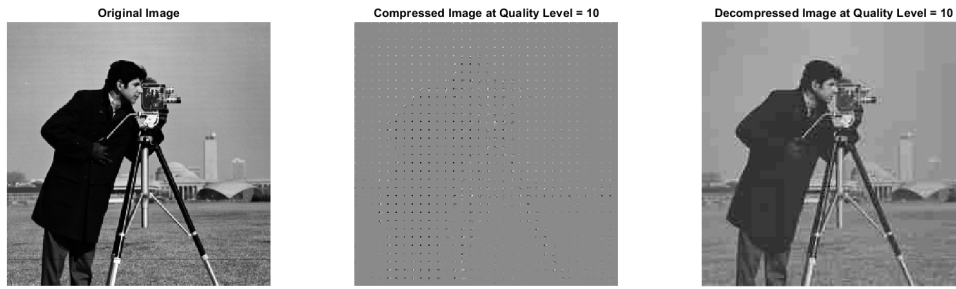


Figure 4 — Compress and observe image 1 at quality level 10

Compress and observe image 2

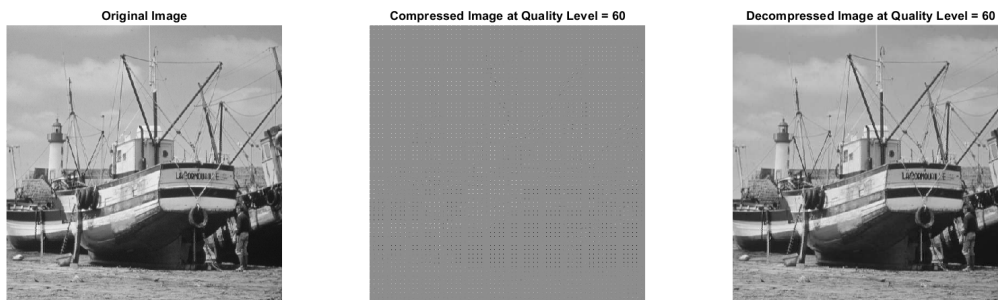


Figure 5 — Compress and observe image 2 at quality level 60

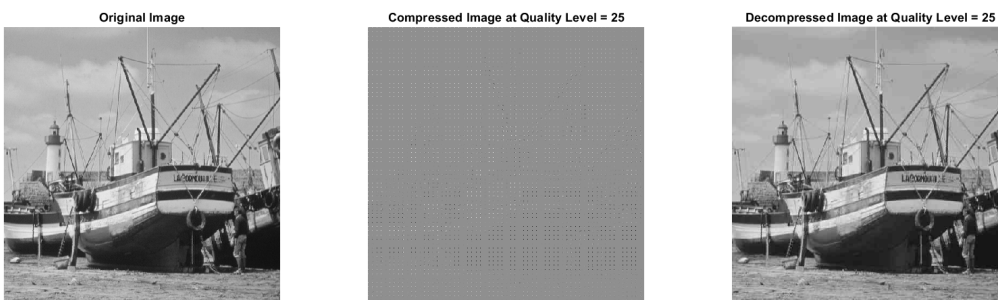


Figure 6 — Compress and observe image 2 at quality level 25

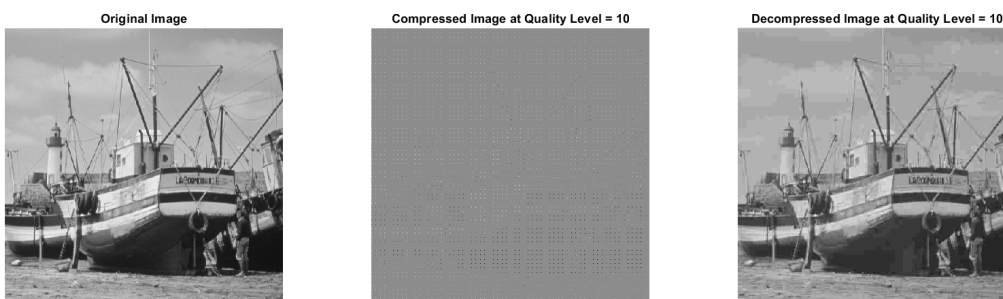


Figure 7 — Compress and observe image 2 at quality level 10

Compress and observe image 3

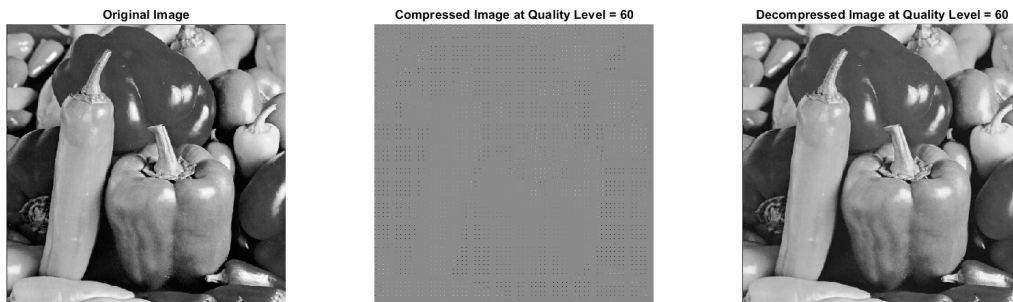


Figure 8 — Compress and observe image 3 at quality level 60

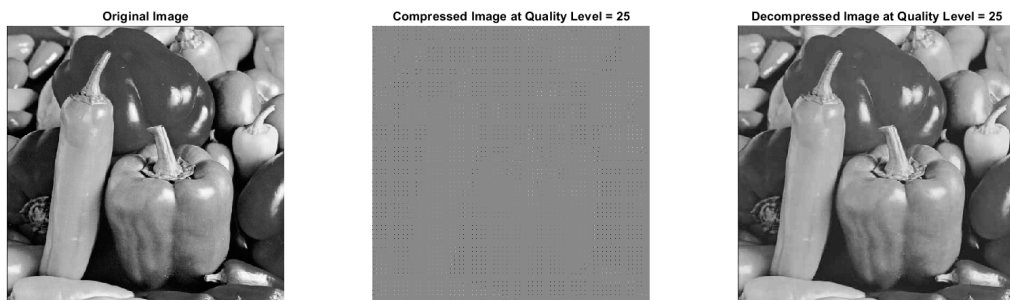


Figure 9 — Compress and observe image 3 at quality level 25

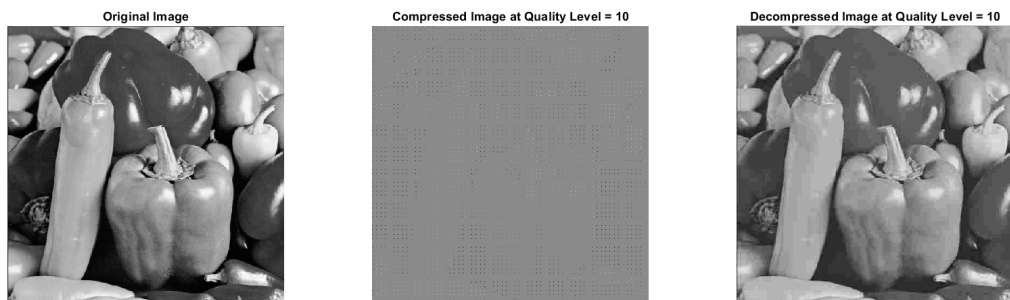


Figure 10 — Compress and observe image 3 at quality level 10

Compress and observe image 4



Figure 11 — Compress and observe image 4 at quality level 60

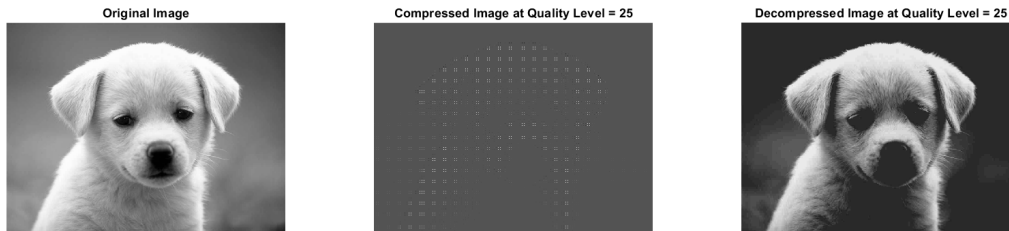


Figure 12 — Compress and observe image 4 at quality level 25

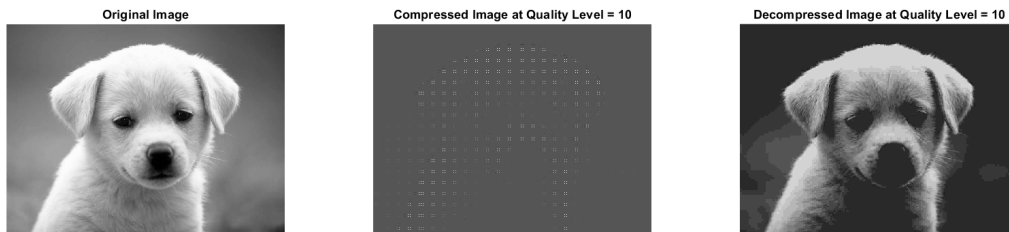


Figure 13 — Compress and observe image 4 at quality level 10

3. Observe the results in terms of:

- Percentage of zeros
- Quality in terms of peak signal-to-noise ratio (PSNR)
- Visual quality of the compressed images as related to the quality level.

Compress and observe image 1

```
When Quality Level = 60
Percentage of Zeros = 83.1192%
Peak Signal-to-Noise Ratio(PSNR) = 32.5619dB

When Quality Level = 25
Percentage of Zeros = 90.6219%
Peak Signal-to-Noise Ratio(PSNR) = 29.1581dB

When Quality Level = 10
Percentage of Zeros = 95.0058%
Peak Signal-to-Noise Ratio(PSNR) = 26.2428dB
```

Figure 14 — Compress and observe the facts of image 1

Compress and observe image 2

```
When Quality Level = 60
Percentage of Zeros = 85.1223%
Peak Signal-to-Noise Ratio(PSNR) = 41.5961dB

When Quality Level = 25
Percentage of Zeros = 91.3395%
Peak Signal-to-Noise Ratio(PSNR) = 38.2472dB

When Quality Level = 10
Percentage of Zeros = 95.3625%
Peak Signal-to-Noise Ratio(PSNR) = 34.8973dB
```

Figure 15 — Compress and observe the facts of image 2

Compress and observe image 3

```
When Quality Level = 60
Percentage of Zeros = 87.1059%
Peak Signal-to-Noise Ratio(PSNR) = 41.4033dB

When Quality Level = 25
Percentage of Zeros = 93.0378%
Peak Signal-to-Noise Ratio(PSNR) = 39.1156dB

When Quality Level = 10
Percentage of Zeros = 95.9991%
Peak Signal-to-Noise Ratio(PSNR) = 36.153dB
```

Figure 16 — Compress and observe the facts of image 3

Compress and observe image 4

```
When Quality Level = 60
Percentage of Zeros = 96.3632%
Peak Signal-to-Noise Ratio(PSNR) = 30.3488dB

When Quality Level = 25
Percentage of Zeros = 97.3148%
Peak Signal-to-Noise Ratio(PSNR) = 30.3305dB

When Quality Level = 10
Percentage of Zeros = 98.6434%
Peak Signal-to-Noise Ratio(PSNR) = 30.2499dB
```

Figure 17 — Compress and observe the facts of image 4

For all 4 images, the following 3 observations can be seen when the quality level decreases from 60 to 25 to 10

- a) **An increase in the percentage of zeros** can be observed when reducing the quality level. This phenomenon can be explained using the following equations. When the quality level is low, the scaling factor τ becomes large. For example, at quality level 90, τ is 0.2, whereas at quality level 10, τ becomes 5. A large τ results in a large quantization matrix Q , which, in turn, leads to a smaller scaled quantization matrix S . Consequently, when employing a quantization matrix Q with a lower quality level, the scaled quantization matrix S contains more zeros, achieving higher compression at the expense of reduced image quality. This expected behavior of the percentage of zeros can be observed in the experimental results obtained from all four images.
- b) **A decrease in Peak Signal-to-Noise Ratio (PSNR)** can be noted as the quality level decreases. This can be explained using the following equations. When the quality level decreases, the deviation between the reconstructed image and the original image increases. As a result, the mean squared error value increases, leading to a decrease in PSNR, as indicated by the equation. This anticipated behavior of PSNR is evident in the experimental results obtained from all four images.
- c) **Visual quality experiences a reduction** as the quality level decreases. However, the relationship between visual quality and the quality value doesn't appear to follow a linear

pattern. This can be elaborated as follows.

- The relationship between quality level and perceived visual quality is **non-linear**. Decreasing the quality level suggests increased compression and a potential decrease in visual quality. However, the extent of perceived quality reduction is influenced by various factors and may not strictly correlate with the numerical change in quality level. For instance, reducing the quality value from 60 to 25 doesn't necessarily result in an equivalent reduction in perceived visual quality. This non-linear relationship is evident in the results from Task 2, where it's observed that a decrease from 60 to 25 doesn't significantly degrade perceived visual quality.
 - The **threshold effect** is noteworthy. At very high-quality levels, slight reductions in quality may not be noticeable to the human eye. However, as the quality level decreases, there's a point where even a minor reduction can lead to a significant loss in visual quality. This phenomenon is referred to as the "threshold effect."
 - **Diminishing Returns**, As the quality level continues to decrease, visual quality degrades more rapidly. Beyond a certain point, further reductions may lead to a disproportionately large drop in visual quality.
 - **Visual quality is subjectively perceived** and can vary from person to person. Some individuals may be more sensitive to compression artifacts, while others may be less discerning.
4. Some images are more difficult to compress than others in the sense that the visual (subjective) quality cannot be maintained as easily as others for a given compression ratio. Observe the compression results obtained in task (2) from this perspective and explain why?

Some images present a greater challenge in terms of compression while preserving visual (subjective) quality compared to others. When examining the results from Task 2, it's essential to understand the reasons behind this phenomenon.

The difficulty of effectively compressing an image while retaining visual quality is influenced by several key factors: image content, complexity, and frequency distribution. Images featuring intricate textures, patterns, and high-frequency details tend to be more demanding to compress without introducing noticeable artifacts.

Image Content: Natural images, such as landscapes and portraits, are characterized by intricate details, subtle color variations, and complex textures. This complexity makes it more challenging to achieve compression without compromising visual quality compared to artificial images like text or diagrams.

Image Complexity: Images with a high degree of randomness or entropy, such as those with considerable noise or fine textures, pose greater difficulties for effective compression.

The compression algorithm struggles to identify redundant patterns or predictable areas within these images.

Frequency Distribution: Images with a broad spectrum of frequencies, including high-frequency components like sharp edges and fine details, also present challenges in compression. High-frequency information is crucial for preserving image sharpness and clarity but is more susceptible to compression artifacts such as ringing and blurring.

In general, images with simpler content, lower complexity, and a narrower frequency distribution are more amenable to compression without compromising visual quality. For instance, images featuring large areas of uniform color, smooth gradients, or simple geometric shapes typically lend themselves well to compression.

These factors, as described, become evident upon reviewing the outcomes from Task 2.

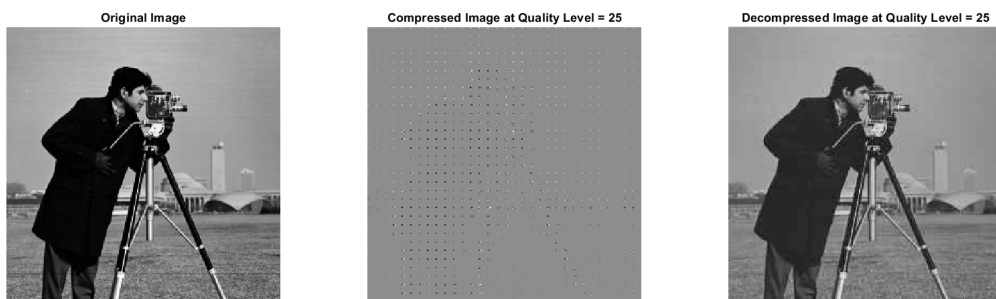


Figure 18 — Compress and observe image 1 at quality level 25

Considering the image in question, it's evident that the quality of smooth regions like the person's coat and the sky remains relatively consistent. However, there is a noticeable loss of fine details in the grass's texture, and the fine lines of the tripod have become less distinct.

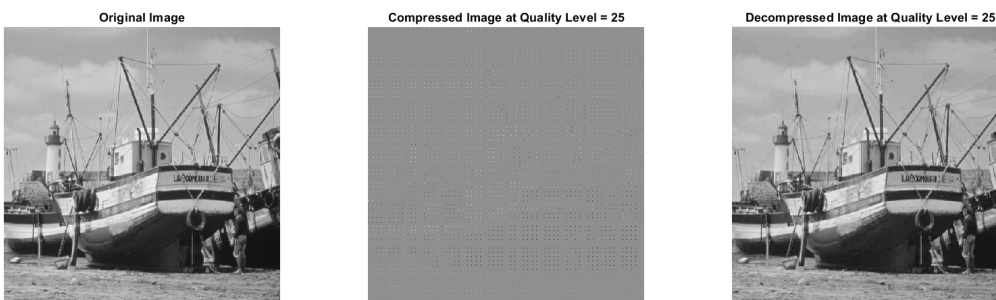


Figure 19 — Compress and observe image 2 at quality level 25

In the image above, the compression has had a more pronounced effect on fine details like the ship's masts and halyards, in contrast to the relatively smooth areas like the sky and the bottom of the ship.

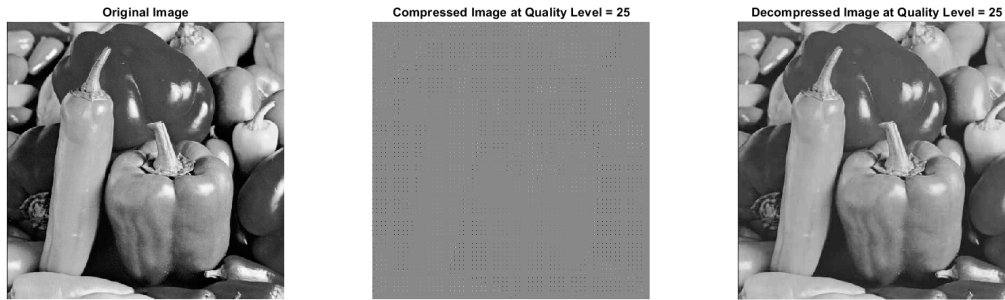


Figure 20 — Compress and observe image 3 quality level 25

This image predominantly consists of fine textures and lacks substantial smooth regions. Consequently, it has suffered significant degradation as a result of compression. This degradation is particularly conspicuous at the edges of the peppers.

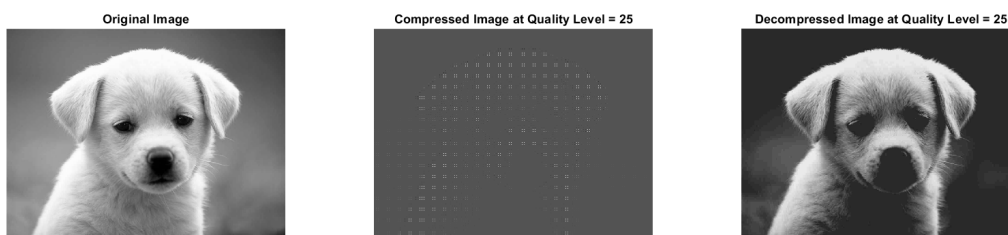


Figure 21 — Compress and observe image 4 quality level 25

In the image depicted above, there is a noticeable preservation of smooth regions, like the solid portions, during the compression process. However, the compression appears to have caused significant degradation in the sharpness of the edges. Additionally, numerous areas within the image containing intricate parts have experienced substantial deterioration as a result of the compression.

1.1.4 Useful MATLAB Commands

- `plot`: plots a function
- `fft`: calculates the DFT
- `dct2`: returns the two-dimensional discrete cosine transform of the input
- `idct2`: returns the two-dimensional inverse discrete cosine transform of the input
- `load`: load contents from a file into a MATLAB workspace.
- `norm`: returns the norm of a vector input.

1.1.5 References

1. Alan Oppenheim, Ronald Schaffer, "Discrete Time Signal Processing," Prentice Hall Signal Processing (3rd edition), 2009.
2. S.A. Khayam, "The discrete cosine transform (DCT): Theory and Application," Report, Dept of ECE, Michigan State University, March 2003.
3. K. Cabeln and P. Gent, "Image compression and the discrete cosine transform," College of the Redwoods.
4. A related demo by Berkeley EECS: JPEG DCT Demo

2 APPENDIX

Github Link :- [Assignment-02](#)

2.1 Application of 2D-DCT for Image Compression

1. Download 3 images assigned to your index number. You have to select one more image of your choice, which is not in the provided set of images.

```
1 % Load the images
2 load('camera256.mat'); % Replace with your image file names
3 load('boat512.mat');
4 load('peppers512.mat');
5 image = imread("dog.jpg");
6 % Display the images
7 figure;
8 subplot(2, 2, 1);
9 imshow(camera256, []);
10 title('Camera256');
11
12 subplot(2, 2, 2);
13 imshow(boat512, []);
14 title('Boat512');
15
16 subplot(2, 2, 3);
17 imshow(peppers512, []);
18 title('Peppers512');
19
20 subplot(2, 2, 4);
21 imshow(image, []);
22 title('Dog');
```

Listing 2.1 — Load images

2. Compress each of these images by the DCT-based method described above with three quality levels. The quality levels are also assigned based on your index number.
3. Observe the results in terms of:
 - Percentage of zeros
 - Quality in terms of peak signal-to-noise ratio (PSNR)
 - Visual quality of the compressed images as related to the quality level.

```
1 clc;
2 clear;
3 close all;
```

```

4
5 % Loading the required image
6 load("camera256.mat")
7 image = camera256;
8
9
10 [rows, cols, ~] = size(image);
11
12 % Determine the number of 8x8 blocks needed along each dimension
13 numBlocksRows = ceil(rows/8);
14 numBlocksCols = ceil(cols/8);
15
16 % Make a copy of the original image before doing operations using it
17 original_image = image;
18
19 % Divide the image into 8x8 blocks
20 image = mat2cell(image, 8 * ones(1, numBlocksRows), 8 * ones(1,
    numBlocksCols));
21
22 % Subtract 128 from every single element
23 image = cellfun(@(x) x - 128, image, 'UniformOutput', false);
24
25 % Apply DCT-2 to each block
26 image = cellfun(@dct2, image, 'UniformOutput', false);
27
28 % Define the quality levels for compression.
29 qualityLevels = [60, 25, 10];
30 numQualityLevels = length(qualityLevels);
31
32 % Loop through each quality level.
33 for level = 1:numQualityLevels
34     % Calculate the quality factor for this level.
35     qualitylevel = qualityLevels(level);
36     % Defining Quantization Matrix
37     quantizationMatrix = createJPEGQuantizationMatrix(qualitylevel);
38
39     % Quantize each block
40     quantizedmatrix = cellfun(@(x)
        quantizeDCTCoefficients(x, quantizationMatrix), image, 'UniformOutput'
41     , false);
42
43     % Combine quantizedmatrix into a single image
44     quantizedmatrix = cell2mat(quantizedmatrix);
45     quantizedmatrix_copy = quantizedmatrix;
46

```



```

47 % Converting quantized matrix into a cell array
48 quantizedmatrix =
    mat2cell(quantizedmatrix,8*ones(1,numBlocksRows),8*ones(1,
49 numBlocksCols));
50
51 % Encoding each block
52 encodedmatrix =
    cellfun(@encodeDCTCoefficients,quantizedmatrix,'UniformOutput'
53 ,false);
54
55 % Pointwise multiplication of quantizationMatrix and
    quantizedmatrix
56 dequantizedmatrix = cellfun(@(x)
    x.*quantizationMatrix,quantizedmatrix,'UniformOutput',false);
57
58 % Apply inverse DCT-2 to each block
59 level_offed_matrix =
    cellfun(@idct2,dequantizedmatrix,'UniformOutput',false);
60
61 % Adding 128 to every single element
62 decompressed_blocks = cellfun(@(x)
    x+128,level_offed_matrix,'UniformOutput',false);
63
64 % Combine all blocks into a single image
65 decompressed_image = cell2mat(decompressed_blocks);
66
67 % Calculating Zero Percentage in the dequantizedmatrix
68 dequantizedmatrix = cell2mat(dequantizedmatrix);
69 zero_percentage =
    (nnz(dequantizedmatrix==0)/numel(dequantizedmatrix))*100;
70
71 % Calculating the maximum light intensity of the original image
    using antilog of one side of the image
72 max_intensity = 2^(log2(rows))-1;
73
74
75 % Calculating Mean Squared Error by iteratively using mean() over
    the two axes of a squared error matrix
76 % First, ensure that both original_image and decompressed_image
    have the same data type (e.g., double)
77 original_image = double(original_image);
78 decompressed_image = double(decompressed_image);
79
80 % Now calculate the Mean Squared Error

```

```

81     mean_squared_error = mean(mean((original_image -
82         decompressed_image).^2));
83
84     % Calculating Peak Signal-to-Noise Ratio
85     peak_signal_to_noise_ratio = 10 * log10((max_intensity^2) /
86         mean_squared_error);
87
88     % Display the calculated performance metrics
89     temp = "When Quality Level = " + num2str(qualitylevel);
90     disp(temp);
91     pm1 = "Percentage of Zeros = " + num2str(zero_percentage)+"%";
92     disp(pm1);
93     pm2 = "Peak Signal-to-Noise Ratio(PSNR) = " +
94         num2str(peak_signal_to_noise_ratio)+"dB";
95     disp(pm2);
96     disp(" ");
97     % Displaying Images
98     myfigure = figure();
99     myfigure.WindowState = 'maximized';
100
101     subplot(1, 3, 1);
102     imshow(original_image, []);
103     title('Original Image');
104
105     subplot(1, 3, 2);
106     imshow(cell2mat(quantizedmatrix), []);
107     title_string = "Compressed Image at Quality Level = " +
108         num2str(qualitylevel);
109     title(title_string);
110
111     subplot(1, 3, 3);
112     imshow(decompressed_image, []);
113     title_string = "Decompressed Image at Quality Level = " +
114         num2str(qualitylevel);
115     title(title_string);
116 end
117
118 function quantizationMatrix = createJPEGQuantizationMatrix(quality)
119     % Define the standard JPEG quantization matrix for quality level 50
120     standardQuantizationMatrix = [
121         16, 11, 10, 16, 24, 40, 51, 61;
122         12, 12, 14, 19, 26, 58, 60, 55;
123         14, 13, 16, 24, 40, 57, 69, 56;

```

```

121         14, 17, 22, 29, 51, 87, 80, 62;
122         18, 22, 37, 56, 68, 109, 103, 77;
123         24, 35, 55, 64, 81, 104, 113, 92;
124         49, 64, 78, 87, 103, 121, 120, 101;
125         72, 92, 95, 98, 112, 100, 103, 99
126     ];
127
128     % Quality should have values between 1 and 100
129     if quality <= 0
130         quality = 1;
131     elseif quality > 100
132         quality = 100;
133     end
134
135     % Adjust Quantization Matrix based on the desired quality level
136     if quality < 50
137         scaleFactor = 50 / quality;
138     else
139         scaleFactor = 2 - (quality / 50);
140     end
141
142     quantizationMatrix = round(standardQuantizationMatrix *
143         scaleFactor);
144
145     % Ensure that no values are less than 1
146     quantizationMatrix(quantizationMatrix < 1) = 1;
147 end
148 % Define a function to quantize the matrix with quantizationMatrix
149 function quantizedmatrix = quantizeDCTCoefficients(matrix,
150     quantizationMatrix)
151     % Initialize the quantized matrix
152     quantizedmatrix = round(matrix ./ quantizationMatrix);
153 end
154 % Define a function to encode [0,0] coefficient using differential PCM
155     and encode AC coefficients with (run,level) pairs
156 function encodedmatrix = encodeDCTCoefficients(matrix)
157     % Initialize the encoded matrix
158     encodedmatrix = zeros(1, 64);
159
160     % Encode the DC coefficient
161     encodedmatrix(1) = matrix(1, 1);
162
163     % Encode the AC coefficients

```

```

163     index = 2;
164     for i = 1:8
165         for j = 1:8
166             if i == 1 && j == 1
167                 continue;
168             end
169             if matrix(i, j) == 0
170                 index = index + 1;
171             else
172                 encodedmatrix(index) = matrix(i, j);
173                 index = index + 1;
174             end
175         end
176     end
177 end

```

Listing 2.2 — compress and observe image 1 ("camera512")

```

1  clc;
2  clear;
3  close all;
4
5  % Loading the required image
6  load("boat512.mat")
7  image = boat512;
8
9
10 [rows, cols, ~] = size(image);
11
12 % Determine the number of 8x8 blocks needed along each dimension
13 numBlocksRows = ceil(rows/8);
14 numBlocksCols = ceil(cols/8);
15
16 % Make a copy of the original image before doing operations using it
17 original_image = image;
18
19 % Divide the image into 8x8 blocks
20 image = mat2cell(image, 8 * ones(1, numBlocksRows), 8 * ones(1,
    numBlocksCols));
21
22 % Subtract 128 from every single element
23 image = cellfun(@(x) x - 128, image, 'UniformOutput', false);
24
25 % Apply DCT-2 to each block
26 image = cellfun(@dct2, image, 'UniformOutput', false);
27

```

```

28 % Define the quality levels for compression.
29 qualityLevels = [60, 25, 10];
30 numQualityLevels = length(qualityLevels);
31
32 % Loop through each quality level.
33 for level = 1:numQualityLevels
34     % Calculate the quality factor for this level.
35     qualitylevel = qualityLevels(level);
36     % Defining Quantization Matrix
37     quantizationMatrix = createJPEGQuantizationMatrix(qualitylevel);
38
39     % Quantize each block
40     quantizedmatrix = cellfun(@(x)
41         quantizeDCTCoefficients(x,quantizationMatrix),image,
42         'UniformOutput',false);
43
44     % Combine quantizedmatrix into a single image
45     quantizedmatrix = cell2mat(quantizedmatrix);
46     quantizedmatrix_copy = quantizedmatrix;
47
48     % Converting quantized matrix into a cell array
49     quantizedmatrix =
50         mat2cell(quantizedmatrix,8*ones(1,numBlocksRows),8*ones(1,
51         numBlocksCols));
52
53     % Encoding each block
54     encodedmatrix =
55         cellfun(@encodeDCTCoefficients,quantizedmatrix,'UniformOutput'
56         ,false);
57
58     % Pointwise multiplication of quantizationMatrix and
59     quantizedmatrix
60     dequantizedmatrix = cellfun(@(x)
61         x.*quantizationMatrix,quantizedmatrix,'UniformOutput',false);
62
63     % Apply inverse DCT-2 to each block
64     level_offed_matrix =
65         cellfun(@idct2,dequantizedmatrix,'UniformOutput',false);
66
67     % Adding 128 to every single element
68     decompressed_blocks = cellfun(@(x)
69         x+128,level_offed_matrix,'UniformOutput',false);
70
71     % Combine all blocks into a single image
72     decompressed_image = cell2mat(decompressed_blocks);

```

```

66
67 % Calculating Zero Percentage in the dequantizedmatrix
68 dequantizedmatrix = cell2mat(dequantizedmatrix);
69 zero_percentage =
    (nnz(dequantizedmatrix==0)/numel(dequantizedmatrix))*100;
70
71 % Calculating the maximum light intensity of the original image
    using antilog of one side of the image
72 max_intensity = 2^(log2(rows))-1;
73
74
75 % Calculating Mean Squared Error by iteratively using mean() over
    the two axes of a squared error matrix
76 % First, ensure that both original_image and decompressed_image
    have the same data type (e.g., double)
77 original_image = double(original_image);
78 decompressed_image = double(decompressed_image);
79
80 % Now calculate the Mean Squared Error
81 mean_squared_error = mean(mean((original_image -
    decompressed_image).^2));
82
83 % Calculating Peak Signal-to-Noise Ratio
84 peak_signal_to_noise_ratio = 10 * log10((max_intensity^2) /
    mean_squared_error);
85
86 % Display the calculated performance metrics
87 temp = "When Quality Level = " + num2str(qualitylevel);
88 disp(temp);
89 pm1 = "Percentage of Zeros = " + num2str(zero_percentage)+"%";
90 disp(pm1);
91 pm2 = "Peak Signal-to-Noise Ratio (PSNR) = " +
    num2str(peak_signal_to_noise_ratio)+"dB";
92 disp(pm2);
93 disp(" ");
94 % Displaying Images
95 myfigure = figure();
96 myfigure.WindowState = 'maximized';
97
98 subplot(1, 3, 1);
99 imshow(original_image, []);
100 title('Original Image');
101
102 subplot(1, 3, 2);
103 imshow(cell2mat(quantizedmatrix), []);

```

```

104     title_string = "Compressed Image at Quality Level = " +
        num2str(qualitylevel);
105     title(title_string);
106
107     subplot(1, 3, 3);
108     imshow(decompressed_image, []);
109     title_string = "Decompressed Image at Quality Level = " +
        num2str(qualitylevel);
110     title(title_string);
111 end
112
113
114
115 function quantizationMatrix = createJPEGQuantizationMatrix(quality)
116     % Define the standard JPEG quantization matrix for quality level 50
117     standardQuantizationMatrix = [
118         16, 11, 10, 16, 24, 40, 51, 61;
119         12, 12, 14, 19, 26, 58, 60, 55;
120         14, 13, 16, 24, 40, 57, 69, 56;
121         14, 17, 22, 29, 51, 87, 80, 62;
122         18, 22, 37, 56, 68, 109, 103, 77;
123         24, 35, 55, 64, 81, 104, 113, 92;
124         49, 64, 78, 87, 103, 121, 120, 101;
125         72, 92, 95, 98, 112, 100, 103, 99
126     ];
127
128     % Quality should have values between 1 and 100
129     if quality <= 0
130         quality = 1;
131     elseif quality > 100
132         quality = 100;
133     end
134
135     % Adjust Quantization Matrix based on the desired quality level
136     if quality < 50
137         scaleFactor = 50 / quality;
138     else
139         scaleFactor = 2 - (quality / 50);
140     end
141
142     quantizationMatrix = round(standardQuantizationMatrix *
        scaleFactor);
143
144     % Ensure that no values are less than 1
145     quantizationMatrix(quantizationMatrix < 1) = 1;

```

```

146 end
147
148 % Define a function to quantize the matrix with quantizationMatrix
149 function quantizedmatrix = quantizeDCTCoefficients(matrix,
    quantizationMatrix)
150     % Initialize the quantized matrix
151     quantizedmatrix = round(matrix ./ quantizationMatrix);
152 end
153
154 % Define a function to encode [0,0] coefficient using differential PCM
    and encode AC coefficients with (run,level) pairs
155 function encodedmatrix = encodeDCTCoefficients(matrix)
156     % Initialize the encoded matrix
157     encodedmatrix = zeros(1, 64);
158
159     % Encode the DC coefficient
160     encodedmatrix(1) = matrix(1, 1);
161
162     % Encode the AC coefficients
163     index = 2;
164     for i = 1:8
165         for j = 1:8
166             if i == 1 && j == 1
167                 continue;
168             end
169             if matrix(i, j) == 0
170                 index = index + 1;
171             else
172                 encodedmatrix(index) = matrix(i, j);
173                 index = index + 1;
174             end
175         end
176     end
177 end

```

Listing 2.3 — compress and observe image 2 ("boat512")

```

1 clc;
2 clear;
3 close all;
4
5 % Loading the required image
6 load("peppers512.mat")
7 image = peppers512;
8
9 [rows, cols, ~] = size(image);

```



```

10
11 % Determine the number of 8x8 blocks needed along each dimension
12 numBlocksRows = ceil(rows/8);
13 numBlocksCols = ceil(cols/8);
14
15 % Make a copy of the original image before doing operations using it
16 original_image = image;
17
18 % Divide the image into 8x8 blocks
19 image = mat2cell(image, 8 * ones(1, numBlocksRows), 8 * ones(1,
    numBlocksCols));
20
21 % Subtract 128 from every single element
22 image = cellfun(@(x) x - 128, image, 'UniformOutput', false);
23
24 % Apply DCT-2 to each block
25 image = cellfun(@dct2, image, 'UniformOutput', false);
26
27 % Define the quality levels for compression.
28 qualityLevels = [60, 25, 10];
29 numQualityLevels = length(qualityLevels);
30
31 % Loop through each quality level.
32 for level = 1:numQualityLevels
33     % Calculate the quality factor for this level.
34     qualitylevel = qualityLevels(level);
35     % Defining Quantization Matrix
36     quantizationMatrix = createJPEGQuantizationMatrix(qualitylevel);
37
38     % Quantize each block
39     quantizedmatrix = cellfun(@(x)
        quantizeDCTCoefficients(x,quantizationMatrix),image,
40     'UniformOutput',false);
41
42     % Combine quantizedmatrix into a single image
43     quantizedmatrix = cell2mat(quantizedmatrix);
44     quantizedmatrix_copy = quantizedmatrix;
45
46     % Converting quantized matrix into a cell array
47     quantizedmatrix =
        mat2cell(quantizedmatrix,8*ones(1,numBlocksRows),8*ones(1,
48     numBlocksCols));
49
50     % Encoding each block

```

```

51     encodedmatrix =
52         cellfun(@encodeDCTCoefficients, quantizedmatrix, 'UniformOutput'
53             , false);
54     % Pointwise multiplication of quantizationMatrix and
55         quantizedmatrix
56     dequantizedmatrix = cellfun(@(x)
57         x.*quantizationMatrix, quantizedmatrix, 'UniformOutput', false);
58
59     % Apply inverse DCT-2 to each block
60     level_offed_matrix =
61         cellfun(@idct2, dequantizedmatrix, 'UniformOutput', false);
62
63     % Adding 128 to every single element
64     decompressed_blocks = cellfun(@(x)
65         x+128, level_offed_matrix, 'UniformOutput', false);
66
67     % Combine all blocks into a single image
68     decompressed_image = cell2mat(decompressed_blocks);
69
70     % Calculating Zero Percentage in the dequantizedmatrix
71     dequantizedmatrix = cell2mat(dequantizedmatrix);
72     zero_percentage =
73         (nnz(dequantizedmatrix==0)/numel(dequantizedmatrix))*100;
74
75     % Calculating the maximum light intensity of the original image
76         using antilog of one side of the image
77     max_intensity = 2^(log2(rows))-1;
78
79     % Calculating Mean Squared Error by iteratively using mean() over
80         the two axes of a squared error matrix
81     % First, ensure that both original_image and decompressed_image
82         have the same data type (e.g., double)
83     original_image = double(original_image);
84     decompressed_image = double(decompressed_image);
85
86     % Now calculate the Mean Squared Error
87     mean_squared_error = mean(mean((original_image -
88         decompressed_image).^2));
89
90     % Calculating Peak Signal-to-Noise Ratio
91     peak_signal_to_noise_ratio = 10 * log10((max_intensity^2) /
92         mean_squared_error);
93
94

```

```

85 % Display the calculated performance metrics
86 temp = "When Quality Level = " + num2str(qualitylevel);
87 disp(temp);
88 pm1 = "Percentage of Zeros = " + num2str(zero_percentage)+"%";
89 disp(pm1);
90 pm2 = "Peak Signal-to-Noise Ratio(PSNR) = " +
    num2str(peak_signal_to_noise_ratio)+"dB";
91 disp(pm2);
92 disp(" ");
93 % Displaying Images
94 myfigure = figure();
95 myfigure.WindowState = 'maximized';
96
97 subplot(1, 3, 1);
98 imshow(original_image, []);
99 title('Original Image');
100
101 subplot(1, 3, 2);
102 imshow(cell2mat(quantizedmatrix), []);
103 title_string = "Compressed Image at Quality Level = " +
    num2str(qualitylevel);
104 title(title_string);
105
106 subplot(1, 3, 3);
107 imshow(decompressed_image, []);
108 title_string = "Decompressed Image at Quality Level = " +
    num2str(qualitylevel);
109 title(title_string);
110 end
111
112
113
114 function quantizationMatrix = createJPEGQuantizationMatrix(quality)
115 % Define the standard JPEG quantization matrix for quality level 50
116 standardQuantizationMatrix = [
117     16, 11, 10, 16, 24, 40, 51, 61;
118     12, 12, 14, 19, 26, 58, 60, 55;
119     14, 13, 16, 24, 40, 57, 69, 56;
120     14, 17, 22, 29, 51, 87, 80, 62;
121     18, 22, 37, 56, 68, 109, 103, 77;
122     24, 35, 55, 64, 81, 104, 113, 92;
123     49, 64, 78, 87, 103, 121, 120, 101;
124     72, 92, 95, 98, 112, 100, 103, 99
125 ];
126

```

```

127 % Quality should have values between 1 and 100
128 if quality <= 0
129     quality = 1;
130 elseif quality > 100
131     quality = 100;
132 end
133
134 % Adjust Quantization Matrix based on the desired quality level
135 if quality < 50
136     scaleFactor = 50 / quality;
137 else
138     scaleFactor = 2 - (quality / 50);
139 end
140
141 quantizationMatrix = round(standardQuantizationMatrix *
    scaleFactor);
142
143 % Ensure that no values are less than 1
144 quantizationMatrix(quantizationMatrix < 1) = 1;
145 end
146
147 % Define a function to quantize the matrix with quantizationMatrix
148 function quantizedmatrix = quantizeDCTCoefficients(matrix,
    quantizationMatrix)
149     % Initialize the quantized matrix
150     quantizedmatrix = round(matrix ./ quantizationMatrix);
151 end
152
153 % Define a function to encode [0,0] coefficient using differential PCM
    and encode AC coefficients with (run,level) pairs
154 function encodedmatrix = encodeDCTCoefficients(matrix)
155     % Initialize the encoded matrix
156     encodedmatrix = zeros(1, 64);
157
158     % Encode the DC coefficient
159     encodedmatrix(1) = matrix(1, 1);
160
161     % Encode the AC coefficients
162     index = 2;
163     for i = 1:8
164         for j = 1:8
165             if i == 1 && j == 1
166                 continue;
167             end
168             if matrix(i, j) == 0

```

```

169         index = index + 1;
170     else
171         encodedmatrix(index) = matrix(i, j);
172         index = index + 1;
173     end
174 end
175 end
176 end

```

Listing 2.4 — compress and observe image 3 ("peppers512")

```

1  clc;
2  clear;
3  close all;
4
5  % Loading the required image
6  image = imread("dog.jpg");
7  [rows, cols, ~] = size(image);
8
9  % Determine the number of 8x8 blocks needed along each dimension
10 numBlocksRows = ceil(rows/8);
11 numBlocksCols = ceil(cols/8);
12
13 % Make a copy of the original image before doing operations using it
14 original_image = image;
15
16 % Divide the image into 8x8 blocks
17 image = mat2cell(image, 8 * ones(1, numBlocksRows), 8 * ones(1,
    numBlocksCols));
18
19 % Subtract 128 from every single element
20 image = cellfun(@(x) x - 128, image, 'UniformOutput', false);
21
22 % Apply DCT-2 to each block
23 image = cellfun(@dct2, image, 'UniformOutput', false);
24
25 % Define the quality levels for compression.
26 qualityLevels = [60, 25, 10];
27 numQualityLevels = length(qualityLevels);
28
29 % Loop through each quality level.
30 for level = 1:numQualityLevels
31     % Calculate the quality factor for this level.
32     qualitylevel = qualityLevels(level);
33     % Defining Quantization Matrix
34     quantizationMatrix = createJPEGQuantizationMatrix(qualitylevel);

```

```

35
36 % Quantize each block
37 quantizedmatrix = cellfun(@(x)
    quantizeDCTCoefficients(x, quantizationMatrix), image,
38 'UniformOutput', false);
39
40 % Combine quantizedmatrix into a single image
41 quantizedmatrix = cell2mat(quantizedmatrix);
42 quantizedmatrix_copy = quantizedmatrix;
43
44 % Converting quantized matrix into a cell array
45 quantizedmatrix =
    mat2cell(quantizedmatrix, 8*ones(1, numBlocksRows), 8*ones(1,
46 numBlocksCols));
47
48 % Encoding each block
49 encodedmatrix =
    cellfun(@encodeDCTCoefficients, quantizedmatrix, 'UniformOutput'
50 , false);
51
52 % Pointwise multiplication of quantizationMatrix and
    quantizedmatrix
53 dequantizedmatrix = cellfun(@(x)
    x.*quantizationMatrix, quantizedmatrix, 'UniformOutput', false);
54
55 % Apply inverse DCT-2 to each block
56 level_offed_matrix =
    cellfun(@idct2, dequantizedmatrix, 'UniformOutput', false);
57
58 % Adding 128 to every single element
59 decompressed_blocks = cellfun(@(x)
    x+128, level_offed_matrix, 'UniformOutput', false);
60
61 % Combine all blocks into a single image
62 decompressed_image = cell2mat(decompressed_blocks);
63
64 % Calculating Zero Percentage in the dequantizedmatrix
65 dequantizedmatrix = cell2mat(dequantizedmatrix);
66 zero_percentage =
    (nnz(dequantizedmatrix==0)/numel(dequantizedmatrix))*100;
67
68 % Calculating the maximum light intensity of the original image
    using antilog of one side of the image
69 max_intensity = 2^(log2(rows))-1;
70

```

```

71
72 % Calculating Mean Squared Error by iteratively using mean() over
    the two axes of a squared error matrix
73 % First, ensure that both original_image and decompressed_image
    have the same data type (e.g., double)
74 original_image = double(original_image);
75 decompressed_image = double(decompressed_image);
76
77 % Now calculate the Mean Squared Error
78 mean_squared_error = mean(mean((original_image -
    decompressed_image).^2));
79
80 % Calculating Peak Signal-to-Noise Ratio
81 peak_signal_to_noise_ratio = 10 * log10((max_intensity^2) /
    mean_squared_error);
82
83 % Display the calculated performance metrics
84 temp = "When Quality Level = " + num2str(qualitylevel);
85 disp(temp);
86 pm1 = "Percentage of Zeros = " + num2str(zero_percentage)+"%";
87 disp(pm1);
88 pm2 = "Peak Signal-to-Noise Ratio(PSNR) = " +
    num2str(peak_signal_to_noise_ratio)+"dB";
89 disp(pm2);
90 disp(" ");
91 % Displaying Images
92 myfigure = figure();
93 myfigure.WindowState = 'maximized';
94
95 subplot(1, 3, 1);
96 imshow(original_image, []);
97 title('Original Image');
98
99 subplot(1, 3, 2);
100 imshow(cell2mat(quantizedmatrix), []);
101 title_string = "Compressed Image at Quality Level = " +
    num2str(qualitylevel);
102 title(title_string);
103
104 subplot(1, 3, 3);
105 imshow(decompressed_image, []);
106 title_string = "Decompressed Image at Quality Level = " +
    num2str(qualitylevel);
107 title(title_string);
108 end

```

```

109
110
111
112 function quantizationMatrix = createJPEGQuantizationMatrix(quality)
113     % Define the standard JPEG quantization matrix for quality level 50
114     standardQuantizationMatrix = [
115         16, 11, 10, 16, 24, 40, 51, 61;
116         12, 12, 14, 19, 26, 58, 60, 55;
117         14, 13, 16, 24, 40, 57, 69, 56;
118         14, 17, 22, 29, 51, 87, 80, 62;
119         18, 22, 37, 56, 68, 109, 103, 77;
120         24, 35, 55, 64, 81, 104, 113, 92;
121         49, 64, 78, 87, 103, 121, 120, 101;
122         72, 92, 95, 98, 112, 100, 103, 99
123     ];
124
125     % Quality should have values between 1 and 100
126     if quality <= 0
127         quality = 1;
128     elseif quality > 100
129         quality = 100;
130     end
131
132     % Adjust Quantization Matrix based on the desired quality level
133     if quality < 50
134         scaleFactor = 50 / quality;
135     else
136         scaleFactor = 2 - (quality / 50);
137     end
138
139     quantizationMatrix = round(standardQuantizationMatrix *
140         scaleFactor);
141
142     % Ensure that no values are less than 1
143     quantizationMatrix(quantizationMatrix < 1) = 1;
144 end
145
146 % Define a function to quantize the matrix with quantizationMatrix
147 function quantizedmatrix = quantizeDCTCoefficients(matrix,
148     quantizationMatrix)
149     % Initialize the quantized matrix
150     quantizedmatrix = round(matrix ./ quantizationMatrix);
end

```



```

151 % Define a function to encode [0,0] coefficient using differential PCM
    and encode AC coefficients with (run,level) pairs
152 function encodedmatrix = encodeDCTCoefficients(matrix)
153     % Initialize the encoded matrix
154     encodedmatrix = zeros(1, 64);
155
156     % Encode the DC coefficient
157     encodedmatrix(1) = matrix(1, 1);
158
159     % Encode the AC coefficients
160     index = 2;
161     for i = 1:8
162         for j = 1:8
163             if i == 1 && j == 1
164                 continue;
165             end
166             if matrix(i, j) == 0
167                 index = index + 1;
168             else
169                 encodedmatrix(index) = matrix(i, j);
170                 index = index + 1;
171             end
172         end
173     end
174 end

```

Listing 2.5 — compress and observe image 4("dog")
