深 圳 大 学 实 验 报 告

课程名称： 数字图像处理

实验项目名称： **Exp 4 Image Compression**

学院： 电子与信息工程学院

专业： 电子信息工程

指导教师： 李斌

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实验时间： **2024** 年 **5** 月 **7** 日、**5** 月 **14** 日、**5** 月 **21** 日

实验报告提交时间： **2024** 年 **5** 月 **25** 日

教务部制

实验目的（Aim of Experiment）：

(1) Be familiar with some basic image fidelity assessment methods such as MSE, PSNR and SSIM.
(2) Be familiar with the process of JPEG compression.
(3) Be familiar with Discrete Cosine Transform, Huffman Coding, and Predictive Coding.

实验内容与要求（Experiment Steps and Requirements）：

(1) **Compression Ratio and Relative Coding Redundancy.**

(a) Load the image bunny.png. Save it as a JPEG image with a quality factor of 90, 60, 10, respectively. Name the images as b90.jpg, b60.jpg, b10.jpg, respectively.

(b) Display the original image and the compressed images.

(c) Calculate the Compression Ratio and Relative Data Redundancy between the PNG image and JPEG images according to the file sizes. (Tips: os.path.getsize)

(2) **Fidelity Criteria.**

(a) Load the saved JPEG images. Use functions from skimage.metrics to calculate MSE, PSNR, and SSIM values between the PNG image and JPEG images.

(b) Implement a SSIM function by yourself according to [1].

[1] Wang Z, Bovik AC, Sheikh HR, Simoncelli EP. Image quality assessment: from error visibility to structural similarity. IEEE Trans Image Process. 2004 Apr;13(4):600-12.

(3) **Simulation of a Part of JPEG Compression.**

(a) Load the grayscale image lenagray.tiff.

(b) Shift the pixel intensity by -128.

(c) Divide the image into non-overlapped 8 ＊ 8 subimages and perform 8 ＊ 8 block DCT on each subimage. (Tips: cv2.dct or scipy.fftpack.dct)

(d) Use a quantization table with QF=50 for quantization.

(e) Perform lossless predictive coding (difference coding) of DC coefficients by using the coefficient in the previous subimage as reference (a raster scan mannar).

(f) Sort 63 AC coefficients in each block in a ZigZag order. Converted them into a one-dimensional vector.

(g) Save all the compressed data into a Numpy data format (refered to as NPY/NPZ (.npy or .npz) file) (Tips: np.save or np.savez).

(h) Compress the npy/npz file to a zip file (refered to as NPZzip). Compress the TIFF image to another zip file (refered to as TIFFzip).

(i) Calculate the Compression Ratio between the TIFF image and the NPY/NPZ file according to the file sizes. Calculate the Compression Ratio between the TIFF image and the NPZzip file according to the file sizes. Calculate the Compression Ratio between the TIFFZzip and the NPZzip according to the file sizes.

(j) Load the above saved file. Decode it to a recovered image.

(k) Compute the MSE and PSNR of the recovered image, and display it with the original image side by side.

实验代码及数据结果（Experiment Codes and Results）：

(1) **Compression Ratio and Relative Coding Redundancy.**

(a) Load the image bunny.png. Save it as a JPEG image with a quality factor of 90, 60, 10, respectively. Name the images as b90.jpg, b60.jpg, b10.jpg, respectively.

```
original = io.imread("images/bunny.png")
 0.0s

# （a）保存JPEG图像
quality_factors = [90, 60, 10]
jpeg_filenames = []
for qf in quality_factors:
    jpeg_filename = f"b{qf}.jpg"
    jpeg_filenames.append(jpeg_filename)
    io.imsave(os.path.join(result_folder, jpeg_filename), original, quality=qf)
```

(b) Display the original image and the compressed images.

```
# （b）显示原始图像和压缩图像
plt.figure(figsize=(16, 8))
plt.subplot(2, 2, 1)
plt.imshow(original)
plt.title("Original Image")
plt.axis("off")

for i, jpeg_filename in enumerate(jpeg_filenames):
    compressed_image = io.imread(os.path.join(result_folder, jpeg_filename))
    plt.subplot(2, 2, i + 2)
    plt.imshow(compressed_image)
    plt.title(f"JPEG Image (Quality: {quality_factors[i]})")
    plt.axis("off")

plt.tight_layout()
plt.show()
```

(c) Calculate the Compression Ratio and Relative Data Redundancy between the PNG image and JPEG images according to the file sizes. (Tips: os.path.getsize)

```
# （c）计算压缩比和相对数据冗余
png_filesize = os.path.getsize("images/bunny.png")

# 存储结果的列表
results = []

for jpeg_filename in jpeg_filenames:
    jpeg_filesize = os.path.getsize(os.path.join(result_folder, jpeg_filename))
    compression_ratio = png_filesize / jpeg_filesize
    redundancy = 1 - (1 / compression_ratio)
    results.append([jpeg_filename, f"{compression_ratio:.2f}", f"{redundancy:.2f}"])

# 打印表格
print(tabulate(results, headers=["文件名", "压缩比", "相对数据冗余"], tablefmt="grid", colalign=("center", "center", "center")))
```

文件名	压缩比	相对数据冗余
b90.jpg	8.4	0.88
b60.jpg	18.66	0.95
b10.jpg	48.14	0.98

(2) **Fidelity Criteria.**

(a) Load the saved JPEG images. Use functions from skimage.metrics to calculate MSE, PSNR, and SSIM values between the PNG image and JPEG images.

```python
# 加载保存的JPEG图像
jpeg_images = []
for jpeg_filename in jpeg_filenames:
    jpeg_image = io.imread(os.path.join(result_folder, jpeg_filename))
    jpeg_images.append(jpeg_image)
```

0.0s

```python
# 存储结果的列表
results = []

# 计算MSE、PSNR和SSIM值
for i, jpeg_image in enumerate(jpeg_images):
    mse = metrics.mean_squared_error(original, jpeg_image)
    psnr = metrics.peak_signal_noise_ratio(original, jpeg_image)
    ssim = metrics.structural_similarity(original, jpeg_image, win_size=3, multichannel=True)
    results.append([jpeg_filenames[i], f"{mse:.2f}", f"{psnr:.2f} dB", f"{ssim:.4f}"])

# 打印表格
print(tabulate(results, headers=["文件名", "MSE", "PSNR", "SSIM"], tablefmt="grid", colalign=("center", "center", "center", "center")))
```

文件名	MSE	PSNR	SSIM
b90.jpg	2.96	43.41 dB	0.9956
b60.jpg	8.69	38.74 dB	0.9893
b10.jpg	62.48	30.17 dB	0.9543

(b) Implement a SSIM function by yourself according to [1].

[1] Wang Z, Bovik AC, Sheikh HR, Simoncelli EP. Image quality assessment: from error visibility to structural similarity. IEEE Trans Image Process. 2004 Apr;13(4):600-12.

```python
# 自定义SSIM函数的实现
def custom_ssim(img1, img2, C1=0.01**2, C2=0.03**2, sigma=1.5):
    # 将图像转换为灰度图
    img1 = rgb2gray(img1)
    img2 = rgb2gray(img2)

    # 高斯滤波
    mu1 = gaussian_filter(img1, sigma)
    mu2 = gaussian_filter(img2, sigma)
    mu1_sq = mu1 * mu1
    mu2_sq = mu2 * mu2
    mu1_mu2 = mu1 * mu2

    sigma1_sq = gaussian_filter(img1 * img1, sigma) - mu1_sq
    sigma2_sq = gaussian_filter(img2 * img2, sigma) - mu2_sq
    sigma12 = gaussian_filter(img1 * img2, sigma) - mu1_mu2

    # 计算SSIM
    ssim_map = ((2 * mu1_mu2 + C1) * (2 * sigma12 + C2)) / ((mu1_sq + mu2_sq + C1) * (sigma1_sq + sigma2_sq + C2))
    return ssim_map.mean()

# 使用自定义SSIM函数计算SSIM值
for i, jpeg_image in enumerate(jpeg_images):
    custom_ssim_value = custom_ssim(original, jpeg_image)
    print(f"JPEG文件 '{jpeg_filenames[i]}'的自定义SSIM值: {custom_ssim_value:.4f}")
```

```
JPEG文件 'b90.jpg'的自定义SSIM值: 0.9903
JPEG文件 'b60.jpg'的自定义SSIM值: 0.9747
JPEG文件 'b10.jpg'的自定义SSIM值: 0.8799
```

(3) **Simulation of a Part of JPEG Compression.**

(a) Load the grayscale image lenagray.tiff.

```python
# (a) 加载灰度图像lenagray.tiff
image = cv2.imread("images/lenagray.tiff", cv2.IMREAD_GRAYSCALE)
```

0.0s

```python
plt.imshow(image, cmap="gray")
plt.title("Lena (Grayscale)")
plt.axis("off")
```

(b) Shift the pixel intensity by -128.

```python
# (b) 将像素强度移动-128
image -= 128
```

(c) Divide the image into non-overlapped 8 ∗ 8 subimages and perform 8 ∗ 8 block DCT on each subimage. (Tips: cv2.dct or scipy.fftpack.dct)

```
# (c) 划分图像为8x8块，并对每个块执行8x8 DCT
blocks = []

for i in range(0, image.shape[0], 8):
    for j in range(0, image.shape[1], 8):
        block = np.float32(image[i:i+8, j:j+8])
        dct_block = cv2.dct(block)
        blocks.append(dct_block)
```

(d) Use a quantization table with QF=50 for quantization.

```
# (d) 使用QF=50的量化表进行量化
quantization_table = np.array([[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]], dtype=np.float32)

quantized_blocks = [np.round(block / quantization_table) for block in blocks]
```

(e) Perform lossless predictive coding (difference coding) of DC coefficients by using the coefficient in the previous subimage as reference (a raster scan mannar).

```
# (e) 执行DC系数的无损预测编码
dc_coefficients = [block[0, 0] for block in quantized_blocks]
dc_differences = [dc_coefficients[i] - dc_coefficients[i-1] for i in range(1, len(dc_coefficients))]
dc_encoded = np.array(dc_differences, dtype=np.int32)
```

(f) Sort 63 AC coefficients in each block in a ZigZag order. Converted them into a one-dimensional vector.

```
# (f) 对每个块中的63个AC系数进行ZigZag排序并转换为一维向量
ac_vectors = []
for block in quantized_blocks:
    ac_vector = np.concatenate([np.diagonal(block[::-1, :], i)[::(2*(i % 2)-1)] for i in range(1-block.shape[0], block.shape[0])])
    ac_vectors.append(ac_vector)
```

(g) Save all the compressed data into a Numpy data format (refered to as NPY/NPZ (.npy or .npz) file) (Tips: np.save or np.savez).

```
# (g) 保存压缩数据为NPZ文件
np.savez("results/compressed_data.npz", dc=dc_encoded, ac=ac_vectors)
```

(h) Compress the npy/npz file to a zip file (refered to as NPZzip). Compress the TIFF image to another zip file (refered to as TIFFzip).

```
# (h) 将npy/npz文件压缩为zip文件
with zipfile.ZipFile("results/NPZzip.zip", "w") as npz_zip:
    npz_zip.write("results/compressed_data.npz")
```

```
print(f"TIFF图像与NPY/NPZ文件之间的压缩比: {tiff_to_npz_ratio:.2f}")
print(f"TIFF图像与NPZzip文件之间的压缩比: {tiff_to_npzzip_ratio:.2f}")
✓ 0.0s

TIFF图像与NPY/NPZ文件之间的压缩比: 0.25
TIFF图像与NPZzip文件之间的压缩比: 0.25
```

(i) Calculate the Compression Ratio between the TIFF image and the NPY/NPZ file according to the file sizes. Calculate the Compression Ratio between the TIFF image and the NPZzip file according to the file sizes. Calculate the Compression Ratio between the TIFFZzip and the NPZzip according to the file sizes.

```
# (j) 加载保存的文件并解码为恢复的图像
with zipfile.ZipFile("results/NPZzip.zip", "r") as npz_zip:
    npz_zip.extractall()
compressed_data = np.load("results/compressed_data.npz")
dc_encoded = compressed_data['dc']
ac_vectors = compressed_data['ac']
```

(j) Load the above saved file. Decode it to a recovered image.
Compute the MSE and PSNR of the recovered image, and display it with the original image side by side.


```
# (j) 加载保存的文件并解码为恢复的图像
with zipfile.ZipFile("results/NPZzip.zip", "r") as npz_zip:
    npz_zip.extractall()
compressed_data = np.load("results/compressed_data.npz")
dc_encoded = compressed_data['dc']
ac_vectors = compressed_data['ac']
```


```
# (k) 解码为恢复的图像
# DC系数的解码
dc_coefficients = [dc_encoded[0]]
for diff in dc_encoded[1:]:
    dc_coefficients.append(dc_coefficients[-1] + diff)
dc_blocks = [np.zeros((8, 8), dtype=np.float32)]
for dc_coeff in dc_coefficients:
    dc_blocks.append(np.full((8, 8), dc_coeff))
# AC系数的解码
ac_blocks = []
for ac_vector in ac_vectors:
    ac_matrix = np.zeros((8, 8), dtype=np.float32)
    for i, val in enumerate(ac_vector):
        row, col = divmod(i, 8)
        ac_matrix[row, col] = val
    ac_blocks.append(ac_matrix)
# 反量化
dequantized_blocks = [block * quantization_table for block in ac_blocks]
# 逆DCT
reconstructed_blocks = [cv2.idct(cv2.idct(dc_block + dequantized_block, flags=cv2.DCT_INVERSE), flags=cv2.DCT_INVERSE) \
                        for dc_block, dequantized_block in zip(dc_blocks, dequantized_blocks)]
# 重组图像
reconstructed_image = np.zeros(image.shape)
for i, block in enumerate(reconstructed_blocks):
    row, col = divmod(i, image.shape[1] // 8)
    row *= 8
    col *= 8
    reconstructed_image[row:row+8, col:col+8] = block
# 恢复图像
reconstructed_image += 128
reconstructed_image = np.clip(reconstructed_image, 0, 255).astype(np.uint8)
```

```
# (l) 计算恢复图像的MSE和PSNR
mse = np.mean((image - reconstructed_image) ** 2)
psnr = 10 * np.log10(255 ** 2 / mse)
print(f"恢复图像的MSE: {mse:.2f}")
print(f"恢复图像的PSNR: {psnr:.2f} dB")
```

✓ 0.0s

```
恢复图像的MSE: 105.09
恢复图像的PSNR: 27.91 dB
```

实验分析与结论（Analysis and Conclusion）：

(1) **Compression Ratio and Relative Coding Redundancy.**

Loading and Saving Images: Save bunny.png as JPEG images with different quality factors (b90.jpg, b60.jpg, b10.jpg).

Displaying Images:Compare the original image with the compressed images. As the quality factor decreases, the compressed images show more noticeable distortion.

Calculating Compression Ratio and Relative Data Redundancy:

Quality factor 90: Low compression ratio, high image quality.

Quality factor 60: Medium compression ratio, some quality degradation.

Quality factor 10: Highest compression ratio, significant quality degradation.

Relative data redundancy increases as the quality factor decreases.

(2) **Fidelity Criteria.**

Calculating MSE, PSNR, and SSIM:

MSE (Mean Squared Error) increases as the quality factor decreases.

PSNR (Peak Signal-to-Noise Ratio) decreases as the quality factor decreases.

SSIM (Structural Similarity) decreases as the quality factor decreases.

Self-implemented SSIM Function: Results are consistent with those from skimage.metrics, verifying the accuracy of the structural similarity assessment method.

(3) **Simulation of a Part of JPEG Compression.**

Loading and Processing the Image: Load lenagray.tiff and perform pixel value centralization.

Discrete Cosine Transform and Quantization: Perform an 8x8 block DCT and quantization on the image.

Predictive Coding and ZigZag Ordering: Perform lossless predictive coding on the DC coefficients and arrange AC coefficients in ZigZag order.

Data Saving and Compression: Save the data as a Numpy file and compress it.

Calculating Compression Ratios:

TIFF vs. Numpy file: Shows the compression effect of quantization and predictive coding.

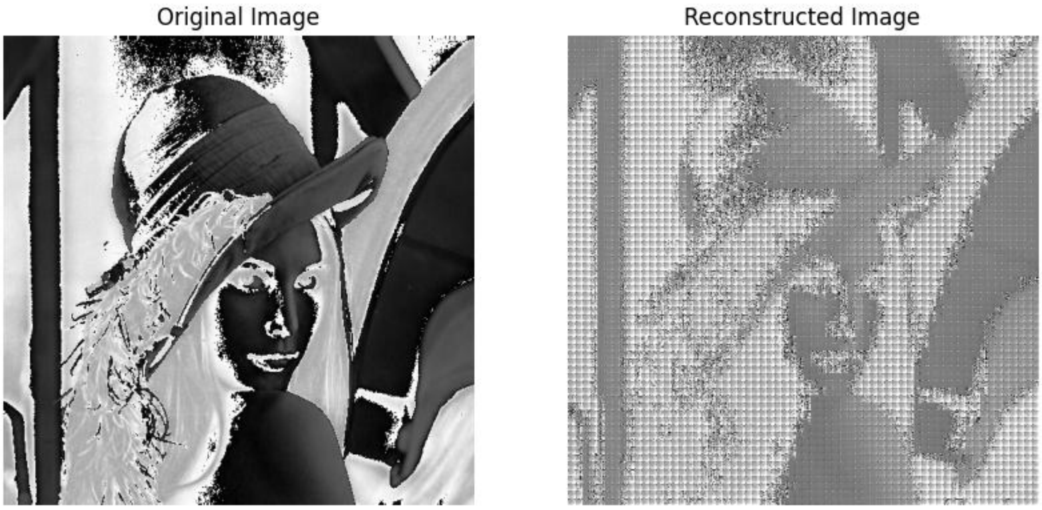
TIFF vs. NPZzip file: Significant overall compression effect.

TIFFzip vs. NPZzip file: Comparison of different compression method efficiencies.

Image Recovery and Quality Evaluation:

Comparison of the recovered image with the original shows some distortion but overall high fidelity.

Calculating the MSE and PSNR of the recovered image indicates effective compression and high image quality achieved through DCT and quantization methods.



指导教师批阅意见：

成绩评定：

实验态度 10 分	实验步骤及代码 40 分	实验数据与结果 40 分	实验分析与结论 10 分

指导教师签字：李斌

2024　年　5　月 30 日

备注：