Matlab 图像处理大作业 实验报告

一、实验目的

1. 掌握计算机处理和存储图像的基本知识；
2. 熟悉 JPEG 编码的基本原理，实现简单的 JPEG 编码；
3. 掌握 DCT 的基本概念；
4. 掌握信息隐藏的基本概念和技巧；
5. 熟练使用 MATLAB，掌握处理二维信息的基本技能；
6. 了解人脸识别的定义，掌握一种人脸识别方法。

二、实验平台

Matlab R2023a

三、实验内容

（一）基础知识

1. 阅读基本功能

输入help images后得到：

```
  Image file I/O.
    analyze75info       - Read metadata from header file of Mayo Analyze 7.5 data
set.
    analyze75read       - Read image file of Mayo Analyze 7.5 data set.
    dicomanon           - Anonymize DICOM file.
    dicomCollection     - Gather details about related series of DICOM files.
    dicomContours       - Extract ROIs information from DICOM-RT Structure Set.
    dicomdict           - Get or set active DICOM data dictionary.
    dicomdisp           - Display DICOM file structure.
    dicominfo           - Read metadata from DICOM message.
    dicomlookup         - Find attribute in DICOM data dictionary.
    dicomread           - Read DICOM image.
    dicomreadVolume     - Construct volume from directory of DICOM
images/slices.
    dicomuid            - Generate DICOM Unique Identifier.
    dicomwrite          - Write images as DICOM files.
    dicom-dict.txt      - Text file containing DICOM data dictionary (current).
    dicom-dict-2005.txt - Text file containing DICOM data dictionary (2005-
2007).
    dicom-dict-2007.txt - Text file containing DICOM data dictionary (2007-
2019).
    dpxinfo             - Read metadata about DPX image.
    dpxread             - Read DPX image.
    hdrread             - Read Radiance HDR image.
    hdrwrite            - Write Radiance HDR image.
    ImageAdapter        - Interface for image format I/O.
    imfinfo             - Information about image file (MATLAB Toolbox).
    imread              - Read image file (MATLAB Toolbox).
    imwrite             - Write image file (MATLAB Toolbox).
    interfileinfo       - Read metadata from Interfile files.
```

```
    interfileread       - Read images from Interfile files.
    isdicom             - Check if file is DICOM.
    isnitf              - Check if file is NITF.
    isrset              - Check if file is reduced-resolution dataset (R-Set).
    makehdr             - Create high dynamic range image.
    niftiinfo           - Read metadata from NIfTI file.
    niftiread           - Read NIfTI image.
    niftiwrite          - Write images as NIfTI files.
    nitfinfo            - Read metadata from NITF file.
    nitfread            - Read NITF image.
    rsetwrite           - Create reduced-resolution dataset (R-Set) from image
file.
    tiffreadVolume      - Read volume from TIFF file.
    images.dicom.decodeUID      - Get information about Unique Identifier (UID).
    images.dicom.parseDICOMDIR  - Extract metadata from DICOMDIR file.
    rawread     - Reads Color Filter Array (CFA) image from RAW files
    raw2rgb     - Transform Color Filter Array (CFA) image in RAW files into an
RGB image
    rawinfo     - Read information about Color Filter Array (CFA) image in RAW
files
    raw2planar  - Separate Bayer patterned CFA image into individual images
    planar2raw  - Combine planar sensor images into a full Bayer pattern CFA
    isexr           - Check if file is valid EXR file
    exrread         - Read image data from EXR file
    exrinfo         - Read metadata from EXR file
    exrwrite        - Write image data to EXR file
    exrHalfAsSingle - Convert numeric values into half-precision values
```

我们将使用这些函数进行实验。

2. 圆与棋盘

利用 `imread` 完成图片读取，利用 `imshow``imwrite` 完成图片写入。

画圆代码：

```
[height, width, ~] = size(hall_color);

% circle
radius_sqrd = (min(height, width)/2)^2;
distance_sqrd = repmat(((1:height)' - height / 2).^2, 1, width) +
repmat(((1:width) - width / 2).^2, height, 1);
circle = distance_sqrd <= radius_sqrd & distance_sqrd > 0.96 * radius_sqrd;
% red
hall_red = hall_color(:, :, 1);
hall_red(circle) = uint8(255);

% blue, green
hall_green = hall_color(:, :, 2);
hall_green(circle) = uint8(0);
hall_blue = hall_color(:, :, 3);
hall_blue(circle) = uint8(0);

% draw circle
hall_circle = uint8(ones(height, width, 3));
hall_circle(:, :, 1) = hall_red;
hall_circle(:, :, 2) = hall_green;
```

```
hall_circle(:, :, 3) = hall_blue;
subplot(1, 3, 2);
imshow(hall_circle);
imwrite(hall_circle, 'hw1_3_2_hall_circle.bmp');
```

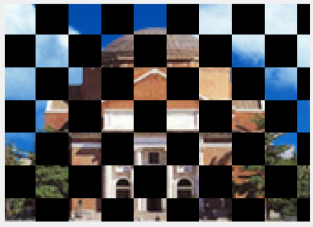
上述代码将半径0.96~1倍的部分涂成红色。

画棋盘代码：

```
% chessboard
length = 36;
height_index = repmat([1:height]', 1, width);
width_index = repmat([1:width], height, 1);
chessboard = xor((mod(height_index, length) < length/2), (mod(width_index,
length) < length/2));

% red
hall_red = hall_color(:, :, 1);
hall_red(chessboard) = uint8(0);

% green
hall_green = hall_color(:, :, 2);
hall_green(chessboard) = uint8(0);

% blue
hall_blue = hall_color(:, :, 3);
hall_blue(chessboard) = uint8(0);

% draw chessboard
hall_chessboard = uint8(ones(height, width, 3));
hall_chessboard(:, :, 1) = hall_red;
hall_chessboard(:, :, 2) = hall_green;
hall_chessboard(:, :, 3) = hall_blue;
subplot(1, 3, 3);
imshow(hall_chessboard);
imwrite(hall_chessboard, 'hw1_3_2_hall_chessboard.bmp');
```

效果如图：





本问题代码位于`hw_1_3_2.m`中，图片文件分别为`hw_1_3_2_hall_circle.bmp`和`hw_1_3_2_hall_chessboard.bmp`。

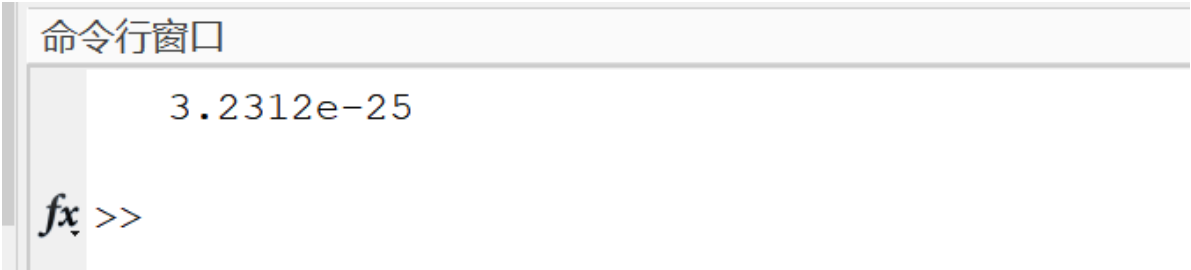
（二）图像压缩编码

1. 图像预处理

由于DCT是线性变换，所以在空域减去128，等于对DCT域减去128的DCT变换，只需要对DCT矩阵的左上角减去一个直流分量即可。

```
first_block = double(hall_gray(1:8, 1:8));
old_C = dct2(first_block - 128);
new_C = dct2(first_block);
new_C(1, 1) = new_C(1, 1) - 128 * 8;
disp(max((old_C - new_C).^2, [], 'all'));
```

将两种方式进行比较，误差采用各个元素的完全平方差的最大值来衡量，得到结果：



可见两种方式的实现效果基本相同。

本问题代码位于 `hw_2_4_1.m` 中。

2. 实现2维dct

首先实现1维dct矩阵：

```
function dctD = my_dct_operator(N)
    col_coe = [1:N-1];
    row_coe = [1:2:2*N - 1];
    dctD = cos(col_coe' * row_coe * pi / (2 * N));
    dctD = sqrt(2/N) * [ones(1, N)/sqrt(2);dctD];
end
```

然后利用公式$C = DPD^T$来计算变换结果：

```
function dct2C = my_dct2(dct2P)
    [rows, cols] = size(dct2P);
    % 初始化结果矩阵
    dct2C = my_dct_operator(rows) * double(dct2P) * my_dct_operator(cols)';
end
```

对比库中的dct2：

```
example = double(hall_gray(1:8, 1:8)) - 128;
dct2C = dct2(example);
my_dct2C = my_dct2(example);
disp(max((dct2C - my_dct2C).^2, [], 'all'));
```

误差采用各个元素的完全平方差的最大值来衡量，得到结果：

```
命令行窗口
    8.1792e-26

fx >>
```

可见与官方库的实现效果基本相同。

本问题代码位于 `hw_2_4_2.m` 中。

3. 四列置零

代码实现如下：

```
subplot(1, 3, 1);
imshow(hall_gray);
imwrite(hall_gray, "hw_4_3_normal.bmp");

dct2P = double(hall_gray);

dct2C = blockproc(dct2P, [8, 8], @(blk) dct2C_cut_right(blk.data - 128));
idct2P_cut_right = uint8(blockproc(dct2C, [8, 8], @(blk) idct2(blk.data) +
128));

subplot(1, 3, 2);
imshow(idct2P_cut_right);
imwrite(idct2P_cut_right, "hw_4_3_right_cut_off.bmp");

dct2C = blockproc(dct2P, [8, 8], @(blk) dct2C_cut_left(blk.data - 128));
idct2P_cut_left = uint8(blockproc(dct2C, [8, 8], @(blk) idct2(blk.data) + 128));

subplot(1, 3, 3);
imshow(idct2P_cut_left);
imwrite(idct2P_cut_left, "hw_4_3_left_cut_off.bmp");


function dct2C = dct2C_cut_right(dct2P)
    dct2C = dct2(dct2P);
    dct2C(:, 5:8) = 0;
end

function dct2C = dct2C_cut_left(dct2P)
    dct2C = dct2(dct2P);
    dct2C(:, 1:4) = 0;
end
```

展现效果如下：

左一为原图，中间为去掉右边4列，右边为去掉左边4列。

右上对应的是横向的高频分量，右下对应的是横向和纵向的高频分量，去掉之后，可以看到图片在横向的色彩变化明显模糊，但是仍然能辨认图像，因为直流和低频分量不受影响。

左上对应的是横向和纵向的低频分量，左下对应的是纵向的高频分量，去掉之后，纵向的低频和高频分量都被去掉，因此纵向纹理消失；横向的低频分量被去掉，但高频分量还在，因此横向纹理中色彩变化激烈的部分被保留下来。

本问题代码位于 `hw_2_4_3.m` 中，图片位于。

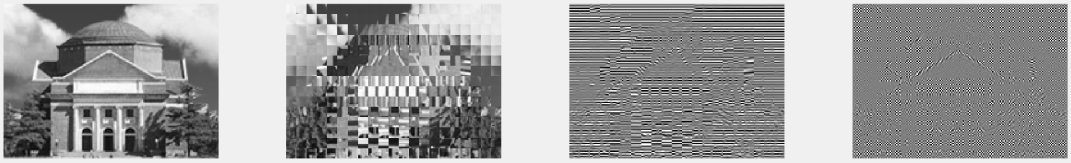
本问题代码位于 `hw_2_4_3.m` 中。`hw_2_4_3_*.bmp` 中保存了图像文件。

4. 转置与旋转

将DCT系数矩阵转置和旋转的代码如下：

```
clear all;
close all;
clc;

dir = "./图像处理所需资源/";
load(strcat(dir, "hall.mat"));

subplot(1, 4, 1);
imshow(hall_gray);
imwrite(hall_gray, "hw_2_4_4_normal.bmp");

dct2P = double(hall_gray);

idct2C_hall_transpos = my_dct_domain_process(dct2P, @my_dct2_transposition);

subplot(1, 4, 2);
imshow(idct2C_hall_transpos);
imwrite(idct2C_hall_transpos, "hw_2_4_4_hall_transpos.bmp");

idct2C_hall_rotate90 = my_dct_domain_process(dct2P, @my_dct2_rotate90);

subplot(1, 4, 3);
imshow(idct2C_hall_rotate90);
imwrite(idct2C_hall_rotate90, "hw_2_4_4_hall_rotate90.bmp");

idct2C_hall_rotate180 = my_dct_domain_process(dct2P, @my_dct2_rotate180);

subplot(1, 4, 4);
imshow(idct2C_hall_rotate180);
imwrite(idct2C_hall_rotate180, "hw_2_4_4_hall_rotate180.bmp");

function idct2C = my_dct_domain_process(dct2P, dct2_process)
```

```
    dct2C = blockproc(dct2P, [8, 8], @(blk) dct2_process(blk.data - 128));
    idct2C = uint8(blockproc(dct2C, [8, 8], @(blk) idct2(blk.data) + 128));
end


function dct2C = my_dct2_transposition(dct2P)
    dct2C = dct2(dct2P');
end


function dct2C = my_dct2_rotate90(dct2P)
    dct2C = rot90(dct2(dct2P));
end


function dct2C = my_dct2_rotate180(dct2P)
    dct2C = rot90(dct2(dct2P), 2);
end
```



从左到右分别是原图、转置、旋转90度、旋转180度的结果（以下分别称为图1，图2，图3，图4）。

由$C = DPD^T$可得$C^T = DP^TD^T$，从而转置dct系数矩阵与转置空域矩阵的效果是相同的。因此可知图2实际上就是将原图转置的结果（按照8*8的像素块）。

旋转90度会将低频分量系数转移到纵向高频分量系数的位置上，一般图片的低频分量系数较大，因此图片在纵向变化上会很激烈。

旋转180会将低频分量系数转移到高频分量系数的位置上，图片在横向和纵向上的变化的都很激烈。

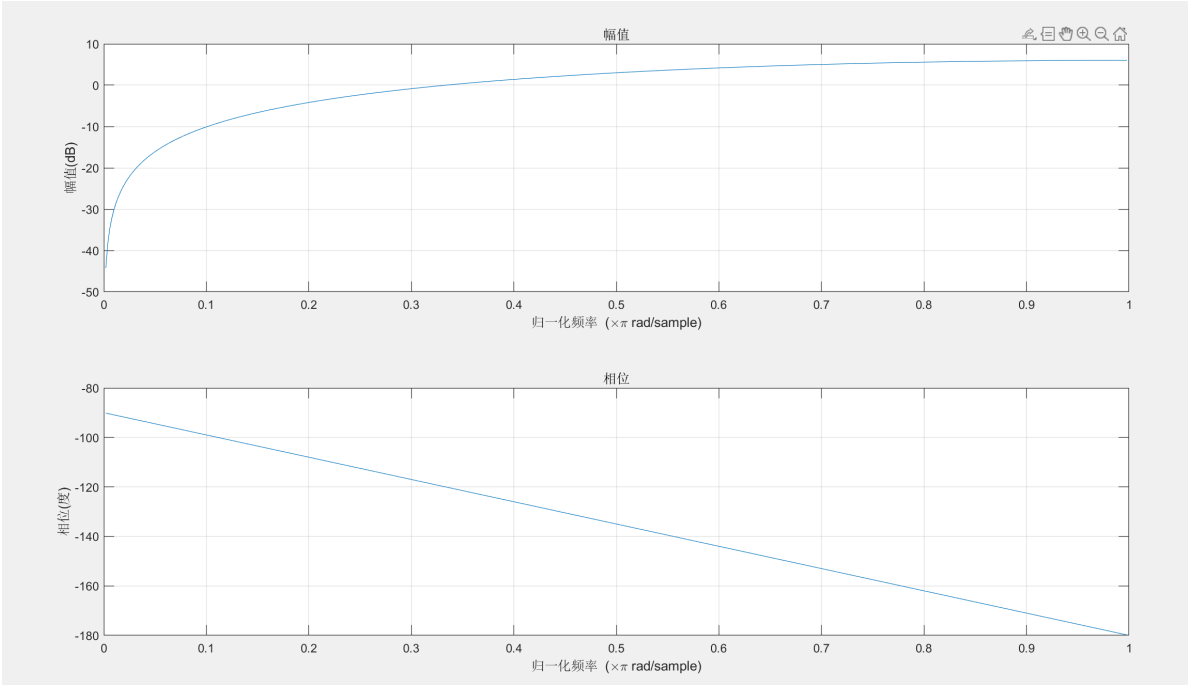
本问题代码位于`hw_2_4_4.m`中。`hw_2_4_4_*.bmp`中保存了图像文件。

5. 差分编码

差分编码的频率响应：

```
% y(n) = -x(n) + x(n - 1)
a = [1];
b = [-1, 1];
figure;
zplane(b, a);
figure;
freqz(b, a);
```

结果：



它是一个高通滤波器，低频的分量会被除去，因此，图像DC系数的高频分量更多。

本问题代码位于 `hw_2_4_5.m` 中。

6. DC 预测误差与 Category

Category实际上就是DC预测误差的二进制表示的位数。因此，我们也可以通过对DC预测误差的绝对值加1，取对数再向上取整得到 Category 的值。

7. Zigzag 扫描方法

`zigzagScan.m`：

```
function zigzag = zigzagScan(matrix)
    [rows, cols] = size(matrix);
    zigzag = zeros(1, rows * cols);

    row = 1;
    col = 1;
    index = 1;
    direction = 'up';  % 初始方向向上

    while index <= rows * cols
        zigzag(index) = matrix(row, col);

        if strcmp(direction, 'up')
            if col == cols
                row = row + 1;
                direction = 'down';
            elseif row == 1
                col = col + 1;
                direction = 'down';
            else
                row = row - 1;
                col = col + 1;
            end
        else  % direction == 'down'
```

```
            if row == rows
                col = col + 1;
                direction = 'up';
            elseif col == 1
                row = row + 1;
                direction = 'up';
            else
                row = row + 1;
                col = col - 1;
            end
        end

        index = index + 1;
    end
end
```

我们采用一个字符串保存当前游走的方向（右和上视为 up，左和下视为 down），当遇到边界时就改变扫描方向。

测试矩阵为一个按照zigzag顺序排列的矩阵，扫描后变成一个顺序排列的行向量。

```
test_matrix = [ ...
 1, 2, 6, 7, 15, 16, 28, 29; ...
 3, 5, 8, 14, 17, 27, 30, 43; ...
 4, 9, 13, 18, 26, 31, 42, 44; ...
 10, 12, 19, 25, 32, 41, 45, 54; ...
 11, 20, 24, 33, 40, 46, 53, 55; ...
 21, 23, 34, 39, 47, 52, 56, 61; ...
 22, 35, 38, 48, 51, 57, 60, 62; ...
 36, 37, 49, 50, 58, 59, 63, 64];

zigzag = zigzagScan(test_matrix);

% 输出是等差数列，证明算法通过测试
disp(zigzag);
```

```
列 1 至 21

   1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    19    20    21

列 22 至 42

  22    23    24    25    26    27    28    29    30    31    32    33    34    35    36    37    38    39    40    41    42

列 43 至 63

  43    44    45    46    47    48    49    50    51    52    53    54    55    56    57    58    59    60    61    62    63

列 64

  64

>
```

本问题代码位于 `hw_2_4_7.m` 中。

8. 量化

`quantify_block.m` 对每个DCT系数矩阵进行量化：

```
function Q = quantify_block(block, quantify)
    Q = round(block ./ quantify);
end
```

`get_dct2C_tilde.m` 对图像分块处理，调用量化函数：

```
function dct2C_tilde = get_dct2C_tilde(hall_gray, QTAB)
    dct2P = double(hall_gray) - 128;
    dct2C = blockproc(dct2P, [8, 8], @(blk) dct2(blk.data));
    dct2C_tilde = blockproc(dct2C, [8, 8], @(blk) quantify_block(blk.data,
QTAB));
    dct2C_tilde = blockproc(dct2C_tilde, [8, 8], @(blk) zigzagScan(blk.data)');
end
```

`get_dct2C_tilde_final.m` 将矩阵转换为题目指定的格式：

```
function dct2C_tilde_final = get_dct2C_tilde_final(dct2C_tilde)
    [rows, cols] = size(dct2C_tilde);
    dct2C_tilde_final = [];
    for i = 1:(rows/64)
        for j = 1:cols
            if i == 1 && j == 1
                dct2C_tilde_final = dct2C_tilde(1:64, 1);
            else
                dct2C_tilde_final = [dct2C_tilde_final, dct2C_tilde((i - 1) * 64
+ 1:i * 64, j)];
            end
        end
    end
end
```

本问题代码位于 `hw_2_4_8.m` 中。

9. 实现 JPEG 码流

`hw_2_4_8.m` 实现 JPEG 编码并保存到 `jpegcode.mat`：

```
dir = "./图像处理所需资源/";
load(strcat(dir, "hall.mat"));
load(strcat(dir, "JpegCoeff.mat"));

[jpeg_row, jpeg_col, dc_code, ac_code] = my_encode(hall_gray, QTAB, DCTAB,
ACTAB);

save('jpegcode.mat', "jpeg_col", "jpeg_row", "ac_code", "dc_code")
```

`my_encode.m` 实现 JPEG 编码部分：

```
function [jpeg_row, jpeg_col, dc_code, ac_code] = my_encode(pic, QTAB, DCTAB,
ACTAB)
    dct2C_tilde = get_dct2C_tilde(pic, QTAB);
    dct2C_tilde_final = get_dct2C_tilde_final(dct2C_tilde);
    dc_code = get_dc_code(dct2C_tilde_final, DCTAB);

    ac_code = [];
    for i = 1:length(dct2C_tilde_final)
        single_block = dct2C_tilde_final(:, i);
        ac_code_single = get_ac_code_single(single_block, ACTAB);
```

```
        ac_code = [ac_code, ac_code_single];
    end

    [jpeg_row, jpeg_col] = size(pic);
end
```

其中，`get_dc_code.m`实现 DC 部分的熵编码：

```
function dc_code = get_dc_code(dct2C_tilde, DCTAB)
    dc = dct2C_tilde(1, :)';
    dc_diff = [dc(1);-diff(dc)];
    dc_diff_bin = arrayfun(@(i) my_d2b(dc_diff(i)), [1:length(dc_diff)],
'UniformOutput', false);
    dc_category = arrayfun(@(i) length(dc_diff_bin{i}), [1:length(dc_diff_bin)],
'UniformOutput',false);
    dc_category = cell2mat(dc_category) + 1;
    dc_code = ...
        arrayfun( ...
            @(i) [ ...
                DCTAB(dc_category(i), 2:(DCTAB(dc_category(i), 1) + 1)), ...
                dc_diff_bin{i}...
            ], ...
            [1:length(dc_diff)], ...
            'UniformOutput', ...
            false ...
        );
    dc_code = cell2mat(dc_code);
end
```

`get_ac_code_single.m`实现单个图像块 AC 部分的熵编码：

```
function ac_code_single = get_ac_code_single(single_block, ACTAB)
    ZRL = get_ZRL();
    EOB = get_EOB();
    zero_num = 0;
    zrl_num = 0;
    ac_code_single = [];
    for scan_idx = 2:length(single_block)
        if single_block(scan_idx) == 0
            if zero_num == 15
                zrl_num = zrl_num + 1;
                zero_num = 0;
            else
                zero_num = zero_num + 1;
            end
        else
            if zrl_num > 0
                ac_code_single = [ac_code_single, repmat(ZRL, 1, zrl_num)];
                zrl_num = 0;
            end
            data = single_block(scan_idx);
            amp = my_d2b(data);
            size = length(amp);
            run = zero_num;
            actab_row = ACTAB(run * 10 + size, :);
            actab_looked_up = actab_row(4:actab_row(3)+3);
```

```
            ac_code_single = [ac_code_single, actab_looked_up, amp];
            % fprintf("data = %d, amp = %s, size = %s, run = %s, actab_looked =
%s\n", data, mat2str(amp), mat2str(size), mat2str(run),
mat2str(actab_looked_up));
            zero_num = 0;
        end
    end
    ac_code_single = [ac_code_single, EOB];
end
```

本问题代码位于 `hw_2_4_9.m` 中。

10. 计算压缩比

原图像的大小为 `row * col` Byte（每个像素点用一个 Byte 表示），压缩后图像的大小为 `(ac_size + dc_size) / 8` Byte。

```
load("jpegcode.mat");

ac_size = length(ac_code);
dc_size = length(dc_code);
fprintf("row = %d, col = %d, ac_size = %d, dc_size = %d\n", jpeg_row, jpeg_col,
ac_size, dc_size);

before_size = jpeg_row * jpeg_col;
after_size = (ac_size + dc_size) / 8;

fprintf("压缩前：%d Bytes\n", before_size);
fprintf("压缩后：%f Bytes\n", after_size);
fprintf("压缩比：%f\n", before_size / after_size);
```

计算结果：

命令行窗口

```
row = 120, col = 168, ac_size = 23072, dc_size = 2031
压缩前：20160 Bytes
压缩后：3137.875000 Bytes
压缩比：6.424730
fx >>
```

压缩比为6.424730

本问题代码位于 `hw_2_4_10.m` 中。

11. JPEG 解码

`hw_2_4_11.m` 实现从 `jpegcode.mat` 中读取数据并 JPEG 解码：

```
load("jpegcode.mat");

dir = "./图像处理所需资源/";
load(strcat(dir, "hall.mat"));
load(strcat(dir, "JpegCoeff.mat"));
```

```
hall_gray_recovered = my_decode(jpeg_row, jpeg_col, dc_code, ac_code, QTAB,
DCTAB, ACTAB);

subplot(2, 1, 1);
imshow(hall_gray);
title('original')
subplot(2, 1, 2);
imshow(hall_gray_recovered);
imwrite(hall_gray_recovered, "hw_2_4_11_hall_gray_recovered.bmp");
title('decoded');

MSE = sum((double(hall_gray_recovered) - double(hall_gray)).^2, 'all') /
(jpeg_row * jpeg_col);
PSNR = 10* log10(255^2 / MSE);
fprintf("PSNR: %f\n", PSNR);
```

`my_decode.m` 包含 JPEG 解码的具体实现：

```
function decoded = my_decode(jpeg_row, jpeg_col, dc_code, ac_code, QTAB, DCTAB,
ACTAB)
    % decode dc
    dc_decode = get_dc_decode(dc_code, DCTAB);
    % decode ac
    ac_decode = get_ac_decode(ac_code, ACTAB);
    % recover image
    dct2C_tilde_recovered = get_dct2C_tilde_recovered([dc_decode; ac_decode],
jpeg_row * 8, jpeg_col / 8);
    decoded = get_hall_gray_recovered(dct2C_tilde_recovered, QTAB);
end
```

`get_dc_decode.m` 对 DC 码流进行解码：

```
function dc_decode = get_dc_decode(dc_code, DCTAB)
    % decode dc
    dc_code = reshape(dc_code, 1, length(dc_code));
    dc_decode_diff = [];
    start_idx = 1;
    idx = 1;
    while idx <= length(dc_code)
        huffman_code = dc_code(start_idx:idx);
        [row, col] = size(DCTAB);
        cat = -1;
        for j = 1:row
            if all(DCTAB(j, 1) == length(huffman_code))
                if all(DCTAB(j, 2:1+length(huffman_code)) == huffman_code)
                    cat = j - 1;
                    break
                end
            end
        end
        if cat ~= -1
            data = dc_code(idx+1:idx+cat);
            data_dec = my_b2d(data);
            dc_decode_diff = [dc_decode_diff, data_dec];
            start_idx = idx + cat + 1;
            idx = idx + cat + 1;
```

```
        else
            idx = idx + 1;
        end
    end
    dc_decode = cumsum([dc_decode_diff(1), -dc_decode_diff(2:end)]);

end
```

`get_ac_decode.m` 对 AC 码流进行解码：

```
function ac_decode = get_ac_decode(ac_code, ACTAB)
    ac_decode = [];
    ZRL = get_ZRL();
    EOB = get_EOB();
    ac_code = reshape(ac_code, 1, length(ac_code));
    start_idx = 1;
    idx = 1;
    ac_decode_single = [];
    while idx <= length(ac_code)
        huffman_code = ac_code(start_idx:idx);
        [row, ~] = size(ACTAB);
        if length(huffman_code) == length(ZRL) && all(ZRL == huffman_code)
            ac_decode_single = [ac_decode_single, zeros(1, 16)];
            % fprintf("insert 16 zeros\n");
            start_idx = idx + 1;
            idx = idx + 1;
        elseif length(huffman_code) == length(EOB) && all(EOB == huffman_code)
            % fprintf("insert %d zeros\n", 63 - length(ac_decode_single));
            ac_decode_single = [ac_decode_single, zeros(1, 63 -
length(ac_decode_single))];
            ac_decode = [ac_decode, ac_decode_single'];
            ac_decode_single = [];
            start_idx = idx + 1;
            idx = idx + 1;
        else
            ac_run = -1;
            ac_size = -1;
            look_up_row = -1;
            for j = 1:row
                actab_len = ACTAB(j, 3);
                if length(huffman_code) == actab_len
                    if all(ACTAB(j, 4:3+actab_len) == huffman_code)
                        ac_run = ACTAB(j, 1);
                        ac_size = ACTAB(j, 2);
                        look_up_row = j;
                        break;
                    end
                end
            end
            if and(ac_run ~= -1, ac_size ~= -1)
                amp = ac_code(idx+1:idx+ac_size);
                data = my_b2d(amp);
                ac_decode_single = [ac_decode_single, zeros(1, ac_run), data];
                % fprintf("data = %d, amp = %s, size = %s, run = %s, actab_looked
= %s, now_size = %d\n", ...
                %     data, ...
                %     mat2str(amp), ...
```

```
                %     mat2str(ac_size), ...
                %     mat2str(ac_run), ...
                %     mat2str(ACTAB(look_up_row, 4:length(amp)+3)), ...
                %     size(ac_decode_single) ...
                % );
                start_idx = idx + ac_size + 1;
                idx = idx + ac_size + 1;
            else
                idx = idx + 1;
            end
        end
    end
end
```

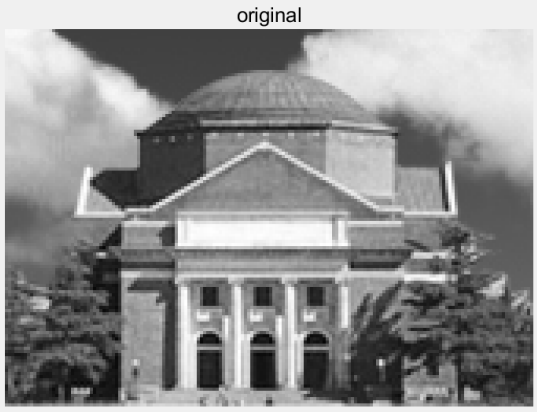
`get_dct2C_tilde_recovered.m` 将DCT系数矩阵恢复到分块矩阵的形式：

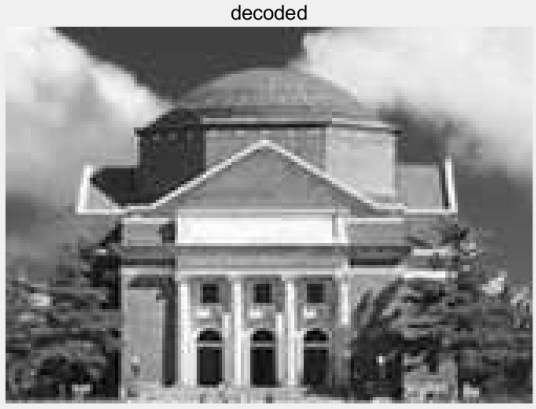
```
function dct2C_tilde = get_dct2C_tilde_recovered(dct2C_tilde_final, row, col)
    dct2C_tilde = zeros(row, col);
    idx = 1;
    for i = 1:(row/64)
        for j = 1:col
            if i == 1 && j == 1
                dct2C_tilde(1:64, 1) = dct2C_tilde_final(:, 1);
            else
                dct2C_tilde((i - 1) * 64 + 1:i * 64, j) = dct2C_tilde_final(:,
idx);
            end
            idx = idx + 1;
        end
    end
end
```

`get_hall_gray_recovered.m` 将每个图像块对应的DCT系数矩阵通过逆变换转换回图像：

```
function hall_gray_recovered = get_hall_gray_recovered(dct2C_tilde, QTAB)
    dct2C_tilde = blockproc(dct2C_tilde, [64, 1], @(blk) zigzagScanInv(blk.data,
8, 8));
    dct2C = blockproc(dct2C_tilde, [8, 8], @(blk) quantify_block_inv(blk.data,
QTAB));
    dct2P =  blockproc(dct2C, [8, 8], @(blk) idct2(blk.data));
    hall_gray_recovered = uint8(dct2P + 128);
end
```

运行结果：





通过客观方法（PSNR）进行评价。

`my_psnr.m`计算得到 PSNR：

```
function PSNR = my_psnr(pic_recovered, pic)
    [jpeg_row, jpeg_col] = size(pic);
    MSE = sum((double(pic_recovered) - double(pic)).^2, 'all') / (jpeg_row *
jpeg_col);
    PSNR = 10* log10(255^2 / MSE);
end
```

计算结果：

```
PSNR: 31.187403
>>
```

此 PSNR 的值为 31.187403 dB。

通过主观方法进行评价：

与原图相比，解码的图“模糊”一些，这是舍弃高频分量的结果。且在一些地方有明显的不连续感，似乎被一些“方块”分隔开来，这是分块处理导致的。

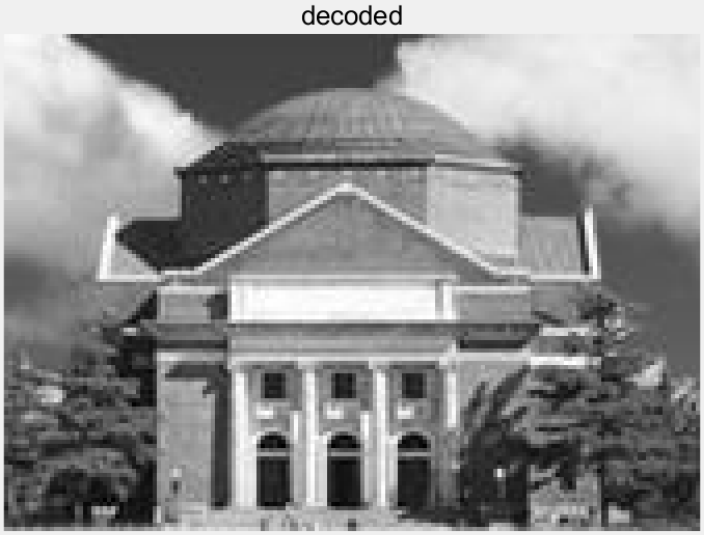
本问题代码位于`hw_2_4_11.m`中。图片位于`hw_2_4_11_*.bmp`中。

12. 量化步长减半

`hw_2_4_12.m`将 `QTAB`减半后重新进行编解码，并计算压缩比和 PSNR：

```
dir = "./图像处理所需资源/";
load(strcat(dir, "hall.mat"));
load(strcat(dir, "JpegCoeff.mat"));

QTAB = QTAB / 2;
% encode & decode
[jpeg_row, jpeg_col, dc_code, ac_code] = my_encode(hall_gray, QTAB, DCTAB,
ACTAB);
hall_gray_recovered = my_decode(jpeg_row, jpeg_col, dc_code, ac_code, QTAB,
DCTAB, ACTAB);
% plot
subplot(2, 1, 1);
imshow(hall_gray);
title('original')
subplot(2, 1, 2);
imshow(hall_gray_recovered);
imwrite(hall_gray_recovered, "hw_4_12_hall_gray_recovered.bmp");
title('decoded');
% 压缩比
ac_size = length(ac_code);
dc_size = length(dc_code);
fprintf("row = %d, col = %d, ac_size = %d, dc_size = %d\n", jpeg_row, jpeg_col,
ac_size, dc_size);

before_size = jpeg_row * jpeg_col;
after_size = (ac_size + dc_size) / 8;

fprintf("压缩前：%d Bytes\n", before_size);
fprintf("压缩后：%f Bytes\n", after_size);
fprintf("压缩比：%f\n", before_size / after_size);
% PSNR
MSE = sum((double(hall_gray_recovered) - double(hall_gray)).^2, 'all') /
(jpeg_row * jpeg_col);
PSNR = 10* log10(255^2 / MSE);
fprintf("PSNR: %f\n", PSNR);
```

结果：



命令行窗口

```
row = 120, col = 168, ac_size = 34164, dc_size = 2410
压缩前：20160 Bytes
压缩后：4571.750000 Bytes
压缩比：4.409690
PSNR: 34.206704
fx >>
```

图像的压缩比为4.409690，有所下降；PSNR 为34.206704，相比未减半有所上升。

量化步长减半，导致被舍弃的高频分量变少，图像信息更完整，因此 PSNR 上升；量化步长减半带来了量化系数的增加，因而对应的熵编码长度增加，压缩比下降。

本问题代码位于 `hw_2_4_12.m` 中。图片位于 `hw_2_4_12_*.bmp` 中。

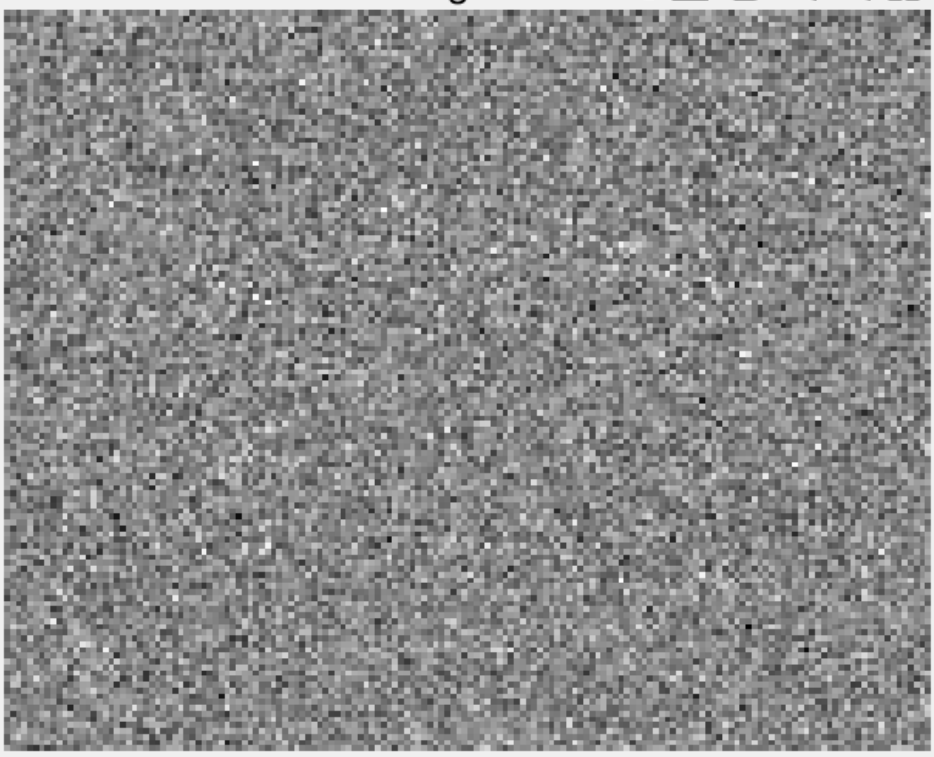
13. 雪花图像处理

对雪花图像编解码：

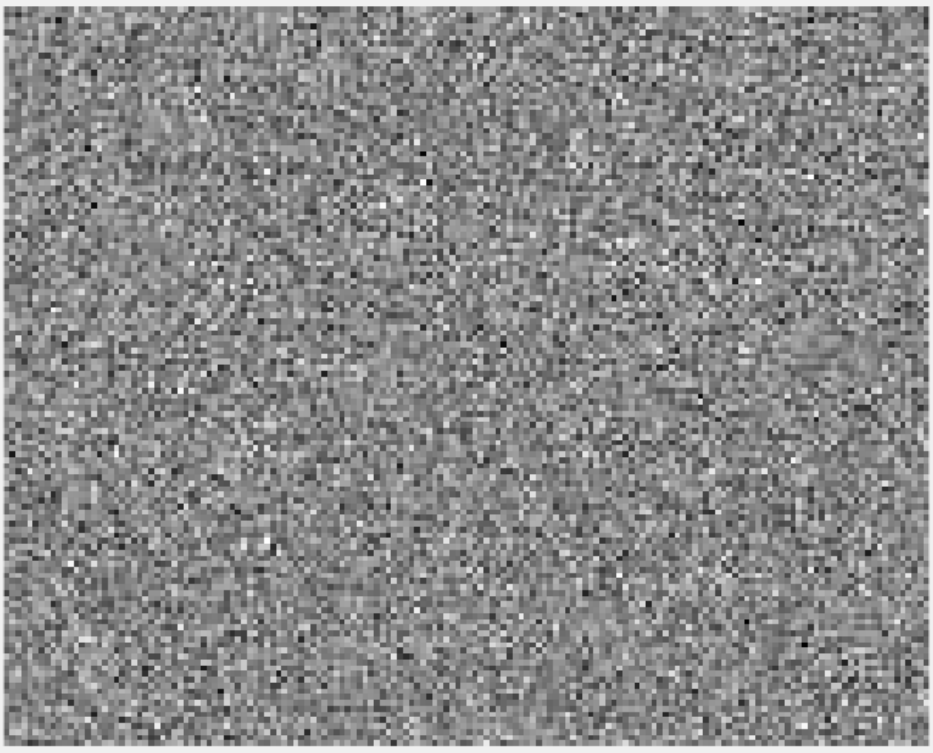
```
dir = "./图像处理所需资源/";
load(strcat(dir, "snow.mat"));
load(strcat(dir, "JpegCoeff.mat"));

% encode & decode
[jpeg_row, jpeg_col, dc_code, ac_code] = my_encode(snow, QTAB, DCTAB, ACTAB);
snow_recovered = my_decode(jpeg_row, jpeg_col, dc_code, ac_code, QTAB, DCTAB,
ACTAB);
% plot
subplot(2, 1, 1);
imshow(snow);
imwrite(snow, "hw_2_4_13_snow.bmp");
title('original')
subplot(2, 1, 2);
imshow(snow_recovered);
imwrite(snow_recovered, "hw_2_4_13_snow_recovered.bmp");
title('decoded');
% 压缩比
ac_size = length(ac_code);
dc_size = length(dc_code);
fprintf("row = %d, col = %d, ac_size = %d, dc_size = %d\n", jpeg_row, jpeg_col,
ac_size, dc_size);

before_size = jpeg_row * jpeg_col;
after_size = (ac_size + dc_size) / 8;

fprintf("压缩前：%d Bytes\n", before_size);
fprintf("压缩后：%f Bytes\n", after_size);
fprintf("压缩比：%f\n", before_size / after_size);
% PSNR
MSE = sum((double(snow_recovered) - double(snow)).^2, 'all') / (jpeg_row *
jpeg_col);
PSNR = 10* log10(255^2 / MSE);
fprintf("PSNR: %f\n", PSNR);
```

结果如图：

original



decoded



命令行窗口

```
row = 128, col = 160, ac_size = 43546, dc_size = 1403
压缩前：20480 Bytes
压缩后：5618.625000 Bytes
压缩比：3.645020
PSNR: 22.924444
fx >>
```

雪花的压缩比只有3.645，PSNR仅有22.9244。主观判断，对比上下两幅图，可以看出图像的失真较为明显，相似度降低。

雪花图像的变化频率很高，高频分量多，因此量化时失去的高频分量更多，恢复图像后失真明显；同时高频分量多也导致量化值的增加，熵编码的长度增加，压缩比下降。

本问题代码位于 `hw_2_4_13.m` 中。图片位于 `hw_2_4_13_*.bmp` 中。

（三）信息隐藏

1. 空域信息隐藏

我们将信息编码为二进制（value_hide），隐藏在每一个像素点的最低位：

```
dir = "./图像处理所需资源/";
load(strcat(dir, "hall.mat"));
load(strcat(dir, "JpegCoeff.mat"));

value_hide = [1, 0, 1, 0, 1, 1, 0, 1, 1];
disp(['原数据：', mat2str(value_hide(1:length(value_hide)))]);

pic = hall_gray;
pic_hide = space_hide(value_hide, pic);
value_show = space_show(pic_hide);
disp(['解码结果：', mat2str(value_show(1:length(value_hide)))]);

[jpeg_row, jpeg_col, dc_code, ac_code] = my_encode(pic_hide, QTAB, DCTAB,
ACTAB);
jpeg_decode = my_decode(jpeg_row, jpeg_col, dc_code, ac_code, QTAB, DCTAB,
ACTAB);
value_show_jpeg = space_show(jpeg_decode);
disp(['压缩后解码：', mat2str(value_show_jpeg(1:length(value_hide)))]);

correct = 0;
for k=1:length(value_hide)
    if value_hide(k) == value_show_jpeg(k)
        correct = correct + 1;
    end
end

disp(['正确率：', mat2str(correct / length(value_hide))]);

subplot(3, 1, 1);
imshow(pic);
title("original picture");
imwrite(pic, "hw_3_4_1_pic.bmp");
subplot(3, 1, 2);
```

```
imshow(pic_hide);
title("hide picture");
imwrite(pic_hide, "hw_3_4_1_pic_hide.bmp");
subplot(3, 1, 3);
imshow(jpeg_decode);
title("jpeg compressed picture");
imwrite(jpeg_decode, "hw_3_4_1_pic_compress.bmp");

function pic_hide = space_hide(value_hide, pic)
    [rows, cols] = size(pic);
    pic_hide = 0 * pic;
    value_hide = reshape(value_hide, 1, length(value_hide));
    value_hide = [value_hide, zeros(1, rows * cols - length(value_hide))];
    for k=1:rows
        for j=1:cols
            pic_hide(k, j) = floor(pic(k, j)/2) * 2 + value_hide((k-1) * cols +
j);
        end
    end
end

function value = space_show(pic_hide)
    [rows, cols] = size(pic_hide);
    value = zeros(1, rows * cols);
    for k=1:rows
        for j=1:cols
            value((k - 1) * cols + j) = mod(pic_hide(k, j), 2);
        end
    end
end
```

运行结果：

original picture

hide picture

jpeg compressed picture

```
原数据：[1  0  1  0  1  1  0  1  1]
解码结果：[1  0  1  0  1  1  0  1  1]
压缩后解码：[0  1  0  0  0  0  1  0  1]
正确率：0.222222222222222
fx >>
```

虽然可以实现信息隐藏，但是压缩后信息发生丢失，正确率很低。而 bmp 文件在传输中有诸多不便，也不是流行的图片保存方式，因此空域隐藏有很多局限性。

本问题代码位于 `hw_3_4_1.m` 中。图片位于 `hw_3_4_1_*.bmp` 中。

2. DCT域信息隐藏

实现了三种信息隐藏的方法：在所有DCT矩阵的系数最后一位隐藏，在DCT矩阵的直流分量的最后一位隐藏， 通过[1, -1]编码在末尾非零元素的后面隐藏。信息采用随机数的方式生成。

实现方式分别记录于函数 `dct_hide1` `dct_hide2` `dct_hide3` 中。

```
dir = "./图像处理所需资源/";
load(strcat(dir, "hall.mat"));
load(strcat(dir, "JpegCoeff.mat"));

pic = hall_gray;
value_hide = randi([0, 1], 100);
disp(['原数据: ', mat2str(value_hide(1:length(value_hide)))]);

[jpeg_row, jpeg_col, dc_code, ac_code] = my_encode(pic, QTAB, DCTAB, ACTAB);
jpeg_decode_ori = my_decode(jpeg_row, jpeg_col, dc_code, ac_code, QTAB, DCTAB,
ACTAB);

jpeg_decode_hide1 = run_hide(value_hide, pic, QTAB, DCTAB, ACTAB, 'hide1',
@dct_hide1, @dct_show1);

jpeg_decode_hide2 = run_hide(value_hide, pic, QTAB, DCTAB, ACTAB, 'hide2',
@dct_hide2, @dct_show2);

jpeg_decode_hide3 = run_hide(value_hide, pic, QTAB, DCTAB, ACTAB, 'hide3',
@dct_hide3, @dct_show3);


subplot(2, 2, 1);
imshow(jpeg_decode_ori);
title("original compressed picture");
imwrite(pic, "hw_3_4_2_pic_compress.bmp");
subplot(2, 2, 2);
imshow(jpeg_decode_hide1);
title("hide1 compressed picture");
imwrite(jpeg_decode_hide1, "hw_3_4_2_pic_hide1_compress.bmp");
subplot(2, 2, 3);
imshow(jpeg_decode_hide2);
title("hide2 compressed picture");
imwrite(jpeg_decode_hide2, "hw_3_4_2_pic_hide2_compress.bmp");
subplot(2, 2, 4);
imshow(jpeg_decode_hide3);
title("hide3 compressed picture");
imwrite(jpeg_decode_hide3, "hw_3_4_2_pic_hide3_compress.bmp");
```

```
function [jpeg_row, jpeg_col, dc_code, ac_code] = dct_hide1(value_hide, pic,
QTAB, DCTAB, ACTAB)
    % prepare
    dct2C_tilde = get_dct2C_tilde(pic, QTAB);
    dct2C_tilde_final = get_dct2C_tilde_final(dct2C_tilde);
    % hide value
    [value_rows, value_cols] = size(value_hide);
    value_hide = reshape(value_hide, 1, value_rows * value_cols);
    [rows, cols] = size(dct2C_tilde_final);
    value_hide = [value_hide, zeros(1, rows * cols - length(value_hide))];
    pic_hide_dct = dct2C_tilde_final;
    for k=1:rows
        for j=1:cols
            pic_hide_dct(k, j) = floor(dct2C_tilde_final(k, j)/2) * 2 +
value_hide((k-1) * cols + j);
        end
    end
    % encode dc
    dc_code = get_dc_code(pic_hide_dct, DCTAB);
    % encode ac
    ac_code = [];
    for i = 1:length(pic_hide_dct)
        single_block = pic_hide_dct(:, i);
        ac_code_single = get_ac_code_single(single_block, ACTAB);
        ac_code = [ac_code, ac_code_single];
    end

    [jpeg_row, jpeg_col] = size(pic);

end

function value = dct_show1(jpeg_row, jpeg_col, dc_code, ac_code, QTAB, DCTAB,
ACTAB)
    % decode dc
    dc_decode = get_dc_decode(dc_code, DCTAB);
    % decode ac
    ac_decode = get_ac_decode(ac_code, ACTAB);
    % recover image
    dct2C_tilde = [dc_decode; ac_decode];
    [rows, cols] = size(dct2C_tilde);
    value = zeros(1, rows * cols);
    for k=1:rows
        for j=1:cols
            value((k - 1) * cols + j) = mod(dct2C_tilde(k, j), 2);
        end
    end
end

function [jpeg_row, jpeg_col, dc_code, ac_code] = dct_hide2(value_hide, pic,
QTAB, DCTAB, ACTAB)
    % prepare
    dct2C_tilde = get_dct2C_tilde(pic, QTAB);
    dct2C_tilde_final = get_dct2C_tilde_final(dct2C_tilde);
    % hide value
    [value_rows, value_cols] = size(value_hide);
    value_hide = reshape(value_hide, 1, value_rows * value_cols);
    [rows, cols] = size(dct2C_tilde_final);
```

```
    value_hide = [value_hide, zeros(1, cols - length(value_hide))];
    pic_hide_dct = dct2C_tilde_final;
    [mini, min_idx] = min(zigzagScan(QTAB));
    for j=1:cols
        pic_hide_dct(1, j) = floor(dct2C_tilde_final(1, j)/2) * 2 +
value_hide(j);
        % disp(['j: ', mat2str(j), ', pic_hide_dct(1, j): ',
mat2str(pic_hide_dct(1, j)), ', dct2C_tilde_final(1, j): ',
mat2str(dct2C_tilde_final(1, j))]);
    end
    % encode dc
    dc_code = get_dc_code(pic_hide_dct, DCTAB);
    % encode ac
    ac_code = [];
    for i = 1:length(pic_hide_dct)
        single_block = pic_hide_dct(:, i);
        ac_code_single = get_ac_code_single(single_block, ACTAB);
        ac_code = [ac_code, ac_code_single];
    end

    [jpeg_row, jpeg_col] = size(pic);

end

function value = dct_show2(jpeg_row, jpeg_col, dc_code, ac_code, QTAB, DCTAB,
ACTAB)
    % decode dc
    dc_decode = get_dc_decode(dc_code, DCTAB);
    % decode ac
    ac_decode = get_ac_decode(ac_code, ACTAB);
    % recover image
    dct2C_tilde_final = [dc_decode; ac_decode];
    [rows, cols] = size(dct2C_tilde_final);
    value = zeros(1, cols);
    for j=1:cols
        value(j) = mod(dct2C_tilde_final(1, j), 2);
    end
end


function [jpeg_row, jpeg_col, dc_code, ac_code] = dct_hide3(value_hide, pic,
QTAB, DCTAB, ACTAB)
    % prepare
    dct2C_tilde = get_dct2C_tilde(pic, QTAB);
    dct2C_tilde_final = get_dct2C_tilde_final(dct2C_tilde);
    % hide value
    [value_rows, value_cols] = size(value_hide);
    value_hide = reshape(value_hide, 1, value_rows * value_cols);
    [rows, cols] = size(dct2C_tilde_final);
    value_hide = [value_hide, zeros(1, rows * cols - length(value_hide))];
    value_hide = (value_hide - 0.5) * 2;
    pic_hide_dct = dct2C_tilde_final;
    for j=1:cols
        if dct2C_tilde_final(end, j) ~= 0
            pic_hide_dct(end, j) = value_hide(j);
        else
            nz_row = 1;
            for m=rows:-1:1
```

```
                if dct2C_tilde_final(m, j) ~= 0
                    nz_row = m;
                    break;
                end
            end
            pic_hide_dct(nz_row + 1, j) = value_hide(j);
        end
    end
    % encode dc
    dc_code = get_dc_code(pic_hide_dct, DCTAB);
    % encode ac
    ac_code = [];
    for i = 1:length(pic_hide_dct)
        single_block = pic_hide_dct(:, i);
        ac_code_single = get_ac_code_single(single_block, ACTAB);
        ac_code = [ac_code, ac_code_single];
    end

    [jpeg_row, jpeg_col] = size(pic);

end

function value = dct_show3(jpeg_row, jpeg_col, dc_code, ac_code, QTAB, DCTAB,
ACTAB)
    % decode dc
    dc_decode = get_dc_decode(dc_code, DCTAB);
    % decode ac
    ac_decode = get_ac_decode(ac_code, ACTAB);
    % recover image
    dct2C_tilde_final = [dc_decode; ac_decode];
    [rows, cols] = size(dct2C_tilde_final);
    value = zeros(1, cols);
    for j=1:cols
        nz_row = 1;
        for m=rows:-1:1
            if dct2C_tilde_final(m, j) ~= 0
                nz_row = m;
                break;
            end
        end
        value(j) = (dct2C_tilde_final(nz_row, j) + 1) / 2;
    end
end

function pic_recovered = run_hide(value_hide, pic, QTAB, DCTAB, ACTAB,
hide_name, dct_hide, dct_show)
    [jpeg_row, jpeg_col, dc_code, ac_code] = dct_hide(value_hide, pic, QTAB,
DCTAB, ACTAB);
    pic_recovered = my_decode(jpeg_row, jpeg_col, dc_code, ac_code, QTAB, DCTAB,
ACTAB);
    value_show_jpeg = dct_show(jpeg_row, jpeg_col, dc_code, ac_code, QTAB,
DCTAB, ACTAB);
    disp([hide_name, ' 压缩后解码: ',
mat2str(value_show_jpeg(1:length(value_hide)))]);

    correct = 0;
    for k=1:length(value_hide)
        if value_hide(k) == value_show_jpeg(k)
```

```
            correct = correct + 1;
        end
    end

    disp(['正确率：', mat2str(correct / length(value_hide))]);

    disp(['PSNR: ', mat2str(my_psnr(pic_recovered, pic))]);

    ac_size = length(ac_code);
    dc_size = length(dc_code);

    before_size = jpeg_row * jpeg_col;
    after_size = (ac_size + dc_size) / 8;

    fprintf("压缩比：%f\n", before_size / after_size);
end
```

运行结果：


```
命令行窗口                                                    工作区
原数据：[1 1 0 1 1 0 0 1 1 1 0 1 1 0 1 0 0 1 1 1 1 0 1 1 1 1 0 1 0 1 0 0 0 0 1 1 0 1 0 0 0 1 1 0 0 0 1 1 1 0 1 1 0 0 0 1 0 1 0 1 0 1
hide1 压缩后解码：[1 1 0 1 1 0 0 1 1 1 0 1 1 0 1 0 0 1 1 1 1 0 1 1 1 1 0 1 0 1 0 0 0 0 1 1 0 1 0 0 0 1 1 0 0 0 1 1 1 0 1 1 0 0 0 1 0
正确率：1
PSNR：23.0712477180997
压缩比：4.681432
hide2 压缩后解码：[1 1 0 1 1 0 0 1 1 1 0 1 1 0 1 0 0 1 1 1 1 0 1 1 1 1 0 1 0 1 0 0 0 0 1 1 0 1 0 0 0 1 1 0 0 0 1 1 1 0 1 1 0 0 0 1 0
正确率：1
PSNR：31.0138148471535
压缩比：6.422428
hide3 压缩后解码：[1 1 0 1 1 0 0 1 1 1 0 1 1 0 1 0 0 1 1 1 1 0 1 1 1 1 0 1 0 1 0 0 0 0 1 1 0 1 0 0 0 1 1 0 0 0 1 1 1 0 1 1 0 0 0 1 0
正确率：1
PSNR：28.9973359882155
压缩比：6.191646
```

三种方法均成功隐藏了信息，且不受 JPEG 编解码的干扰。

客观指标表明，方法二、方法三的效果较好，压缩比与原图像接近。方法二的效果最好，PSNR以及压缩比都与原图像最为接近。

主观判断，方法一的图像质量较差，有很多噪点；方法二和方法三图像质量较好，但是方法二相比之下更为自然，例如大礼堂屋檐这一块，方法二的图像更加“干净”，而方法三则显得有点脏：

原因分析：方法一对每一个 DCT 系数都造成了影响，因此对图像质量的干扰较大，而且可能增加了矩阵中 0 的数量，导致压缩率降低；方法二仅微调 DCT 系数矩阵的 DC 系数，DC 系数对应原图像的低频分量，微调不会造成图像质量的太大变化，也不会造成压缩比的太大变化；方法三修改末尾的0，AC 编码变长，也会降低一些压缩比，而且末尾部分对应高频分量系数，将这些分量修改为非 0 值，会导致更多的高频分量出现，因而图像颜色会发生高频率变化，显得有点“脏”。

本问题代码位于 `hw_3_4_2.m` 中。图片位于 `hw_3_4_2_*.bmp` 中。

（四）人脸检测

1. 训练人脸

a) 不需要。样本的人脸大小不一致，但是我们训练采用的是各颜色占区域的比例，经过了归一化操作，因此图像的大小不会干扰训练结果。

b)

采用$L = 3, 4, 5$分别进行训练：

```
dir = "./图像处理所需资源/";
face_dir = strcat(dir, "Faces/");
subplot(3, 1, 1);
[v, L] = train_standard(face_dir, 3);
plot(v);
subplot(3, 1, 2);
[v, L] = train_standard(face_dir, 4);
plot(v);
subplot(3, 1, 3);
[v, L] = train_standard(face_dir, 5);
plot(v);
save("train_standard.mat", "v", "L", '-mat');
```

`train_standard.m` 计算所有图像的区域特征$\mathbf{u}(R_i)$，并求平均值$\mathbf{v}$：

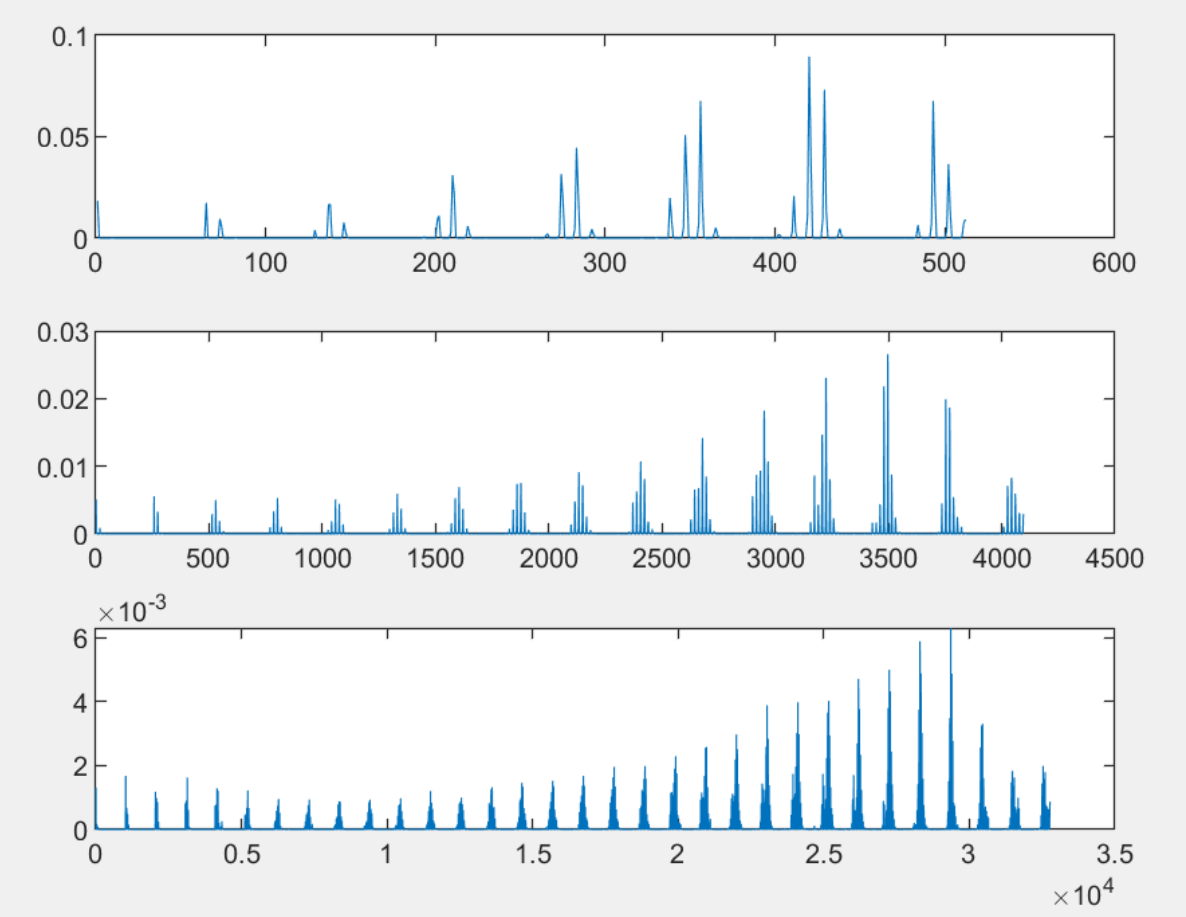
```
function [v, L] = train_standard(dir, L)
    image_list = read_bmp(dir);
    u = zeros(1, power(2, 3 * L));
    for k=1:length(image_list)
        u = u + get_characteristic(image_list{k}, L);
    end
    v = u / length(image_list);
end


function image_list = read_bmp(folder)
```

```
    filePattern = fullfile(folder, '*.bmp');
    bmpFiles = dir(filePattern);
    image_list = {};

    for i = 1:length(bmpFiles)
        baseFileName = bmpFiles(i).name;
        fullFileName = fullfile(folder, baseFileName);
        image = imread(fullFileName);
        image_list(end + 1) = {image};
    end
end
```

`get_characteristic.m`计算单张图像的特征：

```
function u = get_characteristic(pic, L)
    [row, col, ~] = size(pic);
    u = zeros(1, power(2, 3 * L));
    for k=1:row
        for j=1:col
            n = get_n(pic(k, j, 1), pic(k, j, 2), pic(k, j, 3), L);
            u(n + 1) = u(n + 1) + 1;
        end
    end
    u = u / (row * col);
end
```

运行结果：



如上图所示，从上到下依次是 $L=3,4,5$ 时 $\mathbf{v}$ 的分布图。可见，L值关系到"尖峰"的数量（即样本颜色的分辨能力）：L 越大，则尖峰越多。这是因为 L 越大，则颜色的分辨能力越强，对于不同的颜色会被区分到不同的分量中；L 越小，则颜色相近的颜色会被简并到同一个分量中，分辨能力下降。

本问题代码位于 `hw_4_3_1.m` 中。

2. 人脸检测

核心函数 `is_face.m` 计算并返回区域与人脸的距离：

```
% 分块检测
function d = is_face(single_block, v, L)
    u = get_characteristic(single_block, L);
    d = 1 - sqrt(u) * sqrt(v');
end
```

`detect_faces.m` 接受测试图像并返回人脸部分带红框的图像。将图像划分为 `block_size * block_size` 大小的区块，每一块利用 `is_face` 函数判别是否为人脸，将判别为人脸的区块用矩形标注出来：

```
function result = detect_faces(test, v, L, ths, min_face_size)
    % 预处理
    [rows, cols, ~] = size(test);
    block_size = 4;
    blocklize = @(x) ceil(x/block_size) * block_size;
    test_ext = [test, zeros(rows, blocklize(cols) - cols, 3)];
    test_ext = [test_ext; zeros(blocklize(rows) - rows, blocklize(cols), 3)];
    % 人脸检测
    result = blockproc(test_ext, [block_size, block_size], @(blk)
is_face(blk.data, v, L));
    % 标出红框
    valid = result < ths;
    squares = get_all_squares(test_ext, valid, v, L, ths, min_face_size);
    squared_pic_ext = blockproc(test_ext, [block_size, block_size], @(blk)
make_red(blk, squares));
    result = squared_pic_ext(1:rows, 1:cols, :);
end
```

其中，矩形标注的算法如下：

`get_neighbor.m` 计算连通的人脸区块：

```
function [map_r, visited_r] = get_neighbor(map, j, k, visited, map_ori)
    [rows, cols] = size(map);
    visited_r = visited;
    visited_r(j, k) = true;
    map_r = map;
    if map_ori(j, k)
        map_r(j, k) = true;
        if j ~= 1 && ~visited_r(j - 1, k)
            [map_r, visited_r] = get_neighbor(map_r, j - 1, k, visited_r,
map_ori);
        end
        if j ~= rows && ~visited_r(j + 1, k)
```

```
            [map_r, visited_r] = get_neighbor(map_r, j + 1, k, visited_r,
map_ori);
        end
        if k ~= 1 && ~visited_r(j, k - 1)
            [map_r, visited_r] = get_neighbor(map_r, j, k - 1, visited_r,
map_ori);
        end
        if k ~= cols && ~visited_r(j, k + 1)
            [map_r, visited_r] = get_neighbor(map_r, j, k + 1, visited_r,
map_ori);
        end
    end
end
```

`get_square.m`将连通的人脸区块用最小的矩形标注出来：

```
function [top, bottom, left, right] = get_square(area, min_face_size)
    [row, col] = size(area);
    top = row + 1;
    bottom = 0;
    left = col + 1;
    right = 0;
    for l = 1:row
        for m = 1:col
            if area(l, m)
                if l < top
                    top = l;
                end
                if l > bottom
                    bottom = l;
                end
                if m > right
                    right = m;
                end
                if m < left
                    left = m;
                end
            end
        end
    end
end
```

`get_all_squares.m`收集所有矩形，并根据条件判别是否识别为人脸（过小的矩形不被认为是人脸）：

```
function squares = get_all_squares(pic, valid, v, L, ths, min_face_size)
    [row, col] = size(valid);

    visited = false(size(valid));
    squares = false(size(valid));

    for k=1:row
        for j=1:col
            if valid(k, j) & ~visited(k, j)
                area = false(size(valid));
                [area, visited] = get_neighbor(area, k, j, visited, valid);
```

```
                [top, bottom, left, right] = get_square(area, min_face_size);
                square = false(size(area));
                if right - left > min_face_size & bottom - top > min_face_size
                    for l = left:right
                        square(top, l) = true;
                        square(bottom, l) = true;
                    end

                    for l = top:bottom
                        square(l, left) = true;
                        square(l, right) = true;
                    end
                end
                squares = squares | square;
            end
        end
    end
end
```

`hw_4_3_2.m`分别取$L = 3, 4, 5$，并采用不同的阈值，调用`detect_faces`函数识别人脸。

```
dir = "./图像处理所需资源/";
face_dir = strcat(dir, "Faces/");
test = imread(strcat(dir, "awf.jpg"));

% 画图
figure;

subplot(3, 1, 1);
[v, L] = train_standard(face_dir, 3);
wrap(test, v, L, 0.6, 8);


subplot(3, 1, 2);
[v, L] = train_standard(face_dir, 4);
wrap(test, v, L, 0.8, 8);


subplot(3, 1, 3);
[v, L] = train_standard(face_dir, 5);
wrap(test, v, L, 0.92, 8);

function wrap(pic, v, L, ths, min_face_size)
    squared_pic = detect_faces(pic, v, L, ths, min_face_size);
    draw(squared_pic, L, ths, min_face_size);
end

function draw(pic, L, ths, min_face_size)
    imshow(pic);
    imwrite(pic, sprintf("hw_4_3_2_squared_pic_L_%s.bmp", mat2str(L)));
    title(sprintf("L = %s, ths = %s, min face size = %s", mat2str(L),
mat2str(ths), mat2str(min_face_size)));
end
```

我们选用第七届“龙芯杯”比赛照片作为测试图片（放在`./图像处理所需资源/`中）：

运行结果：

L = 3, ths = 0.6, min face size = 8

L = 4, ths = 0.8, min face size = 8

L = 5, ths = 0.92, min face size = 8

`ths`表示被判别为人脸的最小“距离”阈值。`min face size`表示最小的人脸区块大小。

$L=3,4,5$条件下，均成功检测出人脸图像，但是从阈值`ths`来看，L的值越大，则距离阈值需要更大才能检测出人脸。这是因为L增大，颜色更加丰富，则人脸的判别条件更加“严格”，计算得到的距离也更大。同时，L增大后，红框的范围也变得更准确了，这是因为L的增加使得人脸检测的能力更强，能够更完整的标注人脸部分。

本问题代码位于 `hw_4_3_2.m` 中。相关图片位于 `hw_4_3_2_*.bmp` 中。

3. 图像变换

```
dir = "./图像处理所需资源/";
face_dir = strcat(dir, "Faces/");
test = imread(strcat(dir, "awf.jpg"));


% 画图
figure;

subplot(3, 1, 1);
[v, L] = train_standard(face_dir, 3);
test_rot90 = rot90(test);
wrap(test_rot90, v, L, 0.6, 4, 'rot90');


subplot(3, 1, 2);
[v, L] = train_standard(face_dir, 3);
test_scaledw2 = imresize(test, [size(test, 1), size(test, 2)*2]);
wrap(test_scaledw2, v, L, 0.6, 4, 'scaledw2');


subplot(3, 1, 3);
[v, L] = train_standard(face_dir, 3);
test_light = imadjust(test, [0.2 0.8]);
wrap(test_light, v, L, 0.6, 4, 'light');



function wrap(pic, v, L, ths, min_face_size, suffix)
    squared_pic = detect_faces(pic, v, L, ths, min_face_size);
    draw(squared_pic, L, ths, min_face_size, suffix);
end

function draw(pic, L, ths, min_face_size, suffix)
    imshow(pic);
    imwrite(pic, sprintf("hw_4_3_3_squared_pic_L_%s_%s.bmp", mat2str(L),
suffix));
    title(sprintf("L = %s, ths = %s, min face size = %s", mat2str(L),
mat2str(ths), mat2str(min_face_size)));
end
```

运行结果：

图一中，尽管图片发生了旋转，人脸依然被正确的识别出来了。这是因为我们的识别是基于彩色直方图的识别，与人脸的方向无关。

图二中，尽管图片发生了拉伸，人脸依然被正确的识别出来了。这是因为我们的识别是基于彩色直方图的识别，与人脸的长宽无关。

图三中，图片的对比度增强了，可以看出，只有3张人脸识别成功，且框的大小变小了很多，这是因为我们的识别是基于彩色直方图的识别，与图片的颜色有很大的关联，只有图片中与训练数据颜色相近的人脸才能被识别出来。

本问题代码位于 `hw_4_3_2.m` 中。相关图片位于 `hw_4_3_3_*.bmp` 中。

4. 重新选择标准

以上实验表明，基于彩色直方图的人脸检测虽然能成功检测出一部分人脸，但是存在较大的局限性，因此，除了人脸的颜色外，我还建议选择下面的标准作为人脸样本的训练标准：

1. 基于轮廓的识别：人脸的轮廓处颜色变化剧烈，具有更多的高频分量，因此容易识别。但是考虑到人脸的方向、长宽可能在实际情况中有所不同，应当对训练数据进行旋转、拉伸，再进行训练，提高普适性；
2. 基于 PCA 的特征脸识别：人脸具有很明显的特征（例如五官），可以通过训练数据得到一张“平均人脸”，检测时比较待测数据与平均人脸之间的各个特征之间的“距离”。
3. 添加更多肤色的人脸数据集：对于不同人种、不同肤色的人脸，人脸识别的效果可能不同。通过在数据集中添加更多样的人脸数据，会提高人脸识别的普适性和准确性。