INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Department of Electronics & Eletrical Communication Engineering

Vision and Intelligent Systems

EC69211 – Image and Video Processing Laboratory

Mini Project

JPEG Encoder

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CONTENTS

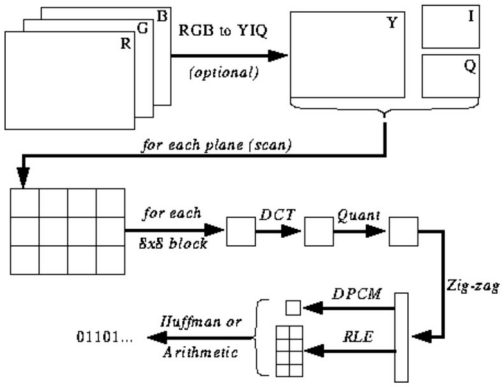
Objective:

1. Designing and implementing entire JPEG pipeline
2. Reading image in any raw format, passing it through JPEG encoder and storing output encoded image on disk

Theory:

Overall JPEG pipeline

The JPEG encoding consists of multiple steps which are pictorially shown below



Color Specification

The YUV colour coordinate defines Y, Cb, and Cr components of one color image, where Y is commonly called the luminance and Cb, Cr are commonly called the chrominance. Describing of a colour in terms of its luminance and chrominance content separately enable more efficient processing and transmission of colour signals in many applications.

$$\begin{pmatrix} Y \\ Cb \\ Cr \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.334 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} + \begin{pmatrix} 0 \\ 128 \\ 128 \end{pmatrix}$$

Discrete Cosine Transform

After colour coordinate conversion, the next step is to divide the three colour components of the image into many 8×8 blocks. For an 8-bit image, in the original block each element falls in the range [0,255]. Data range that is centred around zero is produced after subtracting The mid-point of the range (the value 128) from each element in the original block, so that the modified range is shifted from[0,255] to [-128,127]. Images are separated into parts of different frequencies by the DCT.

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

for $u = 0,\ldots,N-1$ and $v = 0,\ldots,N-1$

where $N = 8$ and $C(k) = \begin{cases} 1/\sqrt{2} & \text{for } k = 0 \\ 1 & \text{otherwise} \end{cases}$

Quantization

We actually throw away data through the Quantization step. We obtain the Quantization by dividing transformed image DCT matrix by the quantization matrix used . Values of the resultant matrix are then rounded off.

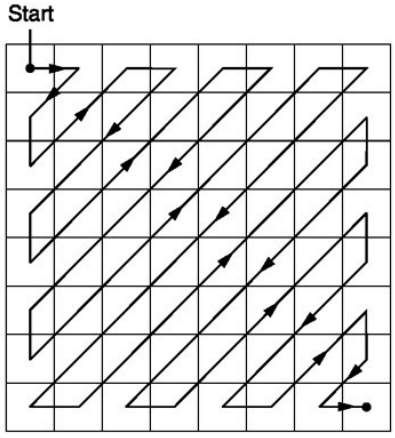
$$F(u,v)_{Quantization} = round\left(\frac{F(u,v)}{Q(u,v)}\right)$$

There are standard quantization tables for JPEG compression and they are constructed in a way that when we divide each value by two and use the resultant matrix, one cannot notice significant degradation in quality of the output image. Standard Qunatization matrices for luminance and chrominance components respectively are as follows:

$$Q_Y = \begin{pmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{pmatrix} \quad Q_C = \begin{pmatrix} 17 & 18 & 24 & 47 & 99 & 99 & 99 & 99 \\ 18 & 21 & 26 & 66 & 99 & 99 & 99 & 99 \\ 24 & 26 & 56 & 99 & 99 & 99 & 99 & 99 \\ 47 & 66 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \end{pmatrix}$$

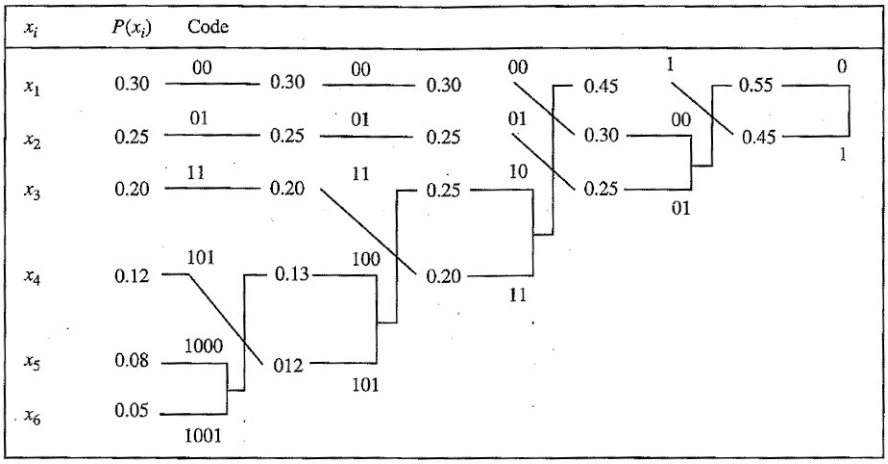
Zig-zag ordering

After quantization, the "zig-zag" sequence orders all of the quantized coefficients. In the "zig-zag" sequence, firstly it encodes the coefficients with lower frequencies (typically with higher values) and then the higher frequencies (typically zero or almost zero).



Huffman Encoding

Entropy Coding achieves more lossless compression by encoding more compactly the quantized DCT coefficients. Huffman coding is used in the baseline sequential codec, but all modes of operation use Huffman coding and arithmetic coding.



Algorithms:

Following is the algorithm used to perform JPEG compression:

1. Read the RGB pixel arrays of input image using OpenCV
2. Pad each channel to make the dimensions a mulitple of 8
3. Convert RGB to YCbCr using the matrix transformations
4. Break the image into 8x8 blocks and carry out the steps below for each block
5. Compute DCT of Y, Cb, Cr matrix
6. Divide each element of DCT matrix with corresponding element of quantization matrix and round each element to nearest integer
7. Apply zigzag ordering on each of quantized matrices
8. Subtract DC coefficient of current block from that of previous block and let the intermediate symbol be (class)(amplitude). Apply huffman encoding on class and store amplitude as Variable Length Code (VLI)
9. For AC coefficient, apply run length encoding to get intermediate symbols of the form (number of preceding zeros, class)(amplitude) with the first part being huffman encoded and the second part as VLI
10. After each occurence of 0xFF in the data add a 0x00 as mentioned in JPEG standard
11. Write all the encoded data, Huffman tables, Quantization tables and other specifications in appropriate segments starting with corresponding segment marker

Following is the algorithm used to do run-length encoding:

1. Find the last index after which all the entries are 0s in the data stream.
2. Maintain 2 pointers, one for the starting index and the next for the current index to find the length of 0s.
3. Loop the current index till the last index and if the current index value is not 0 or if the length of the 0s is 16 then store the run length code. Otherwise just move the current index to the next index.

4. Keep storing the run length code in a list and break out once you reach the last index.
5. Append [0,0] at the end to the run length code to indicate that all the terms are 0 after this.
6. Return the obtained list and this is the run length code.

Following is the algorithm used to generate Huffman code:

1. Calculate the frequency of each unique value from the data stream and then divide it by the total number of values to get the probability of occurrence of the value.
2. Sort the values by their probability from lowest to highest.
3. Choose 2 of the values with the lowest probability and merge them to create a new value with the probability as the sum of those 2 values.
4. Sort the new set of values again based on the new probability distribution.
5. Repeat this process till there is only a single value left.
6. The merged nodes would have formed a tree structure, which is the Huffman tree.
7. Traverse the tree by taking the left child as “0” and right child as “1” and append consecutive values till you reach the leaf node and this will be the Huffman code.

Algorithm used to compute Fast DCT is given in [4]

Results:

Three different BMP images were taken as input and passed through JPEG encoder to obtain the compressed images. For a 256x256 image, the entire process took around 4 seconds to complete its execution. As the size of the input image increased, the execution took longer to complete.

lena_colored_256.bmp, corn.bmp and *cameraman.bmp* were taken as input images and the encoding was repeated for multiple quantization matrices in order to control the amount of compression. It was found that when different images were encoded using the same quantization matrix, different compression ratios were obtained. This happened because the frequency distribution of the symbols required to encode the image were different for different images due to which length of Huffman codes and total length of encoded data were different and hence it achieved different compression ratios. An interesting point to note was that the encoder could achieve much lesser compression ratio on *corn.bmp* as compared to other images. A possible reason can be that *corn.bmp* was in color indexed BMP format with 256 colors due to which the size of the data in raw format itself was much lower.

The output images along with their attributes are given below:

Original BMP Image

Image name – lena_colored_256.bmp

File size – 196.7 kB

JPG image

Quantization matrix – all ones (no loss)

File size – 50.8 kB

Compressio ratio – 3.87

Remark – No noticeable degradation

JPG image

File size – 14.7 kB

Quantization matrix – half of standard values

Compression ratio – 13.38

Remark – No noticeable degradation

JPG image

File size – 10.9 kB

Quantization matrix – standard values

Compression ratio – 18.04

Remark – Some degradation in quality clearly visible on the face

JPG image

File size – 6.5 kB

Quantization matrix – twice of standard values

Compression ratio – 30.26

Quality – Many parts of the image have high degradation in quality

Original BMP Image

Image name – corn.bmp

File size – 130.6 kB

JPG image

File size – 45.9 kB

Quantization matrix – half of standard values

Compression ratio – 2.84

Remark – No noticeable degradation

JPG image

File size – 28.7 kB

Quantization matrix – standard values

Compression ratio – 4.55

Remark – No noticeable degradation

JPG image

File size – 18.2 kB

Quantization matrix – twice of standard values

Compression ratio – 7.18

Remark – Very sharp color variations are no longer present

JPG image

File size – 6.5 kB

Quantization matrix – 8 times of standard values

Compression ratio – 20.09

Remark – Highly degraded image with edges not clearly visible at many positions

Original BMP Image

Image name – cameraman.bmp

File size – 66.6 kB

JPG image

File size – 12.7 kB

Quantization matrix – half of standard values

Compression ratio – 5.244

Remark – No noticeable degradation

JPG image

File size – 8.4 kB

Quantization matrix – standard values

Compression ratio – 7.93

Remark – Some erroneous pixels can be observed when looked at it closely

JPG image

File size – 5.6 kB

Quantization matrix – twice of standard values

Compression ratio – 11.89

Remark – Many erroneous pixels were introduced especially near the edge structures of the image

JPG image

File size – 2.3 kB

Quantization matrix – 10 times of standard values

Compression ratio – 28.96

Remark – Block like structures are visible with totally erroneous pixels at several locations

From the above images and their properties, we got to see the trade-off between compression and quality of output image. Depending on the application, one needs to choose the quality factor so that the quality is good enough for their purpose while getting some compression.

Discussion:

- While encoding the image, we always consider 8x8 blocks. Whenever the image dimensions are not multiples of 8, we must pad the image by some strategy to make its dimensions multiple of 8. In JPEG encoding, zero padding is not a good strategy because it will add lots of high frequency components and compression will not be good. Instead, it is a good choice to pad using the same values as that at the edges and corners of the original image. Also, we mention the height and width of the image in SOF segment due to which the image decoder can always display the image with original dimensions.
- The end of block code (0,0) must be added only if the length of the zigzag length sequence is less than 64. It was observed that when the length was equal to 64, the decoder automatically breaks from current block and scans the next block.
- The quantization matrix is a measure of how much compression we want in the encoded image. If the matrix contains higher values, there will be lesser distinct symbols to be encoded and hence compression will be higher. There are some standard quntization tables which can be used to get good compression while not sacrificing much on the quality of the output image. When the values of the standard matrix are halved, there was no significant degradation in image quality.
- It is interesting to note that JPEG decoder reconstructs the Huffman tree just from the information mentioned in the Huffman segment which contains the number of codes having particular length and the values associated with codes of each length. It can decode unambiguously because there is predefined pattern in which Huffman codes must be used. For Huffman codes, it is the length of the code which matters and not the exact code. So in JPEG, Huffman codes of a particular length are generated as consecutive numbers (ex – 000, 001, 010, 011, ...) and whenever there is an increase in length we must multiply 2 with the current code (ex – 010, 0110, 0111). There is another restriction that no code must have all 1’s in it which can be handled by skipping the code containing all 1’s and going to next code following the pattern mentioned above.

- All segment markers in JPEG starts with 0xFF. As per JPEG standards whenever actual data contains the byte 0xFF we must add a dummy byte 0x00 so that decoder can distinguish whether is a segment marker or it is actual data.
- JPEG compression is a lossy compression and hence must only be used when we can afford to lose some information from the image. For example, if the image is used for entertainment purpose then JPEG can be used as we found that the low compressed image of lena had no noticeable degradation in quality. However, JPEG must not be used in certain medical imaging processes as it might need high details of the image and losing information might give bad results.

References:

[1] Wikipedia, https://en.wikipedia.org/wiki/JPEG

[2] Wikibooks, https://en.wikibooks.org/wiki/JPEG_-_Idea_and_Practice

[3] Decoding a JPEG Image, https://yasoob.me/posts/understanding-and-writing-jpeg-decoder-in-python/

[4] Fast DCT algorithm, https://www.nayuki.io/res/fast-discrete-cosine-transform-algorithms/lee-new-algo-discrete-cosine-transform.pdf