COMPARISON OF JPEG PERFORMANCES USING REGULAR AND MODIFIED QUANTIZATION TABLES

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Abstract: *The JPEG image compression standard is based on the Discrete Cosine Transform (DCT) and coefficient quantization. In this paper we'll discuss only grayscale image compression, and we'll only mention the case of color images. We'll also suppose that the test images are quadratic (256x256 pixels) and each pixel is represented using 8 bits (256 shades of gray). Compression starts by dividing the digital image into 8x8 blocks, and further operations are performed on these 8x8 blocks. The contribution of this paper is that different quantization matrices are used to determine the measure of degradation. In the end, after reconstruction, the degradation is evaluated using the most common measures: the Peak Signal to Noise Ratio (PSNR).*

Keywords: *digital image compression, discrete cosine transform, quantization, peak signal-to-noise ratio*

1. INTRODUCTION

Compression of a digital image is a mean to save memory space. Basic classification of compression methods is to compression without losses and compression with losses. In the case of lossless compression the original signal (in this case image) can be reconstructed without loss of quality. On the other hand, in the case of lossy compression after reconstruction degradation occurs. The degree of degradation depends on the compression factor, and on image content also. Typical value of the compression ratio for the lossless case is 3:1, and in the case of lossy compression the ratio is 15:1. The JPEG standard that was first announced in 1992 refers to the family of lossy compressions. The standard defines several types of JPEG compressions: sequential, hierarchical, progressive and lossless. When talking about JPEG, most often we think of the sequential type that is mostly used in practical implementations [1], [2].
The importance of digital image compression is justified because of huge storage space requirement: without compression, a single 512x512 pixel color image would require 768kB of space, while only one second of full HD 1080x1920 video would require around 200MB of storage space.

2. THE JPEG PROCESS

The JPEG process consists of several steps: 1) Breaking the digital image into 8x8 pixel blocks, 2) Level shift: 128 is subtracted from each pixel value, now the block range concerning pixel intensities will be between -128 and +127, 3) DCT transform on each block, 4) Quantization, 5) Zig-zag scanning of the 8x8 image block, 6) Run-length coding and entropy coding [3]. The flowchart of the algorithm is shown is Figure 1.

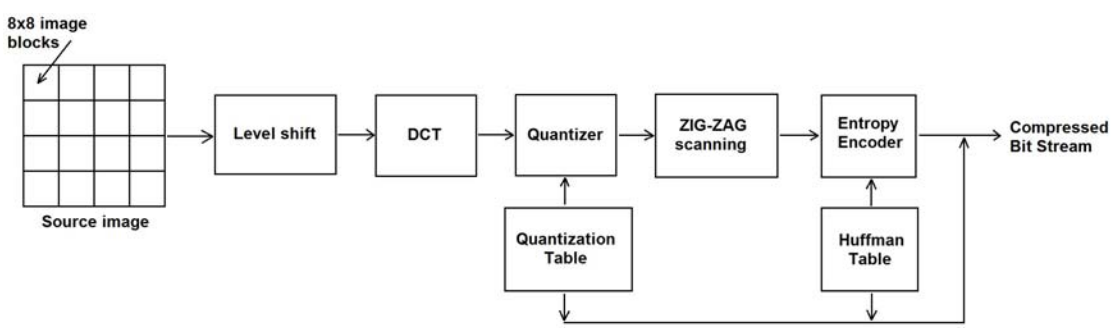

Figure 1: Flowchart of the JPEG process

2.1. Quantization

From the steps listed above, quantization is the only step that introduces irreversible information loss, all other steps are invertible. Different levels of compression and quality are possible by selecting a specific quantization matrix. The exact quantization matrix is not a part of the JPEG standard, so the user can decide on quality levels between 1 and 100. Quality 1 gives the highest compression ratio and worst image quality, while quality 100 gives perfect quality and lowest compression level. Empirical research that included the human visual system resulted in the JPEG Q_{50} standard quantization matrix. The Q_{50} is a good trade-off between compression ratio and reconstructed image quality. If different quality level is needed, the Q_{50} is multiplied with a scalar factor. For a quality level greater than 50 (higher image quality), the Q50 is multiplied by *(100-quality level)/50*. For quality level less than 50 (lower quality, smaller file size) the Q_{50} is multiplied by *50/quality level*. In both cases the scaled quantization matrix is rounded to contain only positive integers and limited to values between 0 and 255 [4]. Examples matrices Q_{10}, Q_{50} and Q_{90} are shown in Figure 2.

$$Q_{10} = \begin{bmatrix} 80 & 60 & 50 & 80 & 120 & 200 & 255 & 255 \\ 55 & 60 & 70 & 95 & 130 & 255 & 255 & 255 \\ 70 & 65 & 80 & 120 & 200 & 255 & 255 & 255 \\ 70 & 85 & 110 & 145 & 255 & 255 & 255 & 255 \\ 90 & 110 & 185 & 255 & 255 & 255 & 255 & 255 \\ 120 & 175 & 255 & 255 & 255 & 255 & 255 & 255 \\ 245 & 255 & 255 & 255 & 255 & 255 & 255 & 255 \\ 255 & 255 & 255 & 255 & 255 & 255 & 255 & 255 \end{bmatrix} \quad Q_{90} = \begin{bmatrix} 3 & 2 & 2 & 3 & 5 & 8 & 10 & 12 \\ 2 & 2 & 3 & 4 & 5 & 12 & 12 & 11 \\ 3 & 3 & 3 & 5 & 8 & 11 & 14 & 11 \\ 3 & 3 & 4 & 6 & 10 & 17 & 16 & 12 \\ 4 & 4 & 7 & 11 & 14 & 22 & 21 & 15 \\ 5 & 7 & 11 & 13 & 16 & 12 & 23 & 18 \\ 10 & 13 & 16 & 17 & 21 & 24 & 2 & 21 \\ 14 & 18 & 19 & 20 & 22 & 20 & 20 & 20 \end{bmatrix} \quad Q_{50} = \begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}$$

Figure 2: Quantization matrices Q_{10}, Q_{90} and Q_{50}

The DCT compacts the energy of the image block into only few coefficients in the upper left part of the block. That is the reason why these low frequency components are quantized lightly, while high frequency components are quantized rather heavily [5]. A typical DCT transformed image block before and after quantization is showed in Figure 3.

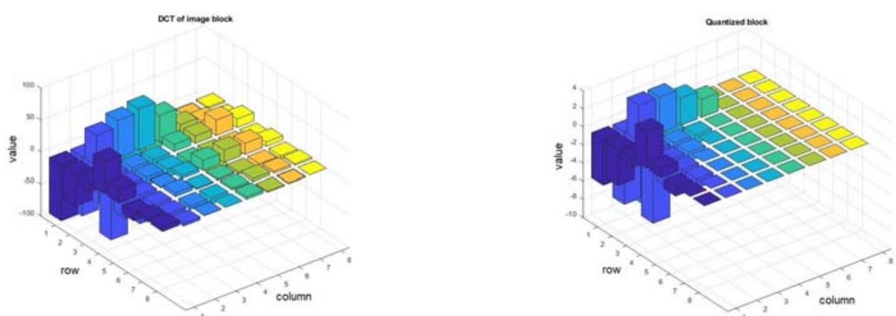

Figure 3: Image block after DCT transformation (left), and after quantization (right)

3. TEST IMAGES

In the first stage of the research the authors examined the influence of the quantization matrix on peak signal-to-noise ratio (PSNR), structural similarity (SS) and compression ratio (CR). Thumbnails of 11 256x256 8-bit test images used are shown in Figure 4.

Figure 4: Test images used in the research: Baboon, Barbara, Boat, Cameraman, Clock, F16 (top row), Lake, Lena, Moon, Peppers and Pirate (bottom row)

4. EXPERIMENTAL RESULTS

In the experimental phase all test images were compressed and decompressed, and several objective quality parameters were measured between the original and the reconstruction digital images. Peak signal-to-noise ratio (PSNR) and structural similarity index (SSIM) were used to evaluate the quality of the compression. The results are summarized in Table 1. For each test image the Q_{50} quantization matrix was used.

Table 1: Experimental results of image compression for quantization matrix Q_{50}

	Bitstream (bits)	CR	PSNR	SSIM
Baboon	59250	8.85	29.35	0.66
Barbara	63303	8.28	33.37	0.86
Boat	66067	7.94	31.86	0.81
Cameraman	54223	9.67	31.50	0.58
Clock	40943	12.81	34.69	0.56
F16	58458	8.97	32.61	0.72
Lake	74022	7.08	31.09	0.80
Lena	52342	10.02	33.58	0.79
Moon	50787	10.32	32.13	0.64
Peppers	56106	9.34	34.14	0.81
Pirate	68076	7.70	31.59	0.81

By modifying the quantization matrix, the results also change. Table 2 shows the results for the same process when using quantization matrices Q_{10} (high compression, low image quality) and Q_{90} (excellent quality, low compression rate). It is on the user to adapt the quantization matrix to his needs.

Table 2: Experimental results for quantization matrices Q_{10} and Q_{90}

	Quantization with Q_{10}				Quantization with Q_{90}			
	Bitstream (bits)	CR	PSNR	SSIM	Bitstream (bits)	CR	PSNR	SSIM
Baboon	12713	41.24	2658.	0.32	172218	3.04	37.45	0.91
Barbara	20972	25.00	26.26	0.64	138730	3.78	40.64	0.94
Boat	20195	25.96	26.33	0.56	155884	3.36	39.69	0.93
Cameraman	17782	29.48	26.22	0.35	133019	3.94	39.90	0.80
Clock	15724	33.34	28.63	0.37	98356	5.33	41.72	0.80
F16	20044	26.16	27.00	0.48	136878	3.83	40.29	0.87
Lake	24340	21.54	25.73	0.58	171558	3.06	38.90	0.92
Lena	17218	30.45	28.36	0.54	128034	4.09	47.25	0.98
Moon	11562	45.35	28.64	0.31	155348	3.37	37.72	0.90
Peppers	18710	28.02	28.41	0.60	128690	4.07	41.15	0.92
Pirate	20062	26.13	26.71	0.56	164441	3.19	39.02	0.94

So far only grayscale images were analyzed. For the color case there is a slight difference. The JPEG standard requires to transform the *RGB* color image to the *YCbCr* color plane. This transformation is done using the following equation:

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.144 \\ -0.159 & -0.332 & 0.050 \\ 0.500 & -0.419 & -0.081 \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

Since the human eye is not as sensitive to color degradation as to luminance degradation, the chrominance planes can be further subsampled for extra space savings. The subsampling can be done using either 4:4:0, 4:2:2 or 4:2:0 method. In this paper 4:2:0 is used what means that the spatial resolution of both the horizontal and the vertical planes are halved. In our case the original test image is composed of 256 rows and 256 columns [6]. After the transformation the luminance component (Y) still has the same resolution, but the chrominance components are halved to 128x128 by averaging each 2x2 image block. This on purpose degradation is hardly visible for the human eye, so the subjective quality remains almost the same. A typical RGB to YCbCr color transform of a test image (with and without subsampling) is shown in Figure 5.

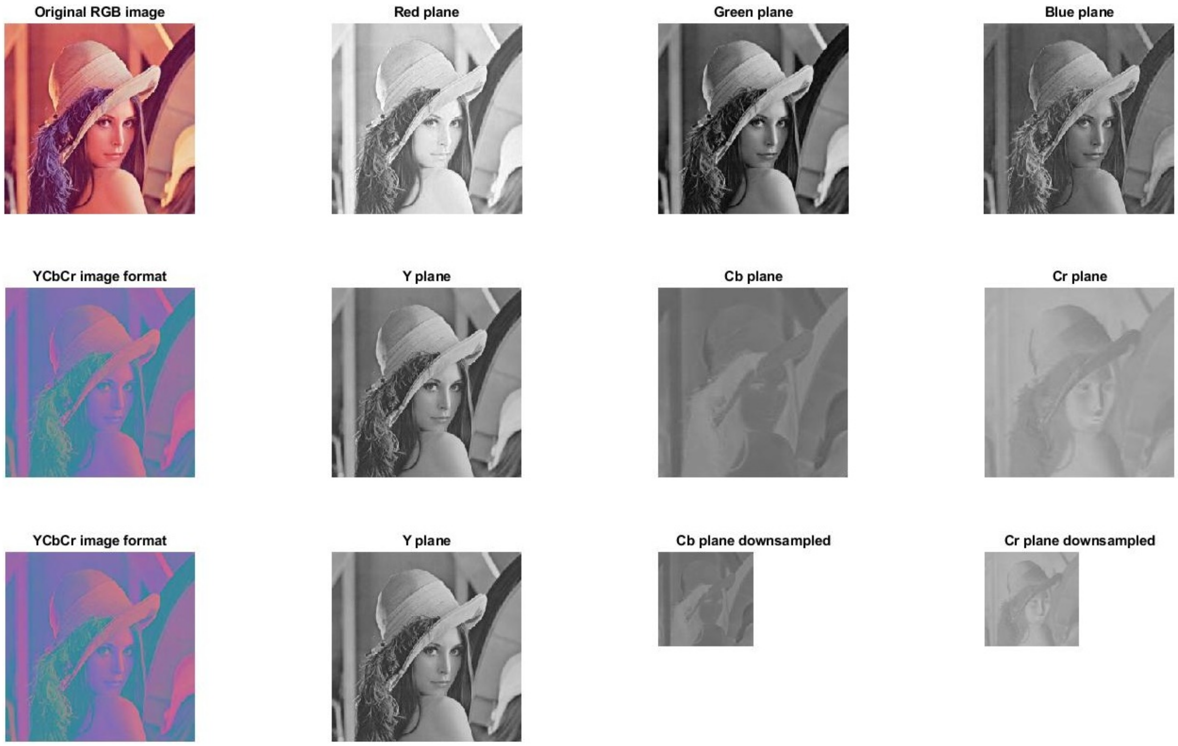

Figure 5: Color test image decomposed to color planes. Top row: Original test image decomposed to Red, Green and Blue components. Middle row: Test image transformed to YCbCr color plane, decomposition to Y (luminance), Cb and Cr (chrominance). Bottom row: YCbCr color image format, color planes subsampled by factor 2.

It would be logical to expect the compression ratio does not change for the color images in comparison to grayscale (if same quantization matrices are used). But because eyes are less sensitive to color, it is possible to quantize the color components more heavily. A typical chroma quantization matrix is shown in Figure 6. As it can be observed, numbers are quite high in comparison to the luminance Q-matrix which means bigger degradation. The other reason the compression ratio increases for color images is the fact that Cb and Cr components were subsampled to 128x128 ,so they occupy 4 times less space than their original version. After all calculations are done, it can be easily calculated that we ended up with 1.5 256x256 digital image (256x256 luminance image plus 2 times 128x128 chrominance images).

$$Q_{90} = \begin{bmatrix} 17 & 18 & 24 & 47 & 99 & 99 & 99 & 99 \\ 18 & 21 & 26 & 66 & 99 & 99 & 99 & 99 \\ 24 & 26 & 56 & 99 & 99 & 99 & 99 & 99 \\ 47 & 66 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \end{bmatrix}$$

Figure 6: Chrominance quantization matrix

Table 3 shows the stream length (number of bits) to represent each color plane. It can be observed that the Y plane needs 7-10 time more space than the color components [7]. There are two main reasons for this: the first is that the color components (Cb, Cr) are four times smaller than the Y component (128x128 compared to 256x256), and the second is that the color components were quantized rather heavily.

Table 3: Number of bits needed to represent the Y, Cb and Cr color planes in bits

	Y (bits)	Cb (bits)	Cr (bits)	Total (bits)	Compression ratio
Baboon	72040	8157	7652	87849	17.90
Barbara	77496	4498	4965	86959	18.09

F16	47403	5718	4145	57266	27.47
Lena	44228	5703	5519	55450	28.37
Peppers	44351	7441	9505	61297	25.66

Finally, Figure 7 shows the original test image Lena along with 3 more images that were obtained after compression and decompression using quantization matrices Q_{10}, Q_{50} and Q_{90}.

(a) (b) (c) (d)

Figure 7: Test image Lena compressed with different quantization matrices. (a) Original test image, (b) Test image quantized with Q_{10}, (c) Test image quantized with Q_{50}, (d) Test image quantized with Q_{90}

5. CONCLUSION

In this paper we investigated different quantization for 11 test images in the process of JPEG compression. We proved that quantization has a considerable impact on the resulting image quality and on the compression ratio. Quantization is a mean to make a trade-off between image quality and compression ratio. Color images were also investigated, and we showed why color images can achieve higher compression ratios. It would be worth investigating how would the JPEG compression perform if the digital image is not broken to 8x8, but bigger pixel blocks. Also better results might be achieved if different quantization matrices would be applied to different blocks based on their content [8].

6. ACKNOWLEDGEMENT

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