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Optimization of Quantization Table Based on Visual Characteristics in DCT Image Coding

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Abstract—The DCT (Discrete Cosine Transform) based coding process of full color images is standardized by the JPEG (Joint Photographic Expert Group). The JPEG method is applied widely, for example a color facsimile. The quantization table in the JPEG coding influences image quality. However, detailed research is not accomplished sufficiently about a quantization table. Therefore, we study the relations between quantization table and image quality. We examine first the influence to image quality given by quantization table. Quantization table is grouped into four bands by frequency. When each value of bands is changed, the merit and demerit of color image are examined. At the present time, we analyze the deterioration component of a color image. We study the relationship between the quantization table and the restoration image. Color image is composed of continuous-tone level and we evaluate the deterioration component visually. We also analyze it numerically. An analysis method using the 2-D FFT (Fast Fourier Transform) can catch a change of a color image data by a quantization table change. On the basis of these results, we propose a quantization table using Fibonacci numbers.

Keywords—Discrete cosine transform, DCT coefficients, JPEG, Image compression, Fibonacci series.

1. INTRODUCTION

Still color images have important characteristics in various media. When we want to convey information to others, it is very effective to utilize images. We can imagine that, without images, it is not easy to convey the contents of still color image to another person from another viewpoint. However, the volume of color image data is large, so it is convenient to compress the image data without damaging its quality as long as possible. The purpose of image compression is to represent images with less data volume in order to save storage costs or transmission time and costs [1,2]. The method of image compression is accomplished by using DCT [3].

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This transformation is adopted to the JPEG algorithm. When the data transformed by DCT is quantized by the JPEG algorithm, the accuracy of each DCT data is able to choose. As of now we do not know what kind of quantization table is to be used, when we want to quantize the given image; therefore, we carried out the research about an optimal quantization table (the DCT coefficients).

2. JPEG IMAGE COMPRESSION

2.1. Constitution of an Image

In an additive color device such as a display CRT (cathode-ray tube), the light is produced by three primary colors RGB (red, green, and blue) [1]. One pixel of an image on the CRT is mixed with RGB tone value, as shown in Figure 1.

2.2. The DCT and Quantization

Image data processing is shown in Figure 2. The quantization operation is only unreversible among these operations. The accuracy of the DCT coefficients is decided with a stage of quantization. The DCT coefficients show that a characteristic of an image differs by each image, and

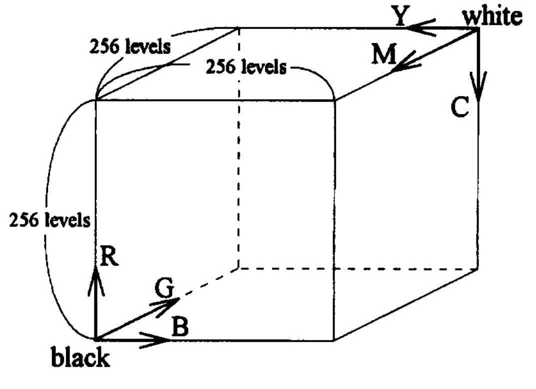


Figure 1. Illustration of the trichromatic theory.

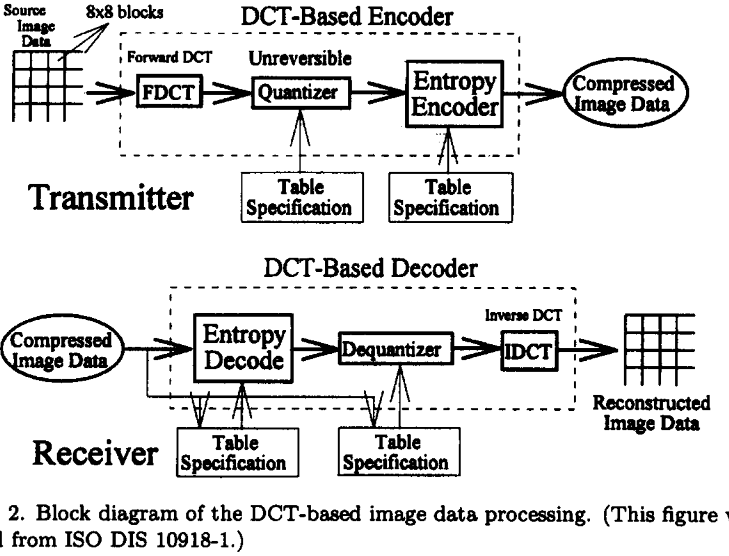


Figure 2. Block diagram of the DCT-based image data processing. (This figure was quoted from ISO DIS 10918-1.)

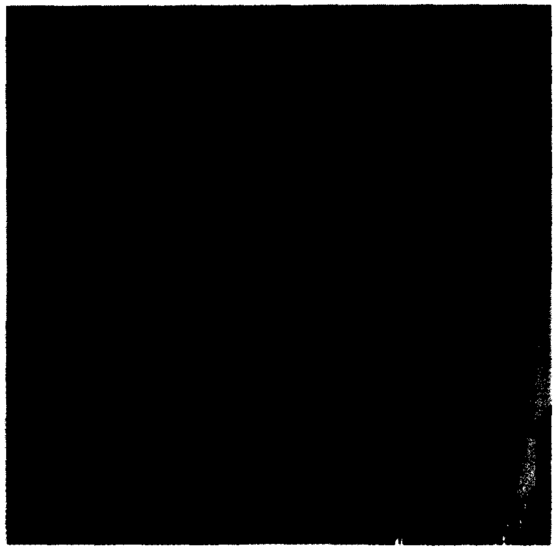
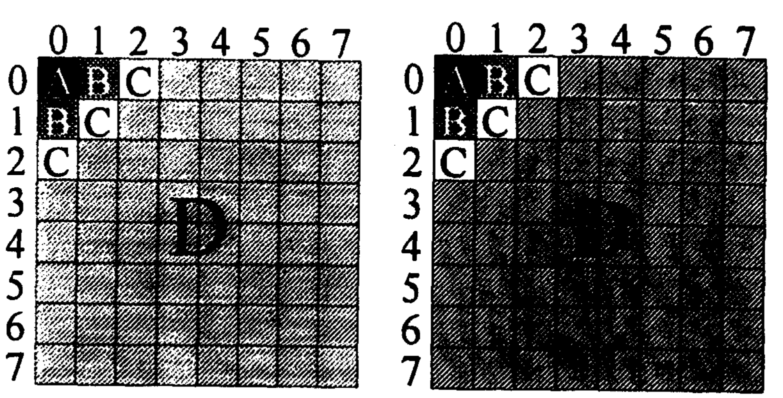


Figure 3. Continuous-tone color image(1).

Figure 4. Continuous-tone color image(2).



(a) Luminance quantization table. (b) Chrominance quantization table.

Figure 5. Example of segmentation of the quantization table.

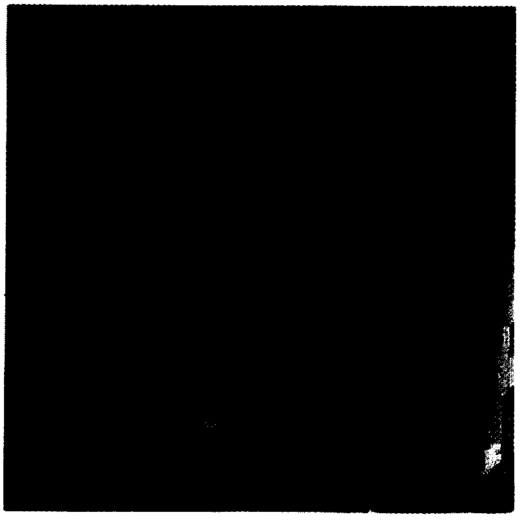


Figure 6. Example of continuous-tone image with false contour lines.

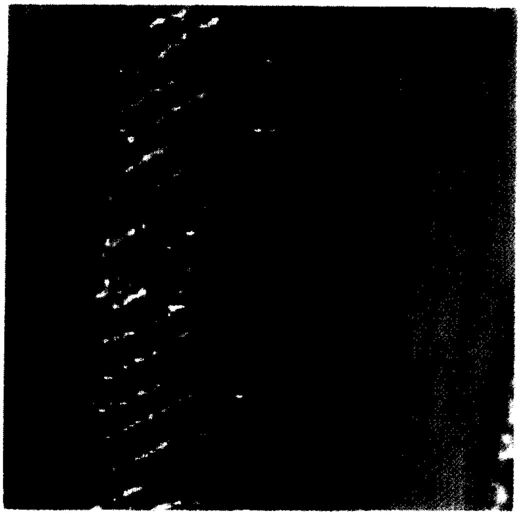


Figure 7. Example of comparative fine image(1).

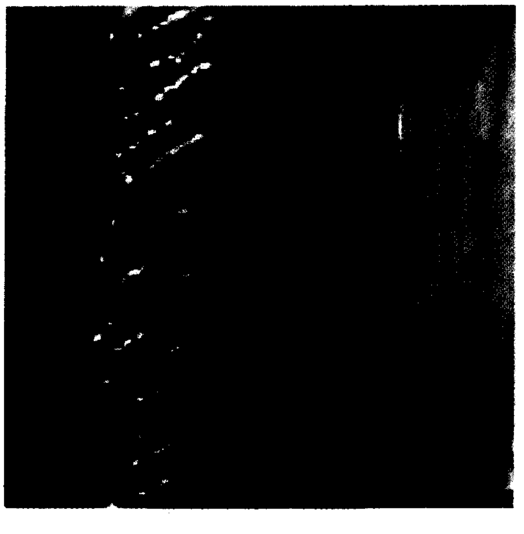


Figure 8. Example of comparative fine image(2).

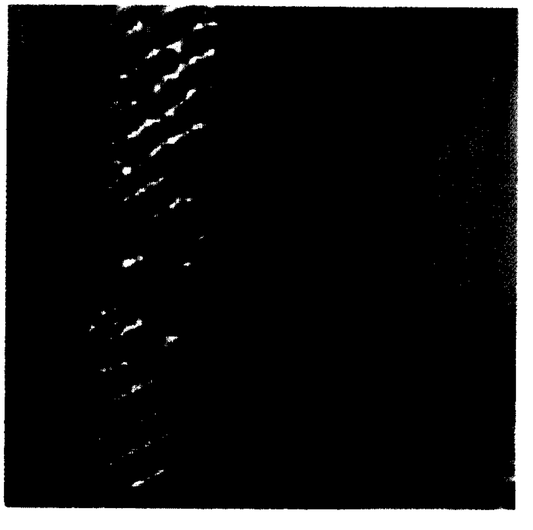


Figure 9. Example of fine image.

an optimal quantization table of the image differs, respectively. The user of JPEG compression is able to choose each value of the quantization table. However, the size of compressed data can be adjusted by adjusting the coefficient (compression parameter) or the multiplier of the whole quantization table.

3. EXPERIMENTAL METHOD

3.1. Images Used for the Computational Experiments

Images that we used for the computational experiments are Figures 3 and 4. The size of these images is 800 × 800 pixels, and the tone of them is 8 bits/color·pixel (24 bits/pixel).

3.2. Segmentation of the Quantization Table

Figure 5 shows the segmentation of the quantization table for our computer experiment [4]. It is difficult to decide a combination of these coefficients, because a quantization table is composed of 64 coefficients. Also, the influence that these four bands give to an image is strong in the order of A, B, C, and D. A value of each band that we used with computer experiment is shown in Table 1.

3.3. Experimental Conditions

Our computer experiments were carried out under the following two conditions.

The first condition: we adjust the scaling factor of a quantization table to keep a constant volume size of image data. It is obtained that DC component become insufficient and deterioration of image quality arise when data of high frequency is increased too much.

The second condition: we fixed a scaling factor of a quantization table to check the influence of each band, namely, a quantization table is adjustable and scaling factor is a constant. Differences among quantization tables influence image quality.

Table 1. Values of our quantization table.

Band	Values of Band		Values of the Other Band
	Luminance Table	Chrominace Table	
A	4	4	default value of JPEG
A	8	8	
A	16	16	
A	32	16	
A	64	64	
B	6	11	default value of JPEG
B	12	12	
B	24	44	
C	9	27	default value of JPEG
C	18	54	
C	36	108	
D	#1	#1	default value of JPEG
D	#2	#2	

#1: default value of JPEG X 1/4

#2: default value of JPEG X 4

4. EXPERIMENTAL RESULTS

4.1. DCT Coefficients

Table 2 shows the relationship between four bands (A, B, C, and D) of the quantization table and degree of a change of an image (see Figures 6, 7, 8 and 9). The band A is called DC coefficient, and means the average of 8×8 blocks. An influence of the DC coefficient is especially strong to a continuous image. The band B, the band C, and the band D influence frequency component of image.

4.2. The FFT of Difference Data

The difference between an original image $T(x, y)$ and a restored image $T'(x, y)$ by compression is processed with FFT. Figure 10 shows a 3-D graph of results that the difference data between an original image and a compression restoration image are processed with 2-D FFT using the table of four times of JPEG default value in the band D. According to Figure 10, a correlation between difference and visual frequency sensitivity is low.

The band D exerts a big influence on a high frequency component. However, a width of a high frequency component in a block is very narrow (i.e., the band D's width of one cycle is very narrow). Therefore, it is hard to judge the quality of this sort of image to the naked eye. Namely, this means that we don't care about the value of quantization table corresponding to the band D. According to this result, it turns out to need the high accuracy in the order of the band A, the band B, and the band C.

5. CONCLUSIONS AND ADDITIONAL CONSIDERATIONS

The summary of the results are as follows.

(1) The band A (DC component) is important, because insufficient values of the band A generate false contours (see Figure 6).

Table 2. Influence that each band gives to an image

Band	Influence That Each Band Gives to an Image
A	false contour (see Figure 6)
B	low frequency change (see Figure 7)
C	medium frequency change (see Figure 8)
D	high frequency change (see Figure 9)

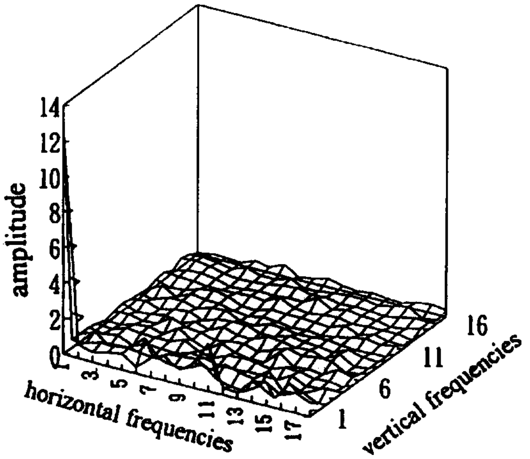


Figure 10. Result of 2-D FFT of the difference between original image and JPEG compressed image.

(2) Values of the band D (the higher frequency components) have only a secondary importance. It is assumed that we human beings lose our visual sensitivity to image quality in high frequency (see Figure 9).

Usually it is difficult for us to design a quantization table to any color image. Accordingly, we propose that a quantization table is designed by utilizing the Fibonacci series. Fibonacci is a nickname for Leonardo da Pisa [5]. The Fibonacci numbers are defined by the following recurrence:

$$F_0 = 1,$$
$$F_1 = 1,$$
$$F_i = F_{i-1} + F_{i-2}, \qquad \text{for } i \geq 2.$$

Thus, each Fibonacci number is the sum of the two previous ones, yielding the sequence 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, ... The daisy's spiral ratio of 21:34 corresponds to two adjacent Fibonacci numbers, as do the pine cone's 5:8 and the pineapple's 8:13—and the same is true of many other plants with a spiral leaf-growth pattern. Fibonacci numbers, besides bearing a curious relationship to botany, also appear to exert a strange influence on art and architecture [6,7]. The ratio between any two adjacent Fibonacci numbers after 3 is about 1:1.6, and moreover, Fibonacci numbers are related to the golden ratio ϕ and to its conjugate ϕ^*, which are given by the following formulas:

$$\phi = \frac{1+\sqrt{5}}{2} = 1.61803\ldots,$$
$$\phi^* = \frac{1-\sqrt{5}}{2} = -0.61803\ldots.$$

Figure 11 shows the human visual sensitivity dependencies to luminance and chrominance intensities. It is recognized that the sensitivities are decaying from certain spatial frequencies. Fibonacci series appears often in natural phenomena and is related to beauty as stated above. The decaying rate of sensitivity versus spatial frequencies is roughly same rate of inverse of Fibonacci series (see Figure 12). The inverse value of quantization table is in proportion to reproducibility of original image. So, it is thought that the Fibonacci series application to JPEG quantization table is effective as one of application of the series.[8]

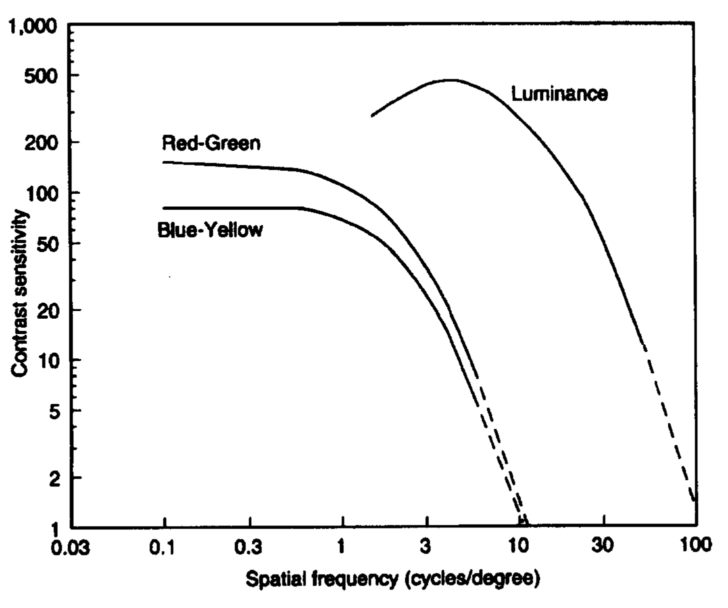


Figure 11. Sensitivity of human eye to luminance and chrominance intensity changes.

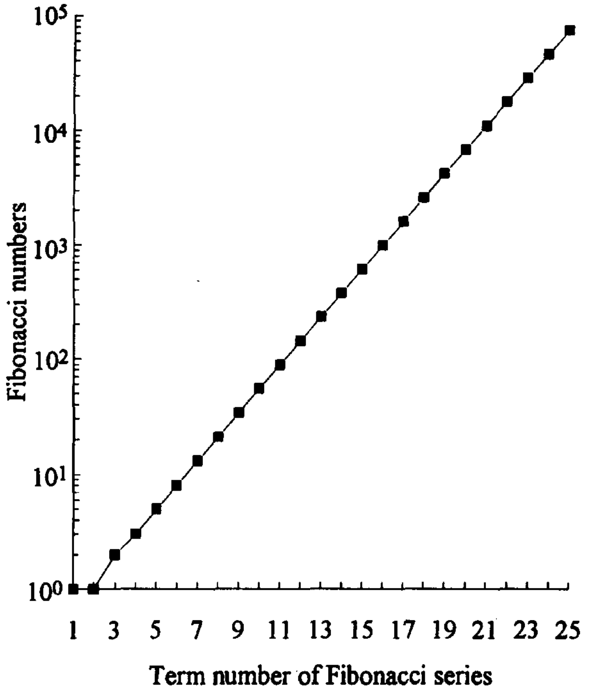


Figure 12. The relationship between Fibonacci numbers and its term numbers.

We use four bands (A, B, C, and D) in a quantization table valued respectively 13, 21, 34, and 89 and the availability of Fibonacci series is confirmed by preliminary application test. However, we feel there is still room for further study, for example, the next step of this study is improved by modulation of Fibonacci series according to the characteristics of images.

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