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Accelerating Compression Time of the Standard JPEG by Employing the Quantized YCbCr Color Space Algorithm

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ABSTRACT

In this paper, we propose a quantized YCbCr color space (QYCbCr) technique which is employed in standard JPEG. The objective of this work is to accelerate computational time of the standard JPEG image compression algorithm. This is a development of the standard JPEG which is named QYCBCr algorithm. It merges two processes i.e., YCbCr color space conversion and Q quantization in which in the standar JPEG they were performed separately. The merger forms a new single integrated process of color conversion which is employed prior to DCT process by subsequently eliminating the quantization process. The equation formula of QYCbCr color coversion is built based on the chrominance and luminance properties of the human visual system which derived from quatization matrices. Experiment results performed on images of different sizes show that the computational running time of QYCbCr algorithm gives 4 up to 8 times faster than JPEG standard, and also provides higher compression ratio and better image quality.

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1. INTRODUCTION

The development of image acquisition technology today continues to grow very rapidly resulting in excellent image quality. This gives a positive impact on users who need a good image quality, as well as a positive impact on the development of information technology and types of technologies such as biomedical, astronomical, remote sensing, and archaeological fields that mostly use the image as data to be studied. Image quality can be improved also followed by the large volume of data generated so that impacting the need for increased memory capacity. It also has an impact on the transmission speed at the time of image data exchange through a communication network. These impacts can be anticipated through the application of image compression algorithms in image acquisition technology devices such as cameras and videos. The image compression algorithm commonly used in this technology for image file storage is JPEG. JPEG is an algorithm type of Lossy compression (compression accompanied by the change in data), which is a compression technique by minimizing the number of bits (reducing value) through quantization process accompanied by rounding the result value [1]. Quality of compression can be maintain with the quantization process is carried out in a frequency domain such as DCT (Discreet Cosine Transform) which is applied in JPEG algorithm [2]-[4].

The two main processes in JPEG image compression are the DCT and quantization processes, where these two processes are performed separately and greatly determine the magnitude of ratio and quality of the compression image. Figure 1 shows the general scheme of a standard JPEG image compression model consisting of two parts: image compression in the top section and decompression in the bottom section [1].

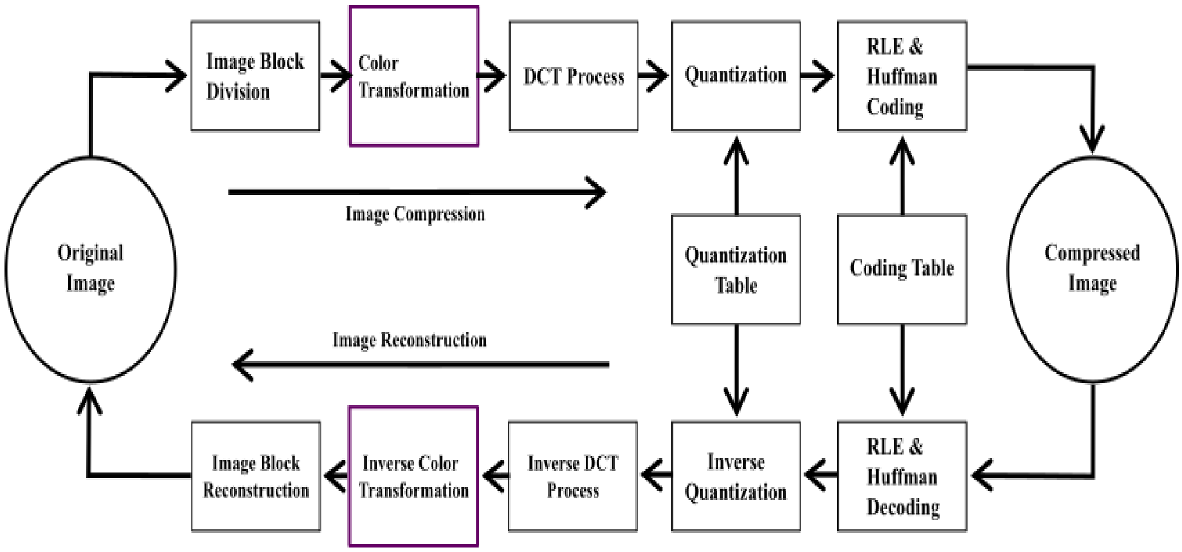

Figure 1. Standard JPEG image compression and decompression scheme

2. DCT AND QUANTIZATION PROCESSES ON STANDARD JPEG

This section deals specifically with the DCT and quantization processes that are directly related to the research proposals in this paper. Equation 1 denotes the DCT process, which converts image data from the spatial domain to the frequency domain, where [f] is the input of an image block of 8x8 pixels, [DCT] is the DCT matrix, $[DCT]^T$ is the transpose matrix of [DCT], and [F] is the result of the DCT process [5].

$$[F] = ([DCT] \,.\, [f]).[DCT]^T \qquad (1)$$

with:

$$[DCT] = \begin{bmatrix} 0.3536 & 0.3536 & 0.3536 & 0.3536 & 0.3536 & 0.3536 & 0.3536 & 0.3536 \\ 0.4904 & 0.4157 & 0.2778 & 0.0975 & -0.0975 & -0.2778 & -0.4157 & -0.4904 \\ 0.4619 & 0.1913 & -0.1913 & -0.4619 & -0.4619 & -0.1913 & 0.1913 & 0.4619 \\ 0.4157 & -0.0975 & -0.4904 & -0.2778 & 0.2778 & 0.4904 & 0.0975 & -0.4157 \\ 0.3536 & -0.3536 & -0.3536 & 0.3536 & 0.3536 & -0.3536 & -0.3536 & 0.3536 \\ 0.2778 & -0.4904 & 0.0975 & 0.4157 & -0.4157 & -0.0975 & 0.4904 & -0.2778 \\ 0.1913 & -0.4619 & 0.4619 & -0.1913 & -0.1913 & 0.4619 & -0.4619 & 0.1913 \\ 0.0975 & -0.2778 & 0.4157 & -0.4904 & 0.4904 & -0.4157 & 0.2778 & -0.0975 \end{bmatrix}$$

$$[DCT]^T = \begin{bmatrix} 0.3536 & 0.4904 & 0.4619 & 0.4157 & 0.3536 & 0.2778 & 0.1913 & 0.0975 \\ 0.3536 & 0.4157 & 0.1913 & -0.0975 & -0.3536 & -0.4904 & -0.4619 & -0.2778 \\ 0.3536 & 0.2778 & -0.1913 & -0.4904 & -0.3536 & 0.0975 & 0.4619 & 0.4157 \\ 0.3536 & 0.0975 & -0.4619 & -0.2778 & 0.3536 & 0.4157 & -0.1913 & -0.4904 \\ 0.3536 & -0.0975 & -0.4619 & 0.2778 & 0.3536 & -0.4157 & -0.1913 & 0.4904 \\ 0.3536 & -0.2778 & -0.1913 & 0.4904 & -0.3536 & -0.0975 & 0.4619 & -0.4157 \\ 0.3536 & -0.4157 & 0.1913 & 0.0975 & -0.3536 & 0.4904 & -0.4619 & 0.2778 \\ 0.3536 & -0.4904 & 0.4619 & -0.4157 & 0.3536 & -0.2778 & 0.1913 & -0.0975 \end{bmatrix}$$

Furthermore, the values in the matrix [F] are quantized as shown by equation (2). Quantization is the process of dividing each element of the matrix F(n,m) against the element of the quantization matrix Q(n,m) [6] [7]. Figure 2 shows an example of DCT process result and followed by quantization process. We can see the result of the quantization process, the values in this matrix become smaller and a lot of redundant values, especially the value of 0. This allows the matrix values to be encoded with a smaller number of bits with the help of zig-zag coding and RLE-Huffman coding.

$$F^Q(n,m) = round\left(\frac{F(n,m)}{Q(n,m)}\right) \quad (2)$$

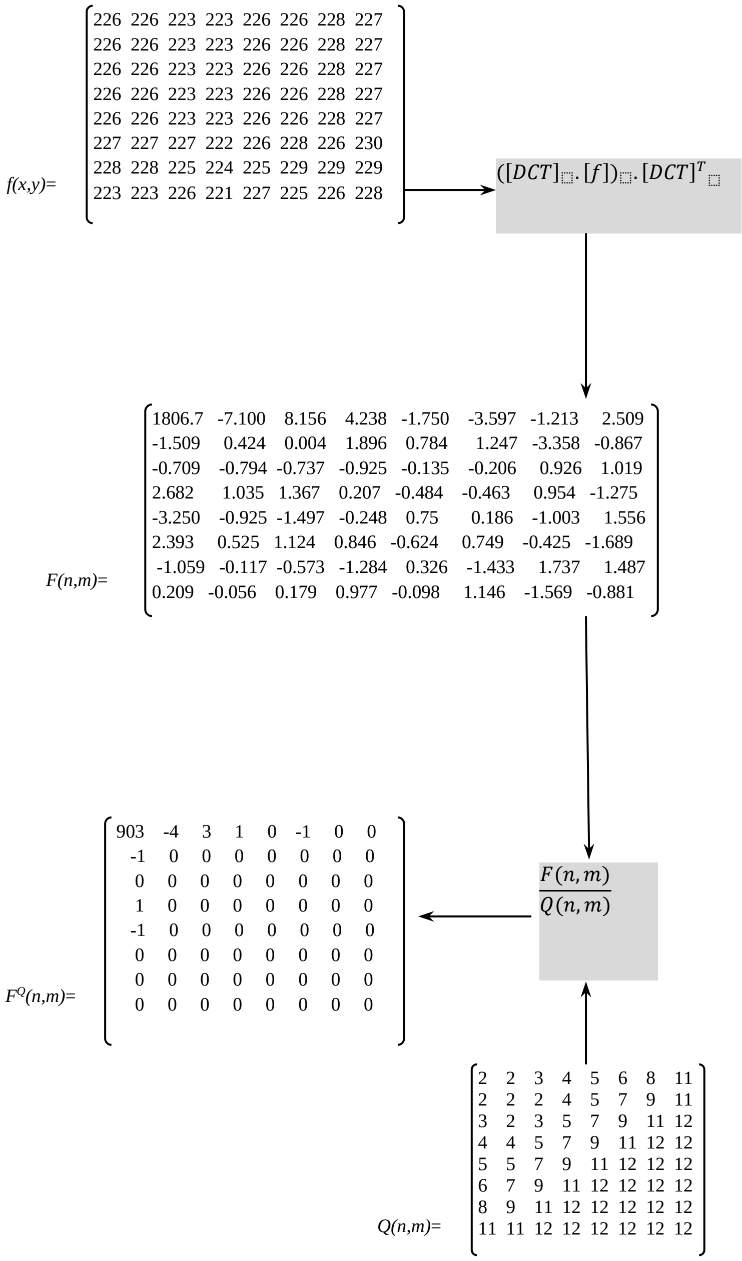

Figure 2. Example of DCT and quantization process

In the decompression process, to return the matrix $F^Q(n,m)$ to its initial data $f(n,m)$, then the inverse process must be done. This process is carried out by equations (3) and (4), which is preceded by the dequantization process and followed by the inverse DCT process. Here $[iDCT]=[DCT]^T$ and $[iDCT]^T=[DCT]$. Example invers process: iDCT and dequantization as shown in Figure 3.

$$F(n,m) = F^Q(n,m).Q(n,m) \quad (3)$$

$$[f] = ([iDCT] \,.\, [F]).[iDCT]^T \quad (4)$$

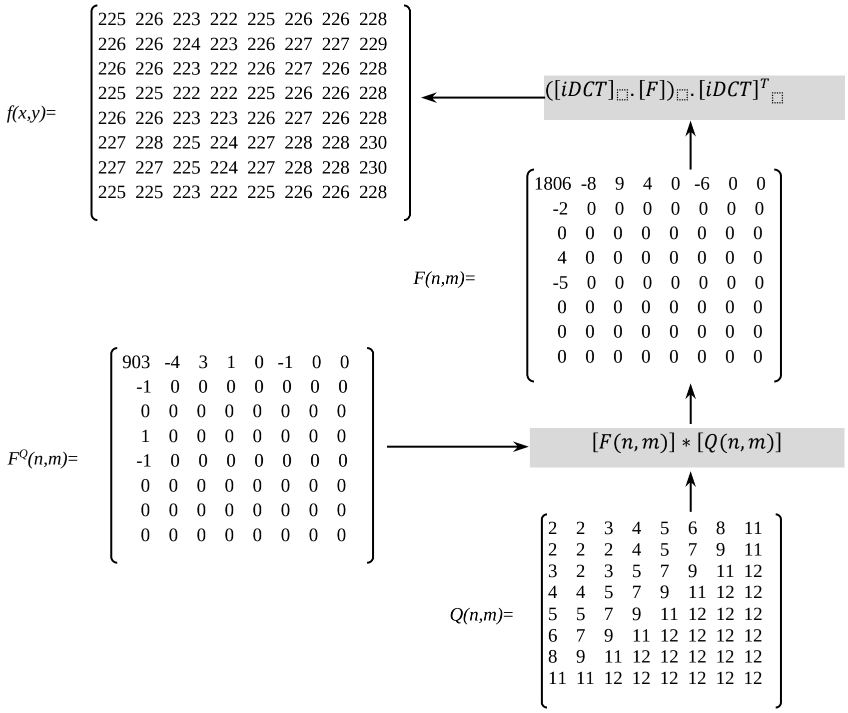

Figure 3. Example Invers Process: iDCT & Dequantization

3. PROPOSED METHOD

In Equation 2, the quantization process of a matrix having 8×8 elements requires 64 divisions and the dequantization process in Equation 3 needs 64 multiplications. This means for the image size of NxM pixels, NxM division and NxM multiplication are required [6]. This process is quite time consuming, so we need to find solutions on how to accelerate the compression and decompression processes. The algorithm of combining DCT and quantization processes to accelerate the compression and decompression processes of JPEG image has been studied previously in [8]-[11]. In this section, we propose solutions by using the YCbCr-quantized color space conversion model. The basic idea of this method is to use Q matrix that has a homogeny value, so that one constant value can express Q. Therefore, the quantization process can be carried out at the beginning along with the YCbCr color conversion process. [12]-[14]

In standard JPEG, the RGB to YCbCr color conversion is given by Equation 5 and from YCbCr to RGB given by Equation 6. Our proposed method is to integrate the Q quantization process into the YCbCr equation, so it is called YCbCr-quantized or QYCbCr. Equations 7 and 8 show the RGB to QYCbCr conversion process that we propose. The next question is what are the quantization values for the luminance component Y (Q_Y) and for the chrominance components Cb and Cr (Q_C)?

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.500 & -0.419 & 0.081 \\ -1.169 & -0.331 & 0.500 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0.0 & 1.402 \\ 1 & 1.772 & 0.0 \\ 1 & -0.344 & -0.741 \end{bmatrix} \begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} (0.299 & 0.587 & 0.114)/Q_Y \\ (0.500 & -0.419 & 0.081)/Q_C \\ (-1.169 & -0.331 & 0.500)/Q_C \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{7}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} (0.299 & 0.587 & 0.114)/Q_Y \\ (0.500 & -0.419 & 0.081)/Q_C \\ (-1.169 & -0.331 & 0.500)/Q_C \end{bmatrix}^{-1} \begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} \quad (8)$$

The JPEG standard compression always uses a chrominance quantization value greater than a luminance quantization value. This corresponds to the human visual system that is more sensitive to luminance change than small change of color or chrominance. Example, Photoshop software uses a different quantization matrix Q for photography and for web applications. For photography application, Photoshop CS uses 12 quantization matrices of Q_{12}, Q_{11}, ..., Q_1 resulting different compression ratio and image quality. Below are two examples of quantization matrices Q_{12} and Q_9, where Q_{iL} and Q_{iC} (i=1, 2, . . ., 12) are used to quantize the luminance and chrominance components, respectively.

$$Q_{12L}= \begin{pmatrix} 1 & 1 & 1 \\ & 1 & 1 \\ & 1 & 1 \\ & 2 & \\ 1 & 1 & 1 \\ & 1 & 1 \\ & 1 & 1 \\ & 2 & \\ 1 & 1 & 1 \end{pmatrix} \quad Q_{12C}= \begin{pmatrix} 1 & 1 & 1 \\ & 2 & 3 \\ & 3 & 3 \\ & 3 & \\ 1 & 1 & 1 \\ & 2 & 3 \\ & 3 & 3 \\ & 3 & \\ 1 & 1 & 2 \end{pmatrix}$$

$$Q_{12L} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 2 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 2 \\ 1 & 1 & 1 & 1 & 1 & 1 & 2 & 2 \\ 1 & 1 & 1 & 1 & 1 & 2 & 2 & 3 \\ 1 & 1 & 1 & 1 & 2 & 2 & 3 & 3 \\ 1 & 1 & 1 & 2 & 2 & 3 & 3 & 3 \\ 1 & 1 & 2 & 2 & 3 & 3 & 3 & 3 \\ 2 & 2 & 2 & 3 & 3 & 3 & 3 & 3 \end{bmatrix} \quad Q_{12C} = \begin{bmatrix} 1 & 1 & 1 & 2 & 3 & 3 & 3 & 3 \\ 1 & 1 & 1 & 2 & 3 & 3 & 3 & 3 \\ 1 & 1 & 2 & 3 & 3 & 3 & 3 & 3 \\ 2 & 2 & 3 & 3 & 3 & 3 & 3 & 3 \\ 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 \\ 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 \\ 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 \\ 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 \end{bmatrix}$$

$$Q_{9L} = \begin{bmatrix} 4 & 3 & 4 & 7 & 9 & 11 & 14 & 17 \\ 3 & 3 & 4 & 7 & 9 & 12 & 12 & 12 \\ 4 & 4 & 5 & 9 & 12 & 12 & 12 & 12 \\ 7 & 7 & 9 & 12 & 12 & 12 & 12 & 12 \\ 9 & 9 & 12 & 12 & 12 & 12 & 12 & 12 \\ 11 & 12 & 12 & 12 & 12 & 12 & 12 & 12 \\ 14 & 12 & 12 & 12 & 12 & 12 & 12 & 12 \\ 17 & 12 & 12 & 12 & 12 & 12 & 12 & 12 \end{bmatrix} \quad Q_{9C} = \begin{bmatrix} 4 & 6 & 12 & 22 & 20 & 20 & 17 & 17 \\ 6 & 8 & 12 & 14 & 14 & 12 & 12 & 12 \\ 12 & 12 & 14 & 14 & 12 & 12 & 12 & 12 \\ 22 & 14 & 14 & 12 & 12 & 12 & 12 & 12 \\ 20 & 14 & 12 & 12 & 12 & 12 & 12 & 12 \\ 20 & 12 & 12 & 12 & 12 & 12 & 12 & 12 \\ 17 & 12 & 12 & 12 & 12 & 12 & 12 & 12 \\ 17 & 12 & 12 & 12 & 12 & 12 & 12 & 12 \end{bmatrix}$$

Our approach, in obtaining a value of scalar quantization, is to calculate the average value of matrix Q_i by using Equations 9 and 10. Example for matrix Q_{12}, we obtaine two values of Q_L=1.7031 and Q_C=2.6719, while for matrix Q_9 we get Q_L=10.4375 and Q_C=12.9688. Furthermore for each Q_i used in Photoshop is calculated the values of Q_L and Q_C, and then embeded them to the Equations 7 and 8 to obtain the final formula of the QYCbCr color conversion and its inverse.

$$Q_L = \frac{1}{N^2}\sum_{j=1}^{N}\sum_{k=1}^{N} Q_{iL}(j,k) \quad (9)$$

$$Q_C = \frac{1}{N^2}\sum_{j=1}^{N}\sum_{k=1}^{N} Q_{iC}(j,k) \quad (10)$$

Our proposed method can replace standard JPEG compression scheme (in the Figure 1) with a new one as shown in the Figure 4. This scheme is simpler and faster because it has integrated the quantization process into the RGB to QYCbCr color space conversion process and also the dequantization process into the QYCbCr to RGB color space conversion process.

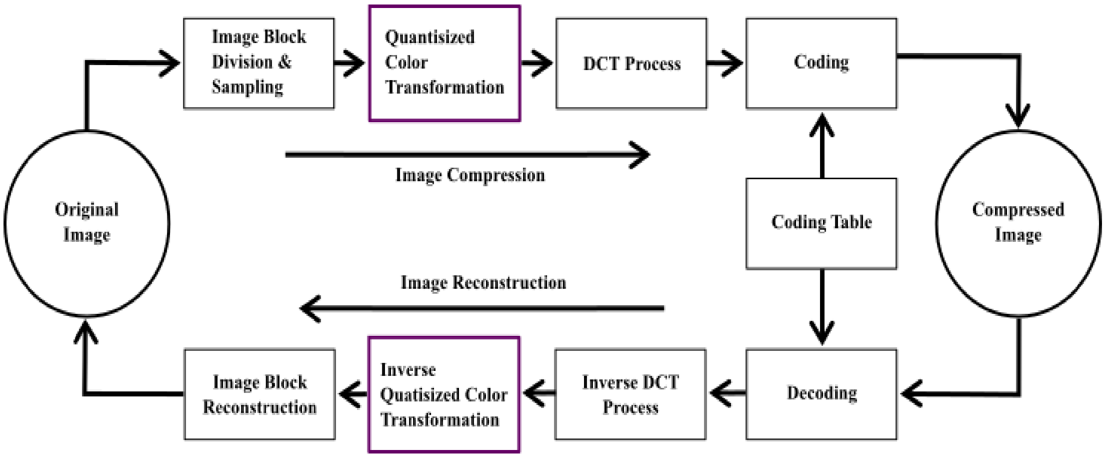

Figure 4. Our proposed method for new JPEG compression and decompression scheme

4. EXPERIMENT RESULTS

Our image compression and decompression algorithms have been implemented and tested in the Matlab programming language. The computer specifications used during the experiment has processor Dual Core i5, 1.8 GHz, 4 GB DDR3L RAM memory and 128 GB SSD. The performance of the developed method is evaluated by measuring its computational time, compression ratio and image quality and then we compare them with those obtained by standard JPEG. Table 1 shows *the performance* of standard JPEG algorithm and our algorithm in term of computational time.

The first column shows 10 test images with different size and containing different characteristics of color, shape and texture. The second and third columns show the computational time of the standard JPEG compression algorithm and the proposed compression algorithm, respectively. From this table, it can be seen that computational time using QYCbCr reaches 4 to 8 times faster than standard JPEG. Here, we can note that the computational time of image compression depends not only on its size but also on the diversity of its color, shape and texture. The more varied colors, shapes and / or textures contained in the image, the longer of the computation time is required.

Table 1. Computational Time of JPEG Standard and JPEG using QYCbCr

Image size (Mega Pixel)	JPEG standard (second)	JPEG using QYCbCr (second)
512x512=0.242	4.411367	1.080972
1000 x 483=0.483	4.803166	1.324323
700 x 800=0.560	6.735555	1.332675
1630 x 1480=2.412	8.684127	1.347561
2102 x 1587=3.336	7.720825	1.530887
2192 x 2020=4.428	8.830231	1.061667
4482 x 1210=5.423	7.468400	1.711763
3758 x 1907=7.167	6.298628	1.927591
6500 x 3637=23.641	7.604468	1.110361
6446 x 4096=26.403	14.439853	1.611074

Besides of computational time, we also measure the compression ratio and image quality resulting by the standard JPEG and our method. For this measurement, seven of quantization matrices from Photoshop CS: Q12, Q11, Q10, Q9, Q8, Q7, and Q6 are used, and just two of ten test images are presented. The first one is Lena image, has many areas with homogeneous colors, a little texture, but it has many shape variations. The second one is Baboon image has a heterogeneous color, shape and texture. The Compression ratio is calculated using equation (11) and the image quality is performed by measuring the peak signal to noise ratio (PSNR) as shown by equation (12). f is uncompressed image, f^i is compressed image, f_{ij} and $f^i{}_{ij}$ are pixel value of uncompressed and compressed image at position (i,j).

$$Compression\ Ratio = \frac{Uncompressed\ Image\ Data\ (bytes)}{Compressed\ Image\ Data\ (bytes)} \quad (11)$$

$$PSNR = 20.Log\left(\frac{255}{MSE}\right) \quad \text{with } MSE = \sqrt{\frac{1}{MxN}\sum_{i=1}^{N}\sum_{j=1}^{M}(f_{ij} - f^{i}{}_{ij})^2} \tag{12}$$

Tables 2 and 3 show the calculation results of compression ratio and image quality (PSNR) for two examples Lena and Baboon images respectively. Figure 5 shows the graph of PSNR (dB) against the compression ratio of Table 2, while Figure 6 is the graph for Table 3. The curve in blue line represents the performance of JPEG with QYCbCr algorithm and the red line curve corresponds to the performance of standard JPEG. On these two graphs, it appears that both the ratio and quality of JPEG compression using QYCbCr are also better than standard JPEG. Images with heterogeneous content have characteristics increased in ratio and quality of compression. That's matter are not too significant, but an increase in ratio and quality of compression become more significant for a more homogeneous image.

Table 2. The Compression Ratio and Image Quality of Lena

Photoshop CS Q-Matrix	JEPG standard		JEPG with proposed QYCbCr	
	PSNR (dB)	Compression Ratio	PSNR (dB)	Compression Ratio
12	46.1425	2.401	46.4944	2.5398
11	39.1108	4.5117	38.97	5.075
10	36.9341	7.4566	36.3781	9.0022
9	36.1172	9.4895	35.7291	11.0165
8	35.3956	11.1696	35.2282	12.985
7	35.3653	11.5038	35.146	13.1047
6	34.5445	13.027	34.7052	15.2815

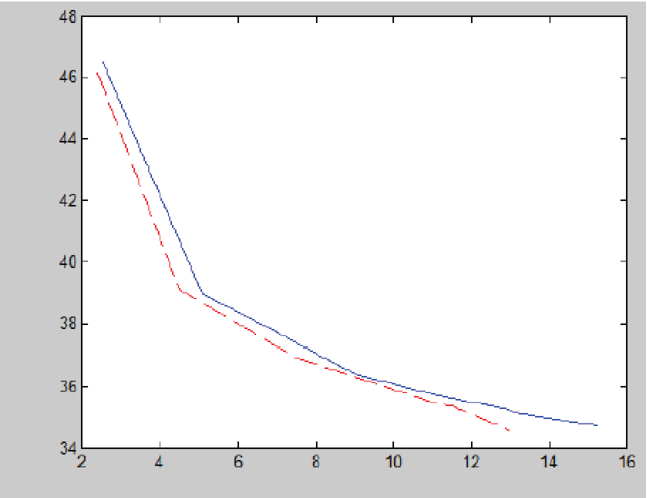

Figure 5. Curves of PSNR vs. Compression Ratio of Lena's Image

Table 3. The Compression Ratio and Image Quality of Baboon's Image

Photoshop CS Q-Matrix	JEPG standard		JEPG using QYCbCr	
	PSNR (dB)	Compression Ratio	PSNR (dB)	Compression Ratio
12	46.1021	1.5344	46.4812	1.6066
11	37.6955	2.3282	38.0211	2.5357
10	33.8144	3.1437	34.0166	3.4111
9	32.8049	3.5543	32.9975	3.7544
8	32.0501	3.8570	32.2617	4.0147
7	31.9122	3.8720	32.2215	4.059
6	30.9142	4.1529	31.4006	4.4114

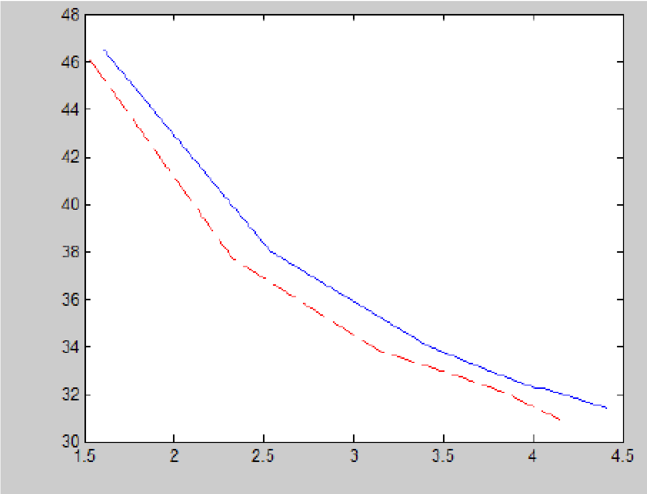

Figure 6. Curves of PSNR vs. Compression Ratio of Baboon's Image

5. CONCLUSION

One of the problem of the JPEG algorithm lies in the scheme (architecture) design of its development in order to get optimum of computation time, ratio and quality of the compression images. In this our study, the QYCbCr algorithm is proposed as one of development of Standard JPEG in which it merges two processes i.e., YCbCr and quantization in JPEG Standard forming one integrated process of color conversion derived from the chrominance and luminance quantization matrices. Experimental results that performed on the processor Dual Core i5, 1.8 GHz, 4 GB DDR3L RAM memory and 128 GB SSD using 10 test images with different size which are respectively containing different characteristics of color, shape and texture, show that the QYbCr algorithm has computational time 4 up to 8 times faster than standard JPEG algorithm. In addition, this method also provides better compression ratio and image quality. The future work, to obtain more efficient running time, the study can be develop by investigating the low level architecture of how QYCbCr algorithms are computed through hardware design.

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