An Improved JPEG Image Compression Algorithm by Modifying Luminance Quantization Table

Lamia Alam1, Pranab Kumar Dhar1*, Mirza A. F. M. Rashidul Hasan2, Mohammed Golam Sarwar Bhuyan3, and Golam Moktader Daiyan4

1Department of Computer Science and Engineering, Chittagong University of Engineering and Technology (CUET), Chittagong-4349, Bangladesh
2Department of Information and Communication Engineering, University of Rajshahi, Rajshahi, Bangladesh
3Department of Computer Science and Engineering, Model Institute of Science and Technology, Bangladesh
4Department of Computer Science and Engineering, East Delta University, Chittagong, Bangladesh

Summary
JPEG has been widely used for lossy image compression. In this paper, we introduce an improved JPEG compression algorithm by modifying the luminance quantization table for color image. Quantization step plays an important role in JPEG compression process. The default quantization table (8x8) depends upon two components named luminance and chrominance of image. Human visual system cannot recognize the slight modification in luminance table slightly. We modify the 8x8 default luminance quantization table. In order to evaluate the performance of modified JPEG algorithm, we have used different color images such as Lena, Baboon, Brick-house and Pepper. The performance of modified JPEG is assessed in terms of compression ratio (CR), mean square error (MSE) and peak signal to noise ratio (PSNR). Experimental results indicate that the performance of modified quantization outperforms the standard quantization in terms of CR, MSE, and PSNR. We observed that CR, MSE and PSNR values of proposed JPEG for different image range from 9.9 to 47, 9.47 to 452, and 21.6 to 38.4 respectively, in contrast to conventional JPEG whose values range from 7 to 25, 18.3 to 927, and 18.5 to 35.5 respectively. This is because the quantization table is modified in a way so that only the lowest frequency DCT coefficients have significant amplitude values.
Key words:
JPEG; image compression; luminance quantization table; compression ratio; mean square error; peak signal-to-noise ratio

1. Introduction

Image compression means minimizing the size in bytes of a graphics file without degrading the quality of the image to an unacceptable level. The reduction in file size allows more images to be stored in a given amount of memory space. It also reduces the time required for image to send over the internet or downloaded from web pages. Many compression algorithms have been found in literatures which are either "lossless" or "lossy". Joint Photographic Experts Group (JPEG) is a very popular image compression technique. The JPEG algorithm takes advantage of the fact that humans can't see colors at high frequencies. These high frequencies are the data points in the image that are eliminated during the compression [1].

A sequence of steps is involved in the JPEG image compression algorithm in which quantization process plays a major role in the image compression process. The Quantization table used in quantization process decides the quality of the encoded image and also controls the amount by which image should be compressed [2]. It is found that quantization table provides DC coefficients that are used in image compression. The default quantization table (8x8) depends upon two components named luminance and chrominance of image. Considering that the distribution for different coefficients is not the same, in JPEG different quantization tables for the Luminance and Chrominance is used. These quantization tables give us a fixed relation across different coefficients. Although there is a standard quantization table recommended by JPEG standard, the quantization table can be arbitrarily defined. In this paper, we introduce a modified luminance quantization table for JPEG.

2. Related Research

For the past few decades, numerous researches have been conducted to generate optimal Quantization table for a given image. Rate distorting method was applied to design the quantization table for black and white images and improvement in PSNR value was observed by Wu and Gersho [3].

(a) DCT-Based Encoder Processing Steps
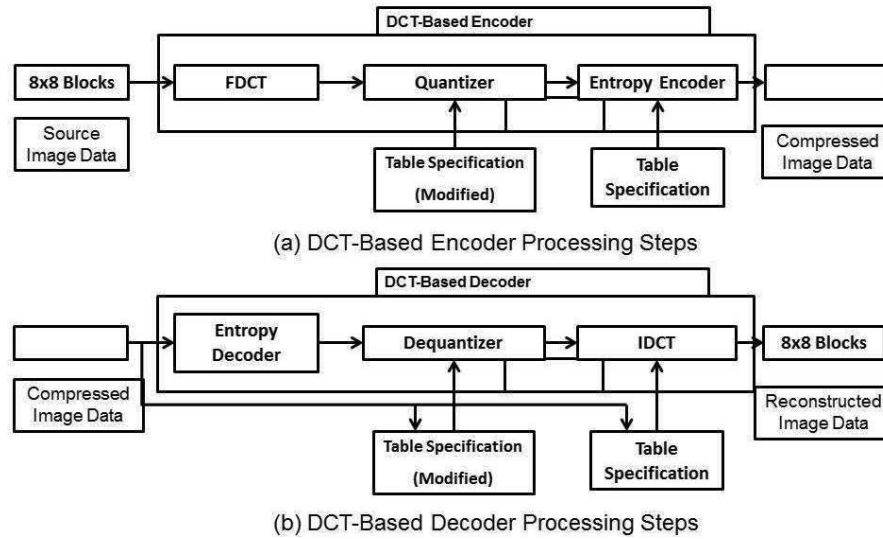
(b) DCT-Based Decoder Processing Steps

Fig 1. Sequence of stages involved in JPEG image compression algorithm

In their work, Peterson et. al used human visual system model to generate quantization table for the JPEG baseline algorithm known as Image-Independent Perceptual approach (IIP) and had several drawbacks [4, 5]. Jiang and Pattichis used perceptual image quality assessment to optimize the quantization table (QT) for JPEG compression. To generate globally optimal quantization tables, optimization algorithm called Simulated Annealing was used [6]. Abu, Ernawan and Suryana investigated a psycho visual error threshold on the gray scale image using discrete cosine transform (DCT) frequency and generated new quantization table by setting the certain threshold to the psycho visual error [7]. Tuba and Bacanin introduced firefly algorithm to determine the optimal quantization table for different image [8]. Kumar and Karpagam proposed knowledge based genetic algorithm (KBGA) to find optimal quantization table [9]. Image characteristics and knowledge about image compressibility are combined with classical genetic algorithm (CGA) operators in KBGA. Customized JPEG quantization matrices for compressing iris polar images to positively impact the recognition performance is discussed in the work of Konrad, Stogner and Uhl [10]. They applied a genetic algorithm to obtain specialized matrices for destined compression ratio. In their work Sanki, Biswas and Sarkar proposed a modified quantization table for better image quality and the compressed cover image was used to hide a secret image [11]. Here, genetic Algorithm (GA) was implemented to modify the quantization table. A novel stenographic method based on JPEG was proposed by Chang, Cheng and Chung [12]. The proposed method modifies the quantization table first, and then the secret message is embedded in the middle-frequency part of the

quantized DCT coefficients. Another method described by Mitra, Dhar and Saha which utilizes modified quantization table in stenography. At first, they create modified default (8x8) quantization table from default 8X8 traditional JPEG quantization table and then by using the table they tried to modify embedding as well as extracting algorithm in frequency domain steganography [13].

In contrast to these methods discussed earlier, our modified quantization is able to increase image quality by decreasing mean square error (MSE) in frequency domain and also by increasing compression ratio (CR) as well as peak signal-to-noise ratio (PSNR) of compressed image.

3. Proposed Method

The JPEG compression scheme is divided into several stages and Fig. 1 represents block diagram of JPEG compression [14]. The stages we implemented and modified in our work are described briefly in following subsection.

3.1 DCT-Based Encoder

3.1.1. Import Image

We have used nine color images (Lena, Baboon, Fruits, Brick-house, Morach, Tulips, Pepper, Pool, and Watch). Details of used images are given in Table 1.

Table 1. Original Input Image Details

File Name	Type of File	Dimensions	Size (bytes)
Lena.tiff	TIFF File	512X512	786572

Baboon.tiff	TIFF File	512X512	786572
Fruits.tiff	TIFF File	512X512	573514
Brick-house.png	PNG File	512X512	403424
Morach.png	PNG File	512X512	499079
Tulips.png	PNG File	512X512	558886
Pepper.jpg	JPG File	512X512	374329
Pool.jpg	JPG File	512X512	18373
Watch.jpg	JPG File	512X512	46212

3.1. 2. RGB to YCbCr Color Space Conversion

In order to reduce the amount of information stored in the image, JPEG compression uses the fact that the human eye interprets spatial and acuity content better than color, so it converts the RGB representation of an image to Luminance (Y) and Chrominance (Cb & Cr) components. The transformation from RGB to YCbCr is given in equation (1).

$$[Y\ Cb\ Cr] = [R\ G\ B] \begin{bmatrix} 0.299 & -0.168935 & 0.499813 \\ 0.587 & -0.331665 & -0.418531 \\ 0.114 & 0.50059 & -0.081282 \end{bmatrix} \quad (1)$$

3.1.3. Subsampling of the Chrominance Components

Once the image has been transformed to this color space, and taking advantage of the fact that humans do not perceive changes in chrominance very effectively, JPEG can subsample the Cb and Cr components. JPEG usually removes every other horizontal and vertical lines of pixels, resulting in subtracting ¾ of the information for each one of these components, or in other words, half the information in the image.

3.1.4. Block preparation

In pixel form, the image is made up of one or more 2D matrices of values. In this step, the total matrix is divided into a set of smaller 8X8 sub matrices each of which is known as block.

3.1.5. DCT

In this step a DCT is applied to each block of pixel, thus removing redundant image data. Formula used for DCT is given in equation (2).

$$F_{u,v} = \frac{C(u)C(v)}{4} \sum_{x=0}^{7} \sum_{y=0}^{7} f(x,y) cos\frac{(2x+1)u\pi}{16} cos\frac{(2x+1)v\pi}{16}$$

$$(2)$$

where, $C(w) = \begin{cases} \frac{1}{\sqrt{2}} & : for\ w = 0 \\ 1 & : for\ w = 1,2,\dots\dots.7 \end{cases}$, u and v are the horizontal spatial frequency and vertical spatial frequency respectively, for the integers $0 \leq u < 8$, $f(x,y)$ is the pixel value at coordinates (x,y) and $f_{u,v}$ is the DCT coefficient at coordinates (u,v).

In order to reduce the size of the DC coefficient, JPEG subtracts 128 to all the pixel values in the image before transforming to the frequency domain (this is equivalent to subtracting 1024 to the DC value).

3.1.6. Quantization

To improve the quality of compressed image quantization table is used. It is found that quantization table provides DC coefficients that are used in image compression. The JPEG committee created different quantization tables for the Luminance and Chrominance components which are given in Table 2 and Table 3 respectively. These quantization tables give us a fixed relation across different coefficients. However, generally luminance property changes because minor change in this component is not visible in normal eyes. For this reason, in this work we intended to modify the standard luminance quantization table.

Table 2. Standard Luminance Quantization Table

16	11	10	16	24	40	51	60
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

Table 3. Standard Chrominance Quantization Table

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

Our proposed quantization table has some modification applied on default (8X8) quantization table. Therefore, by changing the values that is present in default quantization table, quality and other parameters of images are controlled. For this process, the quantization table was partitioned into four bands by frequency. Subsequently, each value in each band was changed and then the quality of image was examined. As a result, it was found that the DC coefficient has an important effect on the image quality while the higher frequency coefficients have only a secondary importance.

Steps to create modified quantization table:

Step-1: Calculate the value of a.[a=(Total no of column/2), for 8X8 table a=8/2=4]

Step-2: for 0<=i<a where i stands for row in Standard Luminance quantization table

　　　　for 0<= j-i<a where j stands for column in Standard Luminance quantization table

if the frequency value i.e. "n" of each cell(i, j) in default quantization table is even
> **then** the value n/2 is placed on same cell in proposed modified quantization table

otherwise the value (n+1)/2 is placed.

End **if**
End **for**
End **for**

Step-3: For remaining cell, the value of frequency is set into 1 till end in 8X8 table.

By executing above sequential steps we generated a table. After placing the numeric value of default quantization table (Table 2), the modified table (Table 4) is obtained.

Table 4. Modified JPEG quantization table

8	6	5	8	1	1	1	1
6	6	7	1	1	1	1	1
7	7	1	1	1	1	1	1
7	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1

The 8x8 quantized DCT coefficients are calculated by the Equation (3), where scale factor defines how much of the information we discard, resulting for a higher factor in higher compression but less image quality.

$$DCT_{quantized} = round\left(\frac{DCT_{coefficient}}{\frac{Q.Sacle_{factor}}{100}}\right) \tag{3}$$

The scale factor is calculated with the formula given in equation (4).

$$Sacle\ factor = \begin{cases} \frac{5000}{QF} & if\ QF \geq 50 \\ 200 - 2QF & if\ QF < 50 \end{cases} \tag{4}$$

Where $0 < QF < 100$

The Quality Factor (QF) is defined by the user and, as we can see from the formula above, ranges from 0 to 100 giving 100 the maximum quality and 0 the minimum. A very common Quality factor is 75.

3.1.7. Encoding

Encode the resulting data using a Huffman variable word length algorithm to remove redundancies in the coefficients.

3.2. DCT-Based Decoder

At the decoder reverse process takes place as shown in Fig. 1. IDCT is used to reconstruct the image. MATLAB Code is used for implementing the compression and decompression steps.

4. Experimental Results and Performance

JPEG image compression and decompression is implemented using MATLAB. There are various performance measures that are calculated are Peak Signal to Noise Ratio (PSNR), Compression Ratio (CR) and Mean Square Error (MSE). Meaning of the above performance measures is as follows:

- Compression Ratio (CR): Compression ratio is the number of bits required to represent the image before compression to the number of bits required to represent the image after compression. i. e.

$$CR = \frac{Number\ of\ Bits\ for\ Original\ Image}{Number\ of\ Bits\ for\ Compressed\ Image} \tag{5}$$

- Mean Square Error (MSE): In statistics, the mean square error or MSE of an estimator is one of many ways to quantify the difference between an estimator and the true value of the quantity being estimated. MSE measures the average of the square of the error. i.e.

$$MSE = \frac{1}{N^2}\sum_{i=1}^{n}\sum_{j=1}^{n}[f(i,j) - \dot{f}(i,j)] \tag{6}$$

Where

- $f(i,j)$ is the pixel value of original image at coordinates (i,j)
- $\dot{f}(i,j)$ is the pixel value of reconstructed image at coordinates (i,j)
- $(N \times N)$ size of original and reconstructed image
- Peak Signal –to –Noise Ratio (PSNR): The PSNR is most commonly used as a measure of quality of reconstruction of lossy compression (e.g., for image compression). The signal in this case is the original data, and the noise is the error introduced by compression. i.e.

$$PSNR = 20\log_{10}(\frac{255}{RMSE}) \tag{7}$$

where $RSME = \sqrt{MSE}$.

In order to investigate the impact of modified quantization matrix on the performance of JPEG, we compared the output generated from our proposed system with the output found from using standard quantization matrix for various users defined Quality Factor (QF) for four images of various file types described in Table 1. Fig 2 illustrates the output. Table 5 summarizes the result. The experimental results show that for various QF, the compression ratio has improved using proposed quantization table. We observed that for 'Lena' image CR, MSE and PSNR values of proposed JPEG range from 20 to 27, 27.6 to 292, and 22.4 to 32.1 respectively, in contrast to conventional JPEG whose CR, MSE and PSNR values range from 15 to 25, 50.3 to 428, and 20.7 to 29.8 respectively.
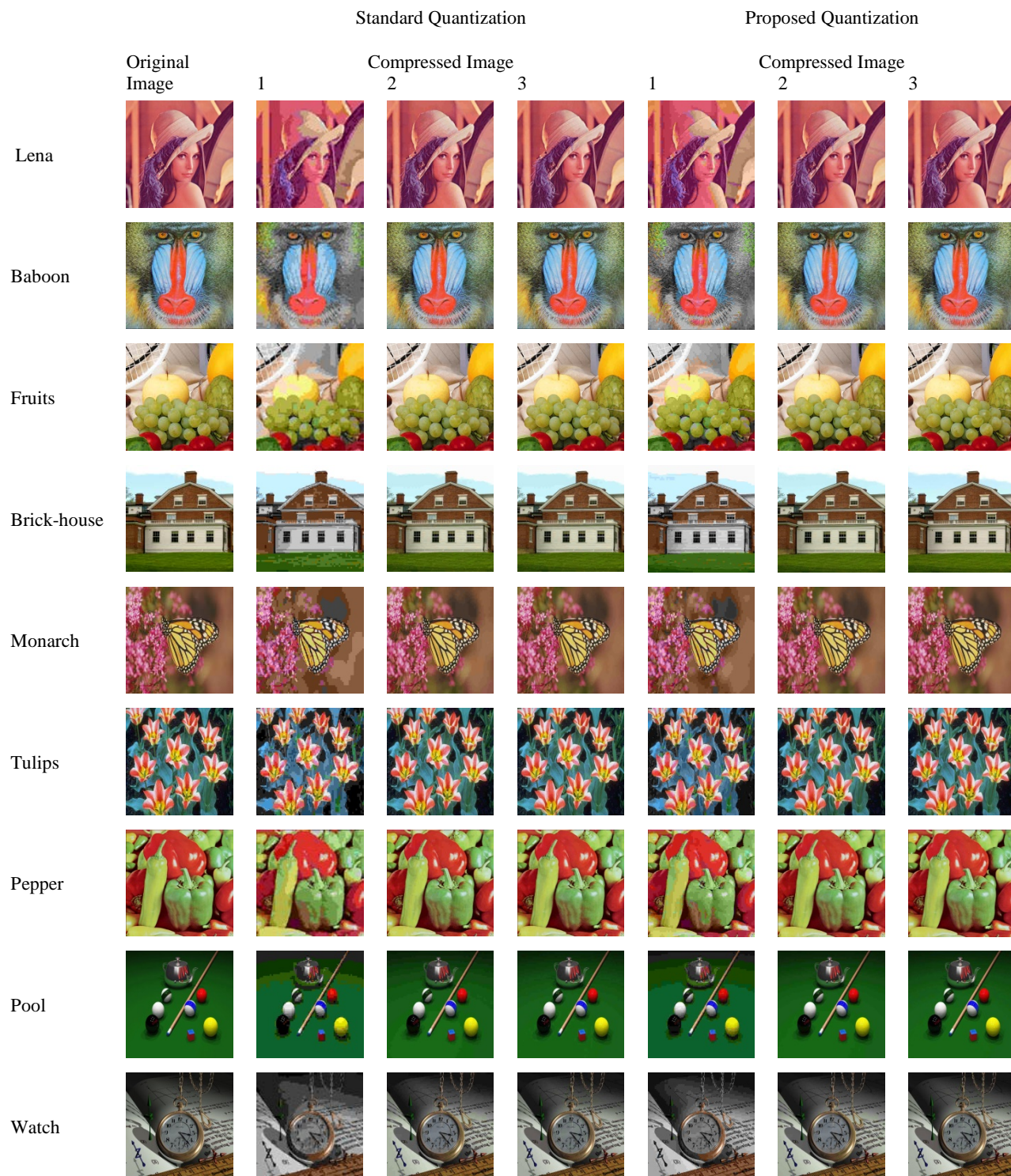
Fig 2. Outputs of both Standard and Proposed Quantization

Similarly for the 'Baboon' image CR, MSE and PSNR values of proposed JPEG range from 9.9 to 11, 113 to 452, and 21.6 to 27.6 respectively, whereas CR, MSE and PSNR values of conventional JPEG range from 7 to 11,

262 to 927, and 18.5 to 24 respectively. For 'Fruits' image CR, MSE and PSNR values of proposed JPEG range from 17 to 22,24.1.5 to 270, and 28.8 to 34.3 respectively, in contrast to conventional JPEG whose CR, MSE and PSNR values range from 13 to 20, 57.9 to 428, and 21.9 to 30.1 respectively. For 'Brick-house' image CR, MSE and PSNR values of proposed JPEG range from 17 to 19, 16.5 to 18, and 25.5 to 36.1 respectively, in contrast to conventional JPEG whose CR, MSE and PSNR values range from 10 to 16, 63.7 to 428, and 21.9 to 30.1 respectively. For 'Monarch' image CR, MSE and PSNR values of proposed JPEG range from 19 to 22, 20 to 262, and 24 to 35.1 respectively, in contrast to conventional JPEG whose CR, MSE and PSNR values range from 14 to 19, 67.2 to 480, and 21.4 to 30.6 respectively. For 'Tulips' image CR, MSE and PSNR values of proposed JPEG range from 14 to 15, 29.1 to 50.7, and 22.2 to 33.5 respectively, in contrast to conventional JPEG whose CR, MSE and PSNR values range from 9 to 11, 69.6 to 616, and 20.3 to 29.1 respectively. For 'Pepper' image CR, MSE and PSNR values of proposed JPEG range from 18 to 24, 50.4 to 327, and 23 to 31.1 respectively, in contrast to conventional JPEG whose CR,MSE and PSNR values range from 12 to 23, 74.3 to 461, and 21.5 to 29.5 respectively. For 'Pool' image CR, MSE and PSNR values of proposed JPEG range from 41 to 51, 9.47 to 231, and 24.5 to 38.4 respectively, in contrast to conventional JPEG whose CR, MSE and PSNR values range from 11 to 18, 18.3 to 306, and 23.3 to 35.5 respectively. Finally, for 'Watch' image CR, MSE and PSNR values of proposed JPEG range from 17 to 19, 9.47 to 132, and 27 to 38.4 respectively, in contrast to conventional JPEG whose CR, MSE and PSNR values range from 11 to 17, 71 to 446,

and 21.7 to 29.7 respectively. It also indicates that PSNR of proposed quantization table greater than PSNR of default quantization table and MSE of proposed quantization table less than MSE of default quantization table. Fig 3 compares the performance of standard JPEG and the proposed method in terms of CR, MSE and PSNR for various QF for these images.

Table 5. Summarized result

| Image	Compressed Image	QF	Standard Quantization			Proposed Quantization		
			CR	MSE	PSNR (db)	CR	MSE	PSNR (db)
Lena	1.	3	25	428	21.9	27	292	23.5
	2.	15	15	71.7	29.6	23	38.6	32.3
	3.	25	17	50.3	31.1	20	27.6	33.8
Baboon	1.	3	11	927	18.5	11	452	21.6
	2.	15	9	337	22.9	10	134	26.9
	3.	25	7	262	24	9.9	113	27.6
Fruits	1.	3	20	428	21.9	22	270	28.8
	2.	15	15	85	28.9	19	37.3	32.4
	3.	25	13	57.9	30.5	17	24.1	34.3
Brick-house	1.	3	16	428	21.9	19	187	25.4
	2.	15	14	95.6	28.4	18	24.7	34.2
	3.	25	10	63.7	30.1	17	16.5	36
Monarch	1.	3	19	480	21.4	22	262	24
	2.	15	17	91.5	28.6	20	36.4	32.6
	3.	25	14	57.2	30.6	19	20.2	35.1
Tulips	1.	3	11	616	20.3	15	393	22.2
	2.	15	10	111	27.7	14	50.7	31.1
	3.	25	9	69.6	29.7	14	29.1	33.5
Pepper	1.	3	23	461	21.5	24	327	23
	2.	15	15	102	28.1	20	68.7	29.8
	3.	25	12	74.3	29.5	18	50.4	31.1
Pool	1.	3	18	306	23.3	51	231	24.5
	2.	15	14	32.1	33.1	47	18.3	35.5
	3.	25	11	18.3	35.5	41	9.47	38.4
Watch	1.	3	17	446	21.7	19	132	27
	2.	15	15	108	27.8	18	17.6	35.7
	3.	25	11	71	29.7	17	9.47	38.4
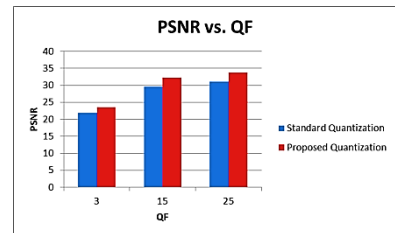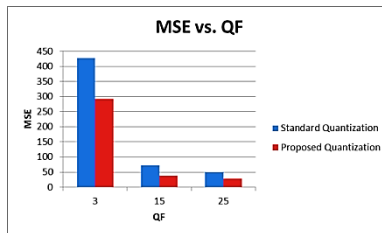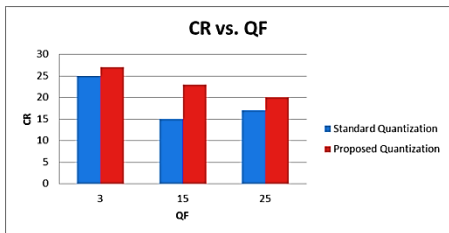
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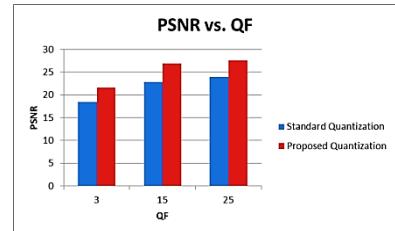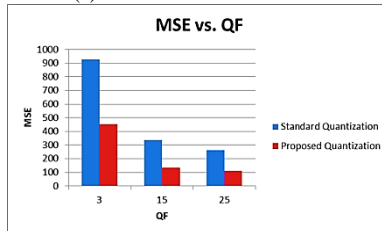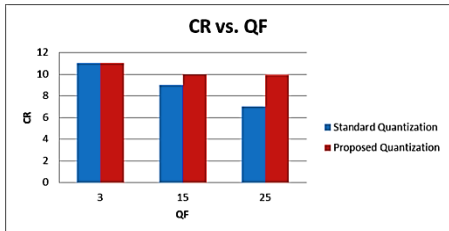
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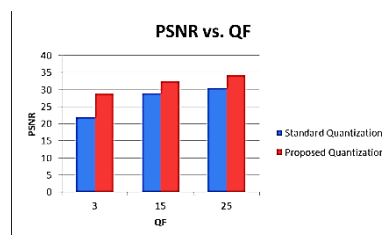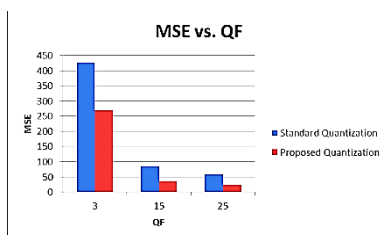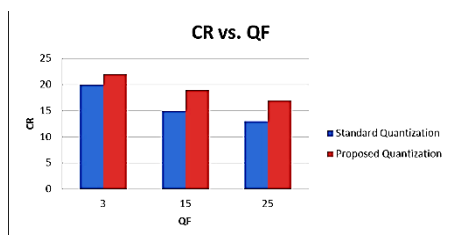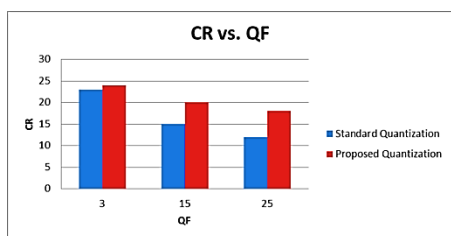
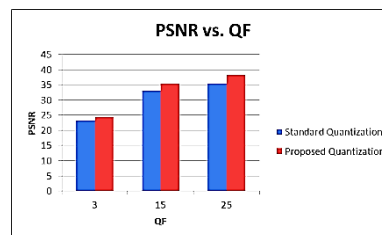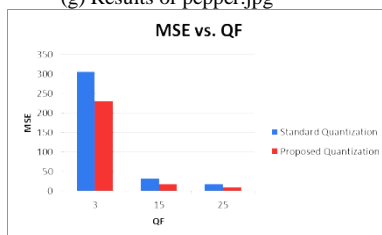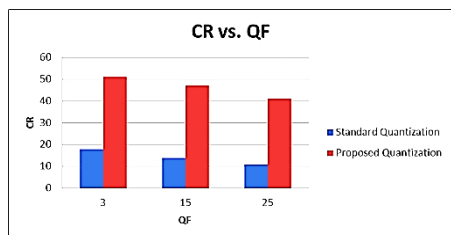(c)Results of fruits.tiff
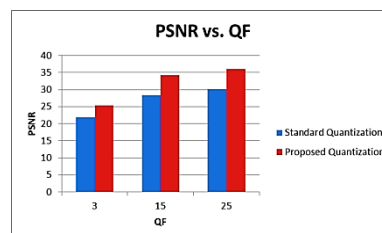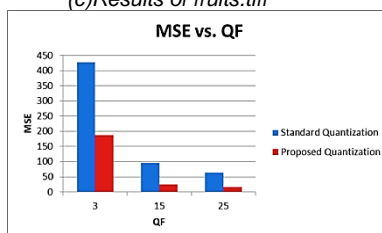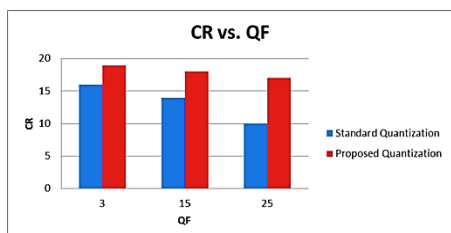
(d) Results of brick-house.png
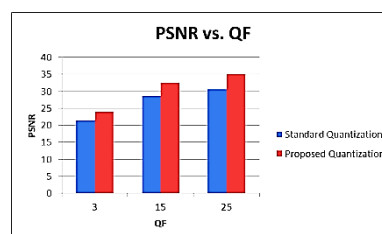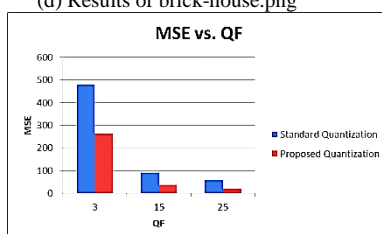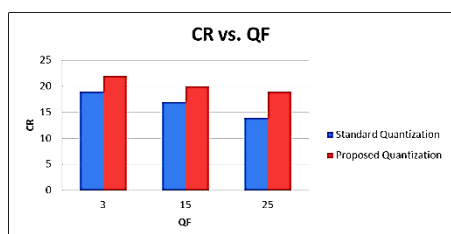
(e) Results of monarch.png
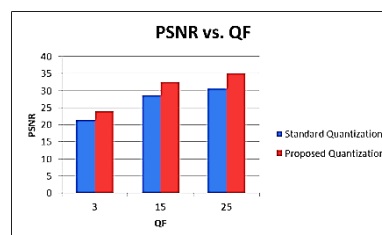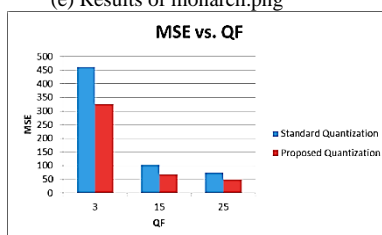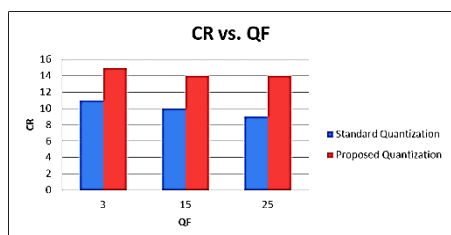
(f) Results of tulips.png
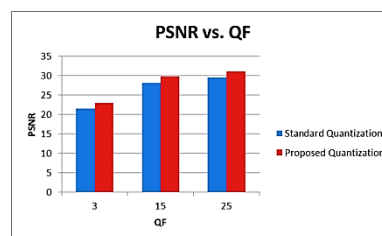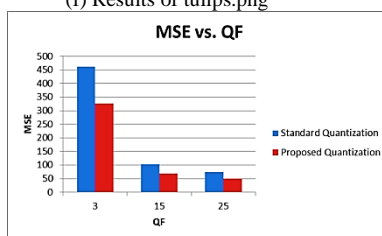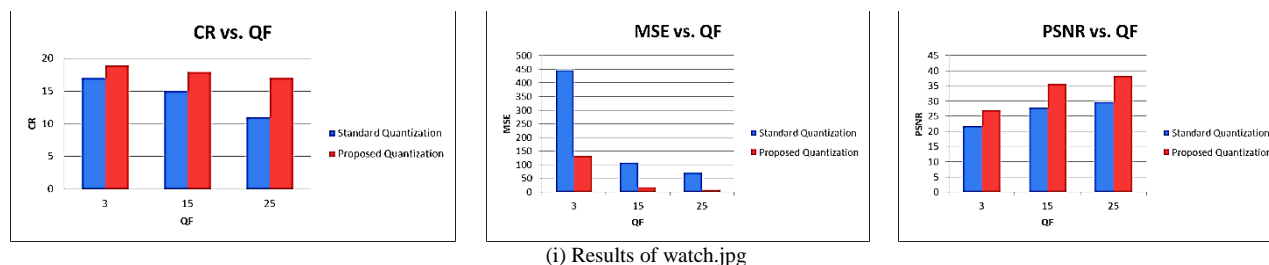

(g) Results of pepper.jpg

(h) Results of pool.jpg`

(i) Results of watch.jpg

Fig 3. Evaluation Results for Various Images in Terms of CR, MSE and PSNR for Different QF

5. Conclusion

In this paper, we proposed an improved JPEG compression algorithm for color image. We mainly focused on the improvement of compressed image quality by modifying luminance quantization table in frequency domain. Here, we calculated different evaluation parameters such as PSNR, MSE and CR for both default 8X8 quantization table and the proposed modified table. Simulation results demonstrate that the proposed method is able to increase the image quality by decreasing MSE and also increasing CR as well as PSNR of compressed imaged. These results verify that the proposed method can be a suitable candidate for image compression

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Lamia Alam received her B.Sc. degree in Computer Science and Engineering from Chittagong University of Engineering and Technology (CUET), Chittagong, Bangladesh in 2014. Currently she is working as a Lecturer in the Department of Computer Science & Engineering (CSE) at Chittagong University of Engineering & Technology (CUET), Chittagong, Bangladesh. Her research interests include Human-Computer Interaction, Digital Image Processing, Multimedia Data Compression, and Digital Watermarking.

Pranab Kumar Dhar received the Bachelor of Science (B.Sc.) Degree in Computer Science and Engineering from Chittagong University of Engineering and Technology (CUET), Chittagong, Bangladesh in 2004. He received the Master of Science (M.Sc.) Degree from the School of Computer Engineering and Information Technology, University of Ulsan, South Korea in 2010. He received his Ph.D Degree from Graduate School of Science and Engineering, Saitama University, Saitama, Japan in 2014. In 2005, he joined as a Lecturer in the Department of Computer Science and Engineering, Chittagong University of Engineering and Technology (CUET), Chittagong, Bangladesh where he is currently serving as an Associate Professor. His research interest includes Multimedia Security, Digital Watermarking, Multimedia Data Compression, Sound Synthesis, Digital Image Processing, and Digital Signal Processing.

Mirza A. F. M. Rashidul Hasan received the B. Sc. (Hons), M. Sc. and M. Phil. Degrees in Applied Physics and Electronic Engineering from University of Rajshahi, Bangladesh in 1992, 1993, and 2001, respectively. In 2006, he joined University of Rajshahi, Rajshahi, Bangladesh as a faculty member, where he is currently serving as an Associate Professor in the Department of Information and Communication Engineering. He was a visiting researcher at Waseda University, Japan from 2003 to 2004 and as a junior fellow of IWMI from 2006 to 2007. He received his Ph. D. degree in 2009 from the faculty of Applied Science and Technology, Islamic University, Kushtia, Bangladesh and also received his D. Engg. degree in 2012 from the Graduate School of Science and Engineering, Saitama University, Saitama, Japan. His current research interests are in digital signal processing and its applications to speech, image and communication systems.

Mohammed Golam Sarwar Bhuyan is currently Associate Professor and Head of the Department of Computer Science and Engineering, Model Institute of Science and Technology, Gazipur (Affiliated by National University, Bangladesh). Presently he is pursuing his PhD in Computer Science and Engineering department at Jahangirnagar University, Bangladesh. He received his Masters Degree in Telecommunication Engineering from University of Information Technology and Science, Bangladesh in 2010 and Bachelor Degree in Computer Science and Information Technology from Islamic University of Technology (IUT), Gazipur, Bangladesh in 2002. His research interest includes Telemedicine, Sensor and Ad Hoc Networks, Cellular Networks, Body Sensor Networks, Internet of Things, Distributed Database, Cloud and Mobile Cloud Computing, Data Warehouse and Data Mining, Analysis of Computer Communications and Networking Protocols.

Golam Moktader Daiyan received his Master of Computer Science and Engineering degree from Islamic University of Technology, Bangladesh and B.E degree from Madurai Kamaraj University, India. Now he is pursing PhD degree at Chittagong University of Engineering and Technology, Bangladesh. Beside his academic career, he is also serving as a faculty member of the Computer Science and Engineering Department, East Delta University, Bangladesh. He has eleven years teaching experience as faculty member of different Universities in Chittagong, Bangladesh His current research interests are in image processing, Bioinformatics and Big Data.