International Journal of Innovation and Scientific Research
ISSN 2351-8014 Vol. 25 No. 1 Jun. 2016, pp. 22-31

http://www.ijisr.issr-journals.org/

DESIGN OF JPEG IMAGE COMPRESSION SCHEME WITH A PARTICLE SWARM OPTIMIZATION-BASED QUANTIZATION TABLE

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ABSTRACT: Usage of Image has been increasing and used in many applications. Some applications such as the transmission of images in computer and mobile environments cannot use images directly due to the large amount of memory space needed to store these images. Image compression has a very important role in digital image processing and for effective transmission and storing of digital images. There are various techniques that can be used in image compression. Today JPEG algorithm has become the de facto standard in image compression. The source of its excellent compression ability is the quantization table which determine which frequency components of the Discrete Cosine Transform (DCT) will be neglected. The JPEG default quantization table is generated from a series psycho-visual experiments from several angle points of experimental views. Particle Swarm Optimization (PSO) is a biologically-inspired optimization algorithm and has been experimentally demonstrated to perform excellent to solve many optimization problems by finding out the global best solution in a complicated search space. In this paper, to enhance the accuracy of the JPEG image compression algorithm, the PSO algorithm has been used to search the optimum quantization table. Simulation results show that the performance of the standard JPEG method can be improved by the proposed method in terms of PSNR and MSE. The proposed color image compression method has produced an average PSNR gain of 69.874 % compared with the standard JPEG color image compression method.

KEYWORDS: Image Compression, Joint Photographic Expert Group (JPEG), Particle Swarm Optimization, quantization process.

1 INTRODUCTION

Image compression is a data compression process of digital images. The objective of digital image compression is to minimize redundancy of image data so as to store or transfer data in an efficient form [1].

The JPEG Standard algorithm is a widely known ISO/ITU-T standard created in the late 1980s. JPEG image format differs from other formats such as Predict Probability Model (PPM) and Graphics Interchange Format (GIF), is a lossy compression technique, this means that some visual data is lost[2]. It first splits the image into (8×8) non-overlapping blocks of pixels. Then, the discrete cosine transform (DCT) of each block is calculated and the resulting blocks of coefficients are quantized by using the JPEG standard quantization table[3]. The JPEG standard quantization table has been designed depending on psycho-visual optimality involving large scale experimentation with a lot of test subjects[4]. The objective of the quantization operation is fulfill additional compression by representing the DCT coefficients with lower precision[5]. Finally entropy coding is applied to the quantized coefficients[3].

Particle swarm optimization (PSO) has been developed by Kennedy and Eberhart (1995) as a stochastic optimization algorithm based on social emulation models[6]. In PSO, each individual is named “particle”, which represents a possible solution. The algorithm gets the optimal solution by the variability of some 'particles' in the tracing area. The particles looking for the best particle in the solution area by changing their positions and the fitness repeatedly, the flying direction and velocity are calculated by the objective function[7]. Due to its many advantages including its simplicity and ease of implementation, the algorithm can be applied for digital signal procession, function optimization, automatic adaptation control, and model classification, etc.[8].

In this paper, the quality of the standard JPEG image compression algorithm has been improved by using PSO based-quantization table. The proposed improvement has been able to obtain better performance compared to the standard JPEG algorithm.

2 RELATED WORKS

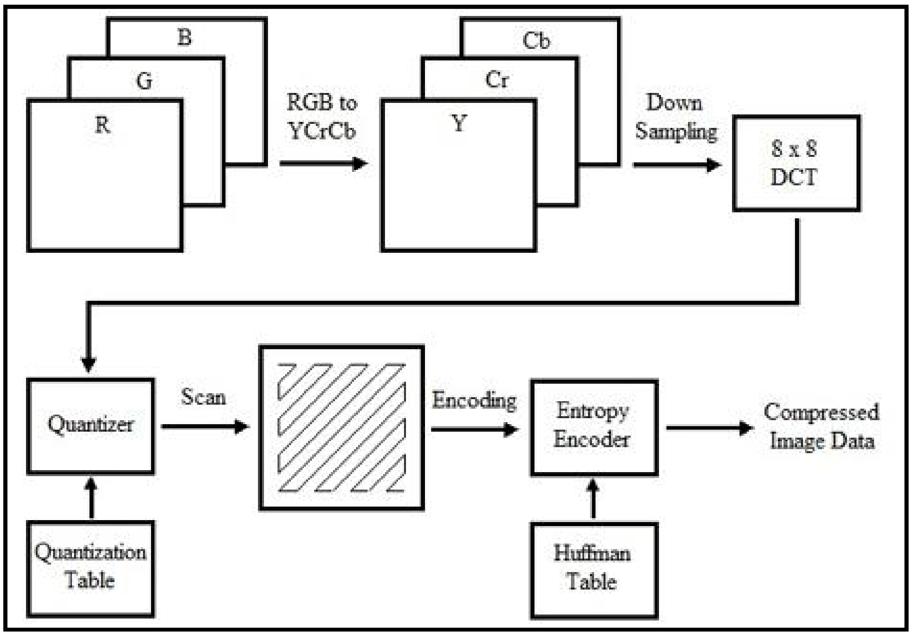
For related works interest with the optimization of JPEG quantization step, **Mario Konrad et al.** have been proposed a customized JPEG quantization tables for iris polar images compression. The genetic algorithm (GA) has been used to procure specialized quantization tables for specified compression ratios[9]. **Julio Pons et al.** have been proposed a quantization algorithm that quantized the first three DCT coefficients using standard JPEG quantization table while the remaining coefficients are quantized by ignoring those lower than a given threshold[3]. **Chengyou Wang et al.** have been suggested a quantization process by minimizing the sum of squares of the quantized distortion variable and constrained by a desired number of coded bits[10]. **Ferda Ernawan and Sitihadiati Nugraini** have been proposed quantization table generation algorithm based on DCT psycho-visual threshold which provides a balance between the quality of output image and compression rate[11]. **T. SHOHDOHJI et al.** have been proposed a quantization table algorithm using Fibonacci numbers and discussed the relation between quantization table and image quality[12]. **Nasir Memona and Daniel Tretter** have been proposed an algorithm for calculating scale factors for the quantization matrices applied to the standard JPEG compression. The algorithm classifies each image block according to its activity and type which index into lookup tables that provide the scale factor to be used for the block[13]. **Balasubramanian Vinoth Kumar and G. R. Karpagam** have been proposed a knowledge-based genetic algorithm (KBGA) to search the best quantization table for the JPEG compression standard[14]. **Yuebing Jiang and Marios S. Pattichis** have been presented a multi-objective optimization framework for JPEG image compression based on perceptual image quality assessment by considering a global optimization process using Simulated Annealing (SA) to produce the best quantization table[15]. Recently, **Hei Tao Fung and Kevin J. Parker** have been presented an adaptive image quantization table to minimizing the computational complexity by allowing the elements of the quantization table to go up or down based on whether coarser or a finder quantization table is needed to achieve the target distortion value[5].

In this paper, a new JPEG image compression scheme with a particle swarm optimization-based quantization table has been designed and compared with the standard JPEG image compression algorithm.

3 STANDARD JPEG IMAGE COMPRESSION

Image compression mechanisms can be categorized into lossless and lossy compression. In lossless compression techniques, the reconstructed image is identical to the original image with low compression ratio while lossy compression techniques permit a loss in the image data therefore the original image cannot be reconstructed exactly from the compressed image[16].

JPEG image compression is defined as a lossy compression system based on the discrete cosine transform. The block diagram of standard JPEG image encoder is shown in figure (1). The greater compression and higher precision provided by the JPEG image compression algorithm can be tailored to some specific applications[1]:



Standard JPEG Image Compression Encoder.

3.1 DISCRETE COSINE TRANSFORM (DCT)

The aim of using the DCT is to take away the information with higher frequency since the eye of human is less sensitive to it. The digital image is first sub divided into (8x8) non-overlapped blocks of pixels. Then the DCT is applied to every block. DCT transforms the spatial digital image format into a frequency map: the low order "DC" term represents the average value in the block, while successive higher order "AC" terms represent the strength of more and more rapid changes across the width or height of the block. The DCT employs cosine functions, therefore the final result matrix depends on the diagonal, vertical, and horizontal frequencies. So an image block with many of changes in frequency has a quite random resulting matrix, while only one color image block, has a large value for the first element (DC term) and zeroes for other elements (ACs) resulting matrix[17]. The formula for (8x8) 2D-DCT is expressed as:

$$G_{v,u} = \sum_{i=0}^{7}\sum_{r=0}^{7} \alpha(u)\alpha(v) g_{i,r} \cos\left[\frac{\pi}{8}\left(i+\frac{1}{2}\right)u\right] \cos\left[\frac{\pi}{8}\left(r+\frac{1}{2}\right)v\right] \quad (1)$$

Where u ϵ [0,7] is the horizontal spatial frequency, and v ϵ [0,7] is the vertical spatial frequency and:

$$\alpha(u) = \begin{cases} \sqrt{\frac{1}{8}}, & if\ u = 0 \\ \sqrt{\frac{2}{8}}, & Otherwise \end{cases} \quad (2)$$

3.2 QUANTIZATION

Each of the 64 coefficients output from the DCT is uniformly quantized with a corresponding element in the quantization table, which must be pre-specified by the application as an input to the JPEG encoder. Each element of the quantizer represents the step-size for its corresponding DCT coefficient and can be any integer value from 1 to 255. The objective of the quantization process is to obtain extra compression by representing each of the 64 DCT coefficients with no greater accuracy than is necessary to obtain the required image quality. In other words, the aim of this step is to reject not visually important information. Quantization is achieved by dividing each DCT coefficient by its corresponding step size quantizer, followed by rounding to the nearest integer[18]:

$$B_{i,r} = round\left(\frac{G_{i,r}}{Q_{i,r}}\right) \qquad for\ i = 0,1,\dots,7;\ r = 0,1,\dots,7 \quad (3)$$

Where, G is the un-quantized (8x8) DCT coefficients block and, Q is the quantization matrix.

The standard JPEG quantization table shown in figure (2) is achieve from the physical characteristics of many natural digital images based on human visual system.

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

Fig. 1. Standard JPEG Quantization Table

3.3 ENTROPY ENCODING

In the entropy encoder ,the last step of the JPEG compressor, the blocks of quantized DCT coefficients are encoded using extra lossless compression. The JPEG algorithm first reorders the quantized coefficients in each DCT block in zigzag sequence, thus converting a (8x8) squared quantized DCT block to a one dimension string of 64 elements.

In the standard JPEG encoder, two methods of entropy coding are specified: Arithmetic and huffman coding. The Standard JPEG algorithm uses huffman only, but both methods are specified for other modes of operation. In huffman coding, one or more of huffman tables are pre-specified by the application. The standard JPEG encoder uses only two sets of huffman tables: one for the DC element and the other for AC elements[19].

3.4 DECOMPRESSION

The compression stage is inverted in the de-compression stage, and in the opposite order. where, the first process is the entropy decoding and proceeds to convert the 1-D strings of 64 elements to a (8x8) squared blocks of zeros and coefficients. Coefficients blocks are then de-quantized and Inverse Discrete Cosine Transform (IDCT) is carry out to restore the de-compressed image.

4 STANDARD PSO ALGORITHM

Particle Swarm Optimization (PSO) emulates the bird flocking behaviors and can be used to solve many problems of optimization. PSO is first started with a set of random particles (solutions) and then looking for optimal solution by updating of generations. In each generation, every particle is updated via two "best" important values. The first value is the best solution which has better fitness. This value is named the *pbest*(p_i). The other "best" value is the best value obtained so far by any particle in the population. This value is a global best and named *gbest*(p_a). The velocity and position of every particle is updated depending on their best received position and according to the following equations[20].

$$\boldsymbol{V}_{\mathrm{ie}} = \boldsymbol{w} * \boldsymbol{V}_{\mathrm{ie}} + \boldsymbol{c1} * \boldsymbol{rand}(\,) * (\boldsymbol{P}_{\mathrm{ie}} - \boldsymbol{X}_{\mathrm{ie}}) + \boldsymbol{c2} * \boldsymbol{rand}(\,) * (\boldsymbol{P}_{\mathrm{ae}} - \boldsymbol{X}_{\mathrm{ie}}) \tag{4}$$

$$\boldsymbol{X}_{\mathrm{ie}} = \boldsymbol{X}_{\mathrm{ie}} + \boldsymbol{V}_{\mathrm{ie}} \tag{5}$$

Where V_{ie} is the velocity of the particle in e-dimension, X_{ie} is the position of the particle in e-dimension, w is the inertia weight. p_i and p_a are as stated before, *rand*( ) is a random value in the range [0,1]. *c1* and *c2* are the cognitive and social learning factors[20]. The flow chart for implementing the standard PSO is shown in figure (3)[21].

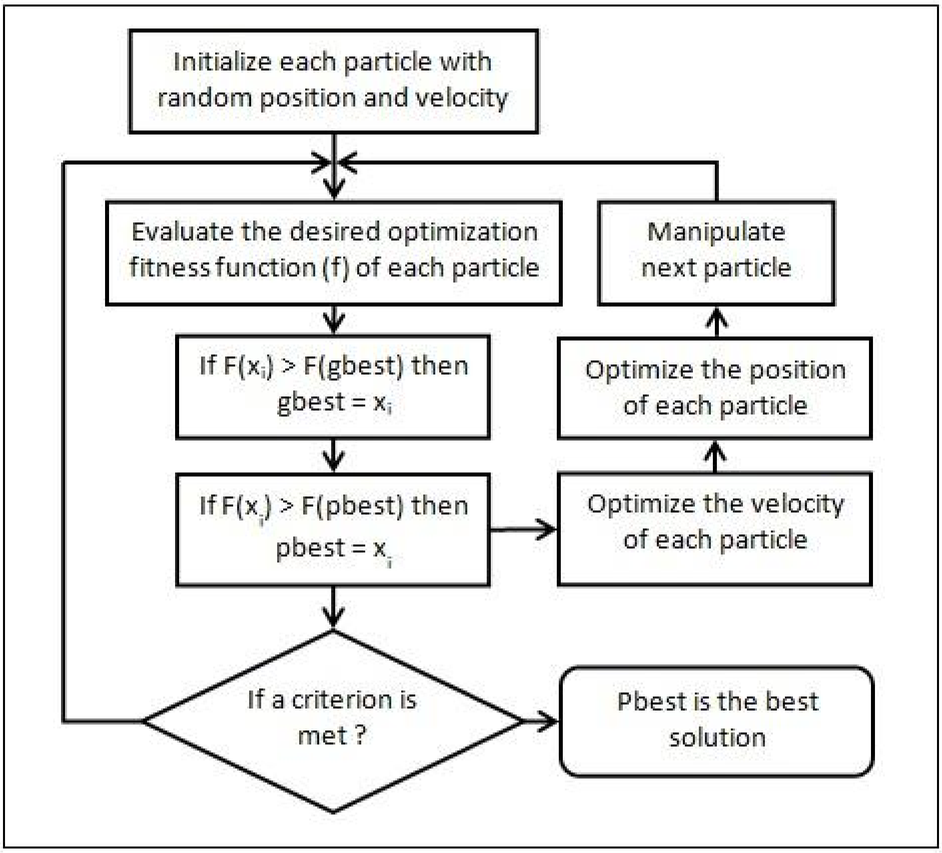


Fig. 2. Standard PSO flow chart[21]

5 DESIGN METHOD OF PSO-BASED QUANTIZATION TABLE FOR JPEG COLOR IMAGE COMPRESSION STANDARD

The basic idea behind the PSO based-adaptive quantization table for the standard JPEG digital image compression can be simply stated as:

1. Read the uncompressed RGB color digital image to be compressed.
2. Converts the 24 bits RGB color space to the YCbCr color space, where (Y) is the luminance and (Cb, Cr) are the chrominance. This color model conversion allows better compression without an important influence on the perceptual digital image quality[18].
3. Divides each of Y, Cb, and Cr color space components into a number of non-overlapping (8x8) sub matrices blocks.
4. Normalize all pixel values in all blocks of all Y, Cb and Cr color space components in the range between [-128, 127].
5. Applies the two-dimensional DCT to each (8x8) block of the Y, Cb & Cr components to converts the digital image from the spatial domain to the numeric domain (frequency domain) so that the quantitative form of the image's information can be manipulated for better compression.
6. Generally, in the standard JPEG color image compression, the default standard JPEG quantization matrix is used to perform the quantization step. In this work, the standard PSO algorithm has been used to produce the optimum (8x8) block of quantization matrix as follows:

   Step 1: Generate an initial random population of quantization matrixes.

   Step 2: Stop, If the pre-specified number of iterations is carried out.

   Step 3: Compute the fitness value of each quantization matrix (particle).

   Step 4: For each iteration, find the local better quantization matrix (particle).

   Step 5: Find the global better quantization matrix (particle).

Step 6: Implement the velocity updating for each particle using equation (4).

Step 7: Implement the position updating for each particle using equation (5).

Step 8: Go back to Step 2.

The fitness function has been used in this paper is the Mean Square Error (MSE) between the original uncompressed color image and the reconstructed color image which it is defined as:

$$\boldsymbol{MSE} = \frac{\mathbf{1}}{y*z}\sum_{i=1}^{y}\sum_{j=1}^{z}[\boldsymbol{m}(\boldsymbol{i},\boldsymbol{j}) - \boldsymbol{n}(\boldsymbol{i},\boldsymbol{j})]^2 \qquad (6)$$

Where y and z are the corresponding color image sizes, m(i,j) and n(i,j) are the pixels in the original and compressed color images respectively.

The quantization step is performed by dividing each of the (8x8) DCT coefficients block by the quantization matrix that has been produced using the standard PSO algorithm.

7. Uses the "zigzag" sequence to reorders all of the (8x8) quantized DCT coefficients blocks and convert them into a one dimension vectors.
8. Uses the Huffman entropy encoded to compress the zigzagged quantized DCT coefficients vectors. Three Huffman modules are used for the JPEG color image compression, one for each of the Y, Cb and Cr components. The output stream of the JPEG algorithm incorporates all Y, Cb, and Cr Huffman codes together, where it starts with the Y Huffman codes, followed by the Cb Huffman codes, and finally the Cr Huffman codes for each (8x8) block of the image and so on for the next block.
9. Finally, the compressed color image is reconstructed through a reverse process using the Inverse Discrete Cosine Transform (IDCT).

6 RESULTS AND COMPARISON

In order to proof the performance of the proposed JPEG color image compression method, simulation has been performed using MATLAB 7.14 (R2012a) by applying the well-known (24 bits/pixel, 512×512) color images Lena, Baboon, Airplane, Peppers, Sailboat and Tiffany shown in figure (4).

Fig. 3. Original color test images (a) Lena, (b) Baboon, (c) Airplane, (d) Peppers, (e) Sailboat, and (f) Tiffany

The standard PSO algorithm with the following control parameters have been used in this work:

- Generation Number = 30.
- Population Size = 20.
- Fitness function = *MSE*.
- Cognitive (*c1*) & Social (*c2*) = 0.3.
- Inertial weight (*w*) = 0.9.

Figure (5) represents the convergence behavior of the proposed JPEG color image compression with a PSO-based quantization table.

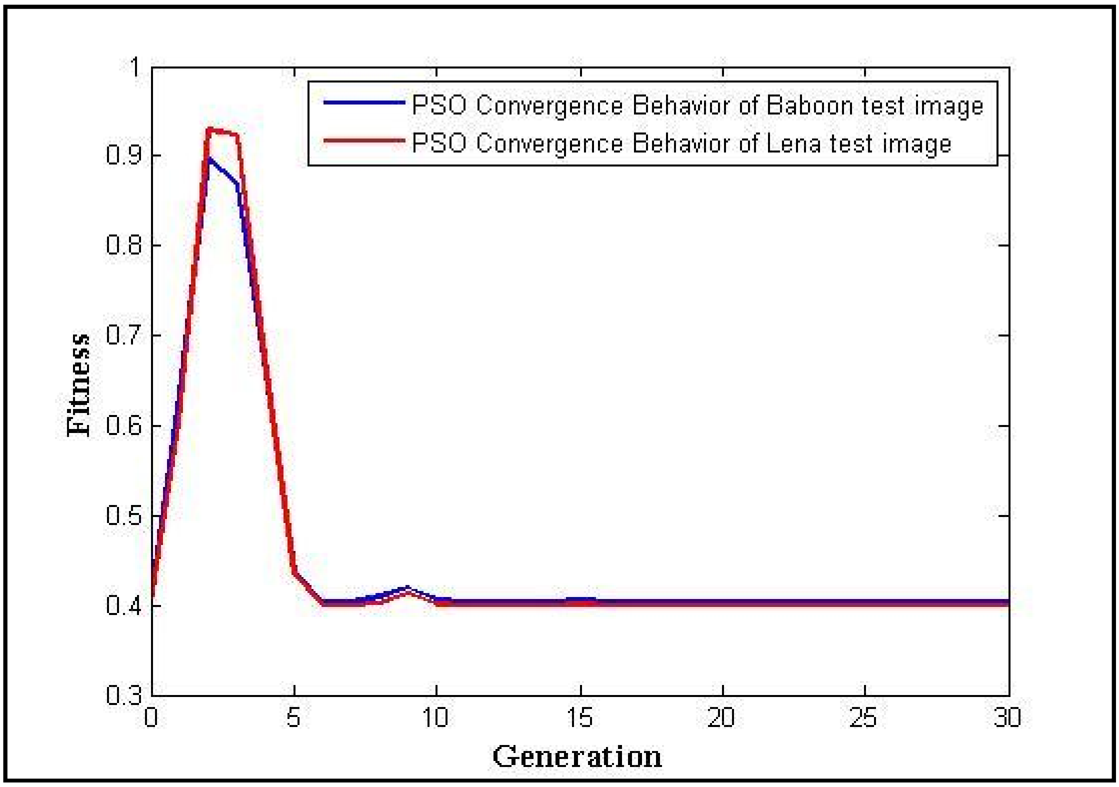


Fig. 4. Convergence behavior of the proposed JPEG color image compression with a PSO-based quantization table for Lena and Baboon test images

Table 1 shows an experimental results comparison in terms of peak signal to noise ratio (PSNR) and mean square error (MSE) between the standard JPEG color image compression algorithm and our proposed method applied to color Lena, Baboon, Airplane, Peppers, Sailboat and Tiffany test images. Mathematically peak signal to noise ratio (PSNR) is defined as:

$$PSNR = 10\ lim_{10} \frac{(2^{w}-1)^{2}}{MSE} \quad (7)$$

Where *w* is the bit depth of the considered pictures.

Table 1. CR, PSNR and MSE comparison of Standard JPEG and Proposed Method applied to color Lena and mandrill images

Image	Standard JPEG Method		Proposed PSO-based Method		Gain (%)
	MSE	PSNR in dB	MSE	PSNR in dB	PSNR Gain
Lena	32.198	33.052	0.399	52.118	57.684 %
Baboon	190.03	25.17	0.402	51.907	106.225 %
Airplane	25.479	33.322	0.399	51.372	54.168 %
Peppers	42.062	31.256	0.393	51.544	64.909 %
Sailboat	71.907	29.356	0.401	51.887	76.750 %
Tiffany	32.983	32.947	0.361	52.554	59.510 %
Average PSNR GAIN IN 100%					**69.874 %**

Figure (6) shows the original tested color images and the corresponding reconstructed images using the proposed color image compression for Lena and Baboon images.

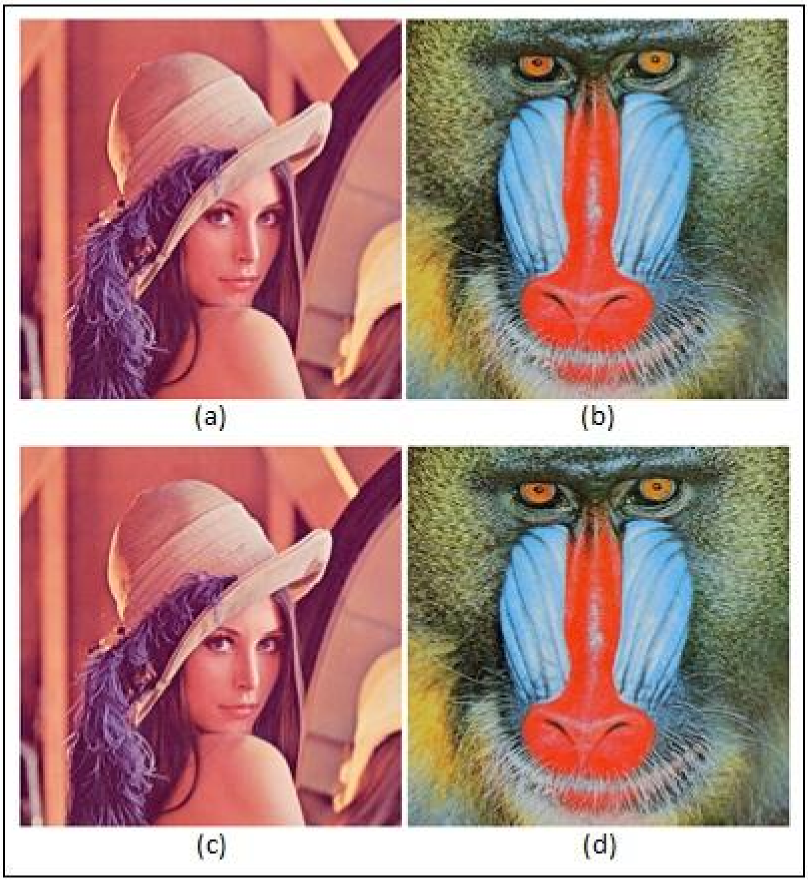


Fig. 5. (a and b) Original Lena and Baboon images, and (c and d) Reconstructed Lena and Baboon images using Proposed Method

From the simulation experimental results and the reconstructed color tested images, it can be concluded that the proposed method in this paper has better performance and visual quality than standard JPEG algorithm.

7 CONCLUSIONS

Image compression is a very important section of modern digital computing by having the power to compress digital images to portion of their original size and valuable disk space can be saved. In addition, sending of digital images through a computer networks becomes easier and less time consuming.

Particle swam optimization algorithm is a modern heuristic optimization technique depended on swarm intelligence. Compared with other optimization algorithms, this algorithm is quite simple, can be implemented easily and it needs only a few parameters, which made it fully developed.

JPEG standard has turn into the most common image format; but it still as yet has some properties that can be improved. The quantization stage is the crucial element in the performance of the JPEG image compression technique and has an essentially role in minimizing the redundancy of visual image information in digital image compression. The main objective of the proposed JPEG color image compression with a PSO based-quantization stage is to achieve superior image quality, where, the PSO algorithm has been used to search the optimal quantization table.

From the simulation results, it can be concluded that the PSNR of the proposed method has a superior performance compared with the standard JPEG algorithm and improved visual quality has been achieved. Thus it can expect that the proposed image compression method can be used widely in digital image and video compression.

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