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JPEG Image Compression and Decompression using Discrete Cosine Transform (DCT)

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Abstract: Image compression is the application of data compression on digital images. Digital images contain large amount of digital information that need effective techniques for storing and transmitting large volume of data. An Image can be compressed with use of Discrete Cosine Transform (DCT), quantization encoding are the steps in the compression of the Joint Photographic Expert Group (JPEG) image format. The 2-D Discrete Cosine transform is used to convert the 8×8 blocks of image into elementary frequency components .The frequency components(DC and AC) are reduced to zero during the process of quantization which is a lossy process [5]. These frequency components are then quantized with the standard Q_{50}. Run length coding is used to produce the compressed representation. Distortion between the original image and reconstructed image is measured with Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR) with different compression factors. The compression ratio and PSNR values are different for different images. It is found that performance will not remain same for different images even though compression factor was same.

Keywords: Discrete Cosine Transform, Encoding, JPEG, MSE, PSNR, Quantization, Run length.

I. INTRODUCTION

Image compression is minimizing the size in bytes of a graphics file without degrading the quality of image. Many applications need large number of images for solving problems[6]. Image Compression means reducing the amount of data required to represent a digital image. One of the most popular compression methods is Joint Photographic Expert Group (JPEG). JPEG create a web page with a picture can be accessed faster than a web page with an image without compression. JPEG provides for lossy compression of images. Image compression may be lossy or lossless. Lossless compression is preferred for archiving and often for medical imaging, technical drawings, etc. Lossy methods are especially suitable for natural images such as photographs in applications. JPEG was developed in 1992, based on DCT [6]. It has been one of the most widely used compression method. Color image JPEG compression consists of five steps. The steps are: color space conversion, down sampling, 2-D DCT, quantization and entropy coding. This paper is organized as follows: related works of the system are described in section two. In section three, background theory is explained. In section four, system design and implementation result are presented. Finally, in section five, the paper has been concluded.

II. RELATED WORKS

K. Deepthi proposed that Design and Implementation of JPEG Image Compression and Decompression [1]. In this paper, architecture and VHDL design of 2-D DCT, combined with quantization and zigzag arrangement, is described. The output of DCT module needs to be multiplied with post-scalar value to get the real DCT coefficients. Post-scaling process is done together with quantization process. The decompression has to revert the transformations applied by the compression to the image data. The decoder therefore takes the compressed image data as its input. It then subsequently applies a Run length decoding [RLD], Inverse zigzag scan [ZZ], de-quantization [DQ], inverse discrete cosine transform [IDCT], a color conversion and reordering to it. It then obtains the reconstructed image.

Deepak Singla and Rupali Syal proposed that Data Security Using LSB & DCT Steganography in Images [2]. In this paper, there propose a LSB & DCT-based steganographic method for hiding the data. Each bit of data is embedded by altering the least significant bit of low frequency DCT coefficients of cover image blocks. Some techniques utilize the idea of SSB-4 technique in modifying the other bits to obtain the minimum variation between the original and the modified coefficient. This algorithm has better PSNR value and high capacity in comparison to other techniques such as LSB, modulus arithmetic, SSB4-DCT. It also maintains satisfactory security as secret message cannot be extracted without knowing the decoding algorithm. This is achieved using a Public Private key. It combined both feature of Steganography and cryptography.

Lei Wang, Jiaji Wu, Licheng Jiao, Li Zhang and Guangming Shi proposed that Lossy to Lossless Image Compression based on Reversible Integer DCT [3]. In this paper, a progressive image compression scheme is investigated using reversible integer discrete cosine transform (RDCT). DCT suffer from bad performance in lossy image compression compared with wavelet image codec. And lossless compression methods such as IntDCT, I2I-DCT and so on could not compare with JPEG-LS or integer discrete wavelet transform (DWT) based codec. Lossy to lossless image compression can be implemented by our proposed scheme which consists of RDCT, coefficients reorganization, bit plane encoding, and reversible integer pre and post-filters.

Dipti Bhatnagar and Sumit Budhiraja proposed that Image Compression using DCT based Compressive Sensing and Vector Quantization [4]. In this paper, compressive sensing (CS) provides a mathematical framework for utilizing the potentiality of sparse nature of the commonly used signals. CS involves the compression of the data at the first step of image acquisition. This paper presents an image compression algorithm based on DCT based CS and Vector Quantization (VQ). It has been observed from the implementation of the Proposed CS-VQ algorithm that the proposed algorithm gives better PSNR and visual quality when compared with the existing CS-VQ algorithm. The results obtained are even comparable with JPEG algorithm but only when small queue size is considered.

Ryuji Matsuoka, Mitsuo Sone, Kiyonari Fukue, Kohei Cho and Haruhisa Shimoda proposed that Quantitative Analysis of Image Quality of Lossy Compression Images [7]. In this paper, an empirical investigation is decided to carry out into the effects of lossy image compression on quality of color aerial images by using color and texture measures. From the experiment results, it can be concluded that color space conversion and down-sampling in JPEG compression have an effect on quality of a reconstructed image. Lossy JPEG 2000 compression does not necessarily provide an image of good quality in texture features. Moreover, the results indicated that an image of finer texture features is less compressible, and quality of the reconstructed image is worse in both color and texture features. Finally, it was confirmed that it is difficult to set an appropriate the quality factor, because the optimal setting of the quality factor varies from one image to another.

III. BACKGROUND THEORY

The JPEG image compression system is composed of four main steps: image acquisition, preprocessing, image compression and image decompression.

A. Image Acquisition

The images are acquired by two techniques: online and offline. This system uses the offline technique. The input image is RGB and JPEG type. And then, the size of the image is arbitrary size. Bilinear interpolation is used to resize the pixel values of the original image.

B. Image Preprocessing

In the preprocessing step, it is necessary to perform changing color and chrominance down-sampling.

1. **RGB to YCbCr Conversion:** Changing color is necessary to transform for image quantization. The luminance component represents the intensity of the image and look likes a gray scale version. The chrominance components represent the color information in the image. In the image compression step, luminance and chrominance quantization is done after transforming using DCT. Converting from color into YCbCr color space consists of the luminance and two chrominance components.
2. **Chrominance Down-sampling:** After changing YCbCr color space, the image is down-sampled by the factor of 2. The format is 4:2:0. Down-sampling can cause reduction ofpixels in chrominance (CbCr) in image compression system. Chrominance down-sampling format is shown in figure1.

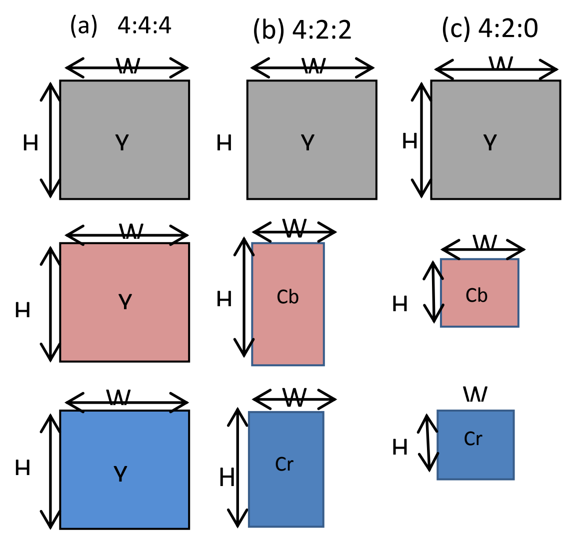

Figure1. Chrominance Down-Sampling Format.

C. Image Compression

In the image compression step, the DCT image transform, image quantization and entropy encoding are performed.

1. DCT Image Transform

For image compression, Discrete Cosine Transform (DCT) is used. An input image f(x, y) is a two dimensional M by N matrix image with different intensity values. To transform spatial to frequency domain for image compression, the system is needed to determine with the forward 2D-DCT transformation equation. The transform matrix is calculated as shown in Equation (1).

$$F(i,j) = \frac{1}{4} C(i)C(j) + \sum_{x=0}^{7}\sum_{x=0}^{7} P[x,y] \cos[\frac{(2x+1)i\pi}{16}] \cos[\frac{(2y+1)j\pi}{16}] \quad (1)$$

Where, i,j = 0,1,2,3,…….., N-1
P(x,y)=input matrix
F(i,j)=transformed matrix.

The resulted transformed image is shown in Figure 2.

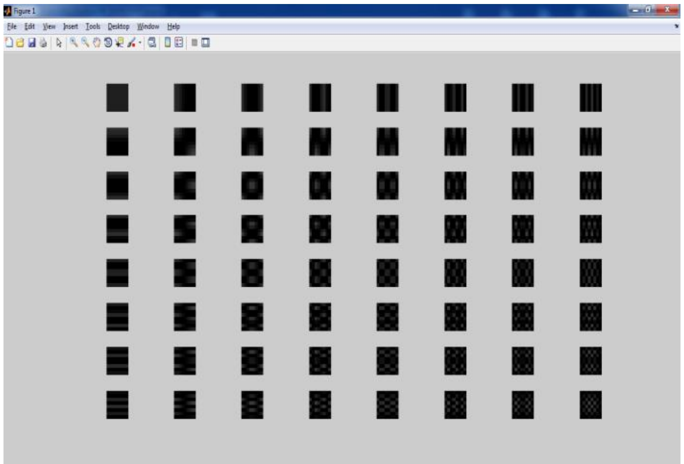

Figure2. 8x8 Blocks of DCT Transformed Image.

2. Image Quantization

Quantization is the step where most of the image compression takes place. DCT really does not compress the image because it is almost lossless. For obtaining quantization matrices with other quality levels, scalar multiplications of standard quantization matrix are used. JPEG standard has two quantization tables for the luminance and chrominance coefficients. Values of resultant matrix are then rounded to be the nearest integer value. The transformed image matrix by using DCT is divided into the quantization matrix. This formula is shown in Equation (1). The quantization formula with rounding to the quantized values is shown in Equation (3).

$$\text{Quantization}=\frac{\textit{Transformed image matrix}}{\textit{Quantization matrix}} \qquad (2)$$

Quantization:

$$F_Q\,(i,j)=\text{round}(F(i,j)/Q(i,j)) \qquad (3)$$

The compression level of an image can be controlled by a constant, which is generally called the quality factor (Q-factor). The quality levels ranging from 1 to 100 are selected, where 1 gives poorest image quality and highest compression, while 100 gives the best quality and lowest compression. Different JPEG compression programs have different Q-factors. In this proposed system, the performance is shown with different Q factor for the same input image. JPEG committee suggests matrix with quality level 50, Q_{50} as standard matrix. Luminance quantization matrix Q_{ij} is shown in Table 1. And then, Chrominance quantization matrix $Q_{i,j}$ is shown in Table 2.

TABLE I: LUMINANCE QUANTIZATION TABLE IN JPEG

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

TABLE II: CHROMINANCE QUANTIZATION TABLE IN JPEG

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

3. Entropy Encoding

In the entropy coding stage, the 8x8 block of quantization indices of the DCT coefficients (or shortly quantized DCT coefficients) is compressed. Entropy encoding stage has the following steps:

Step-1: Zigzag Scan

After quantization, the zigzag scan orders 64 coefficients (1 DC and 63 AC coefficients) into the one-dimensional vector format. Zigzag order rearranges the quantized coefficients of each 8x8 block for further encoding.

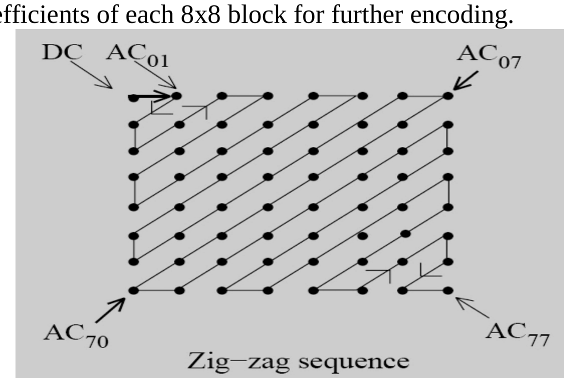

Figure 3.ZigZag Scan Format

The DC coefficient is encoded by using Digital Pulse Code Modulation (DPCM).The AC coefficients are coded by applying the run-length encoding.

Step-2: DPCM on DC component

Differential Pulse Code Modulation (DPCM) is the coding method. The DPCM coding is processed by the following equation.

$$d_i = DC_i - DC_{i-1} \text{ and } d_0 = DC_0$$

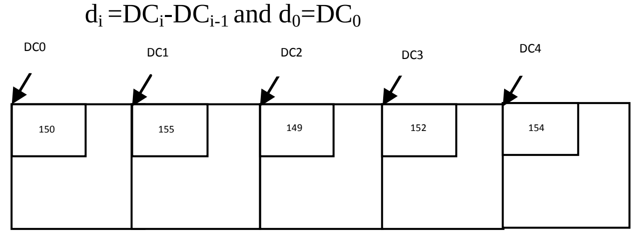

Figure4. DPCM Coding Format on DC Coefficients

d_0=150, d_1=5, d_2=-6, d_3=3 and d_4=-8.

Step-3: Run Length Encoding (RLE) on AC component

After quantization and zigzag scanning, the one-dimensional vectors with a lot of consecutive zeros are obtained. Thus, the run length coding technique is applied which called variable length coding. The 63 AC coefficients in the original 64 quantized vectors first. To be more efficient to save the non-zero values and to skip the number of zeros, run-length encoding is used.

The RLE stores a skip and a value

RLE = (skip, value);

Where, Skip = the number of zeros

Value = the next non-zero component

-26	-3	0	0	0	-4	21	0	0	12	-	-

The above coefficients are encoded into this form.

(0,-26); (0,-3); (3,-4); (0, 21); (2, 12); EOB

Where, EOB is the End of Block. Another coding technique is Huffman coding technique that is shown in step 4. In this research, the run length coding technique is used.

Step-4: Huffman Coding

Huffman table is created which represents commonly used strings of values with a shorter code. Example: coefficient 57 is in category 6. Thus the bit for the value, 57 is 111001. To represent commonly used strings of values with a shorter code, Huffman table is created. This is shown in Table 3.

TABLE III: THE HUFFMAN ENCODED TABLE

Category	Values	Bits for the Values
1	-1,1	0,1
2	-3,-2,2,3	00,01,10,11
3	-7,-6,-5,-4,4,5,6,7	000,001,010,011,100,101,110,111
4	-15,-----,-8,8,-----,15	0000,-----,0111,1000,-----,1111
5	-31,-----,-16,16,-----,31	00000,----,01111,10000,----,11111
6	-63,-----,-32,32,-----,63	000000,-----,011111,100000,---,111111

D. Image Decompression

In the image decompression step, each of the above compression steps is reversed in reverse order.

1. Use the run length decoding technique to decode strings of bits into a 64-element array;
2. Reform the 64-element array into an 8 × 8 block;
3. Multiply each element in the block by a corresponding quantization value;
4. Performs the IDCT on the de-quantized block;
5. Add 128 to each of the de-transformed pixels to recover an approximation of the original image.

IV. SYSTEM DESIGN AND IMPLEMENTATION RESULTS

This section describes system design of the proposed system, implementation and performance evaluation.

A. Design of the Proposed System

In this paper, Discrete Cosine Transform (DCT) is applied to implement image compression system. The overall block diagram of the proposed system is shown in Figure 5.

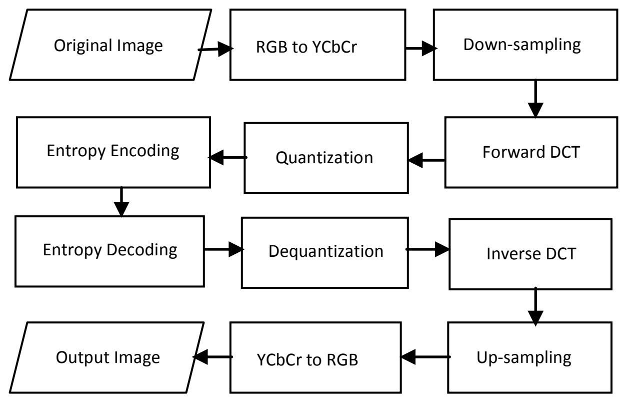

Figure5. Overview of JPEG Compression and Decompression Process.

In image preprocessing step, RGB and YCbCr conversion is included. This is explained in the background theory. DCT transform, image quantization and entropy encoding are included in image compression system. Image decompression step includes the reverse processes of image compression.

B. Implementation of the Proposed System

There are two main steps in the image compression system. The first step is image compression and the second step is image decompression. Initially, we can see implementation of Peppers' compressed and error images with quality level, Q_{35} is shown in Figure 6. Figure 7 shows the quality level, Q_{70} of Peppers compressed and error images.

Figure 6. Original and Compressed Images of Peppers at Q $_{35}$.

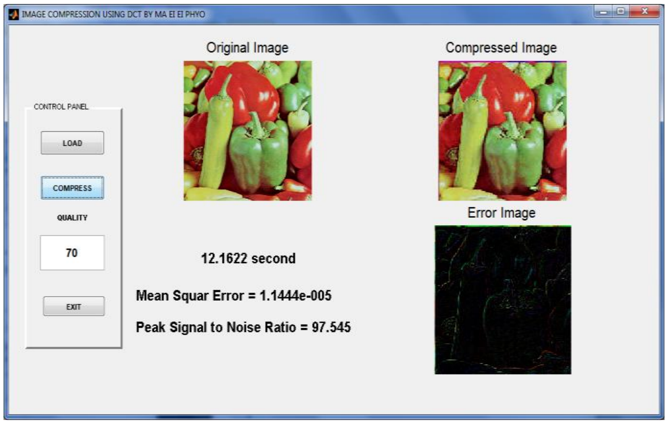

Figure 7. Original and Compressed Images of Peppers at Q $_{70}$.

Figure 6 and Figure 7 uses the same images with different quality levels. But, in these figures, the performance parameters compression time, compression ratio (CR), MSE and PSNR are not the same. The performance of the compression of Lena image at Q_{50} is shown in Figure 8.

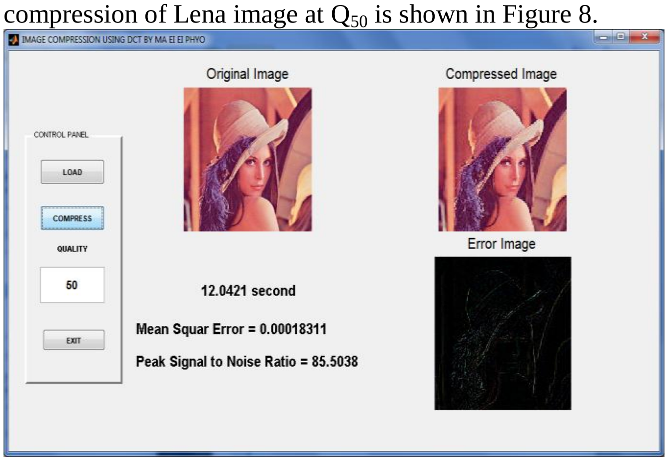

Figure 8. Original and Compressed Images of Lena at Q $_{50}$.

The original and compressed images of Lena at quality level, Q_{100} is shown in Figure 9. The error image is shown by differencing the original and compressed image. In this figure, the compression time, MSE and PSNR are also calculated.

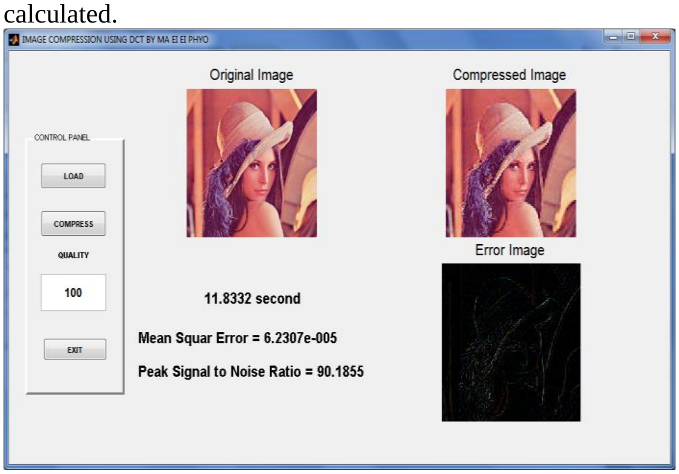

Figure9. Original and Compressed Images of Lena at Q_{100}

The performance of compression is also researched with Baboon image with quality level, Q_{20} and Q_{50}. This is shown in Figure 10 and Figure 11.

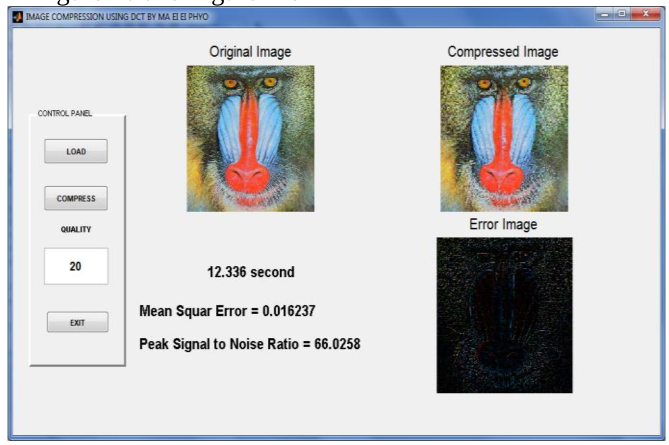

Figure 10. Original and Compressed Images of Baboon at Q $_{20}$.

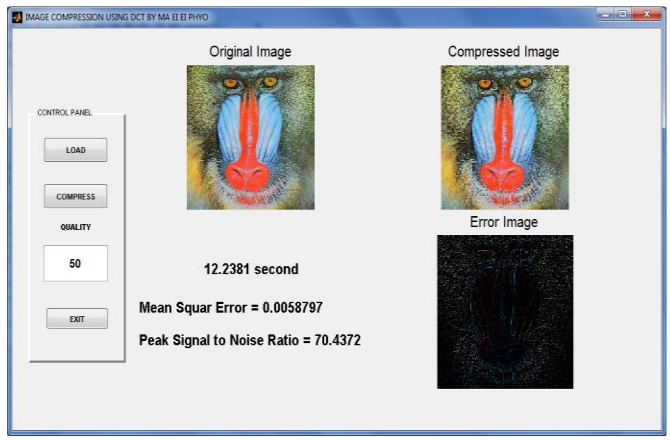

Figure11. Original and Compressed Images of Baboon at Q $_{50}$.

TABLE IV: THE PERFORMANCE COMPARISON OF IMAGE COMPRESSION SYSTEM

Input Image	Q-Factor	CR	Compression Time	MSE	PSNR
Peppers	Q-35	45%	12.37s	2.49×10^{-4}	84.16
Peppers	Q-70	52%	12.16s	1.14×10^{-5}	97.55
Lena	Q-50	53%	12.04s	1.83×10^{-4}	85.50
Lena	Q-100	79%	11.83s	6.23×10^{-5}	90.19
Baboon	Q-20	41%	12.34s	1.62×10^{-2}	66.03
Baboon	Q-50	49%	12.23s	5.87×10^{-3}	70.44

In this application, three different images are calculated with different quality levels. Although the quality levels are not the same, compression ratio (CR), compression time, MSE and PSNR are different. The performance is measured by the parameters such as quality factor (Q-factor), compression ratio (CR), compression time, MSE and PSNR is shown in Table 4.

V. CONCLUSIONS

Image compression is an extremely important part of modern computing. The JPEG image compression algorithm proves as a very effective way to compress images with minimal loss in quality [7]. Using the run length coding, the results may be compared with the above outputs which are implemented by using MATLAB. The performance of this research is measured by compression ratio, MSE and PSNR. The performance of compression can be increased when the Q-factors are increased. The performances of compression are not the same because of different Q-factors and different images. In this research, the same quality factor of Lena and Baboon images has different performances.

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