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Advanced Lossy Compression Techniques for Image Compression: A Comparative Study

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Abstract
With the development of communication technology and high-resolution images that can be captured by smart phones and cameras, row images need a lot of storage space and high bandwidth to be transmitted. This seems to be a big issue during the transmission of images over the networks. To store these images as well as make them available over the internet, compression methods are required. There are several methods for compression, such as Huffman, Arithmetic, LZWe, etc. However, Huffman, Arithmetic, LZW do not achieve a high compression ratio for images. Therefore, The research paper compares JPEG based on the discrete cosine transform (DCT) and JPEG 2000 based on the discrete wavelet transform (DWT) to achieve the highest image compression ratio and good image quality .They are implemented using Matlab software and a wavelet toolbox for DWT decomposition and synthesis. Particularly, the Harr wavelet is used in this research. The results have shown that DWT outperforms DCT in avoiding blocking artifacts, improving compression by 20-30% and enhancing image quality compared to classic JPEG, as demonstrated by PSNR at the same bit rate.
Keywords: Data Compression, JPEG, JPEG2000, lossless compression, lossy compression, Discrete Cosine Transform, Discrete Wavelet Transform.

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تقنيات متقدمة للضغط الفاقد في مجال ضغط الصور

(دراسة مقارنة)

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الملخص

مع تطور تكنولوجيا الاتصالات والصور عالية الدقة التي يمكن التقاطها بواسطة الهواتف الذكية والكاميرات. تحتاج الصور إلى مساحة تخزين كبيرة ونطاق ترددي عالٍ ليتم نقلها. يبدو أن هذه مشكلة كبيرة أثناء نقل الصور عبر الشبكات. لتخزين هذه الصور وإتاحتها عبر الإنترنت، يلزم استخدام طرق لضغط الصور. هناك عدة طرق للضغط مثل LZW, Huffman, Arithmetic...إلخ. ومع ذلك، فإنها لا تحقق نسبة ضغط عالية للصور. لذلك، يقدم هذا البحث مقارنة بين خوارزمية JPEG التي تعمل على أساس تحويل جيب التمام المنفصل (DCT) و JPEG 2000 التي تعمل على أساس تحويل المويجات المنفصلة (DWT) لتحقيق أعلى نسبة ضغط للصور مع الحصول على صورة ذات جودة عالية. حيث تم إجراء المقارنة بين اثنان من خوارزميات الضغط الفاقد JPEG JPEG200, وتم تنفيذ هذه المقارنة باستخدام برنامج Matlab وكذلك صندوق أدوات المويجات المرفق معه وذلك لتحليل وتركيب المويجات المنفصلة DWT، حيث تم استخدام مويجات Harr في هذا البحث.أظهرت النتائج بأن خوارزمية JPEG2000 تفوقت على JPEG التقليدية من ناحية التخلص من آثار التشوهات التي كانت تنتج عند إعادة بناء الصورة في الخوارزمية التقليدية JPEG وكذلك هناك تحسن بنسبة 20–30% في الضغط بنفس الجودة للصورة. بالإضافة إلى ذلك، تظهر نتائج المقارنة بين JPEG 2000 وJPEG الكلاسيكي أن JPEG 2000 قام بتحسين جودة الصورة والتي تم تقييمها بواسطة PSNR بنفس معدل البت.

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الكلمات المفتاحية: ضغط البيانات،JPEG ، JPEG2000 ، الضغط بدون فاقد، الضغط الفاقد، تحويل جيب التمام المنفصل ، تحويل المويجات المنفصلة

1. Introduction

The digital image is a set of pixel values that needs a large amount of storage space for saving the image and also a high bandwidth to be transmitted [1]. The main objective of image compression is to decrease the amount of irrelevant information and noise in the image. Consequently, it can be stored and transmitted efficiently [2]. Image compression reduces the amount of required data to represent and store a digital image, which can be done by removing redundant bits from the image. In general, the major forms of redundancy can be identified as coding redundancy, which occurs when more bits are utilized than required; spatial and temporal redundancies that occur as a result of the correlation between neighboring pixels that causes redundant unnecessary information between related pixels; and irrelevant data Psycho visual Redundancy that happens because human visual system ignores visually insignificant data [1].
Image or data compression is considered some form of compression that is used to reduce the size of a file of any type. When we decrease the memory size of a file, it requires less space to be stored and transmit images in a short time. The essential form of the compression process is shown in Figure 1 [3].

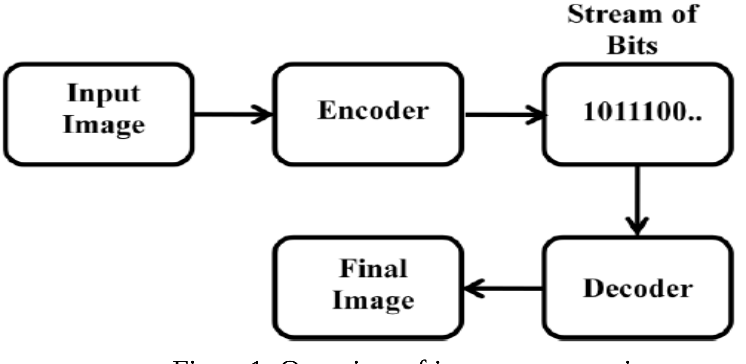

Figure1: Overview of image compression

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Therefore, it can be seen from the figure1 that inputted image encoded by one of the compression techniques is encoded to a stream of bits then will be decoded to reconstruct the compressed image.

Nowadays, communication technology and multimedia have developed rapidly. In most systems today, creating, editing, and generating images is considered a major priority. Thus, image compression is becoming very important to save storage space on our devices and also to reduce transmission time on networks. Many techniques of image compression are used to reduce the amount of data needed to represent a digital image. There are several methods for compression, such as Huffman, Arithmetic, LZWe, etc. [4].

However, Huffman, Arithmetic, LZW, etc. do not achieve a high compression ratio for images. Therefore, the research paper introduces a comparison between two compression algorithms, JPEG based on discrete cosine transform and JPEG 2000 based on discrete wavelet transform (DWT), to achieve the highest image compression ratio and good image quality.

2. Types of Compression

Image compression techniques can be classified into the following types:

2.1 Lossless compression techniques.

Lossless methods are ideal for artificial images like technical drawings and icons, high-value content like medical images, and scanned research images, as reconstructed images are nearly identical [5]. Here, some lossless compression algorithms are introduced as follows:

- Run Length Encoding
- Predictive Coding
- Arithmetic Encoding.
- LZW Coding.
- Huffman Coding.

Lossless compression is utilized for graphical images, computer data files like spreadsheets, text documents, and software applications, and for sending files attached to emails.

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2.2 Loosy Compression techniques.

Lossy compression reduces file size by eliminating redundant information, often used in human visualization systems. JPEG compression is commonly used for website images, providing a higher compression ratio and satisfactory quality. [1].

Lossy techniques are commonly used to compress audio, video, and images, with the compressed file having a better compression ratio than the uncompressed file. Audio compression ratio can be 10:1 with minimal quality loss, while video compression ratio can be 300:1 [6].

2.2.1 JPEG(Joint Photographic Experts Group)

Image compression is a widely used method that converts pixel values into numbers with specific intensity values, representing colors like red, green, and blue using bit depth [7].

The lossy compression technique compresses 24-bit depth or gray scale images by adjusting quantization matrix coefficients and compression ratios. It relies on the human visual system's response to luminance and sensitivity to homogeneous changes and is primarily used for internet storage and transmission [6].

a) Process of JPEG compression Algorithm.

This section presents JPEG compression steps as illustrated in Figure 2.

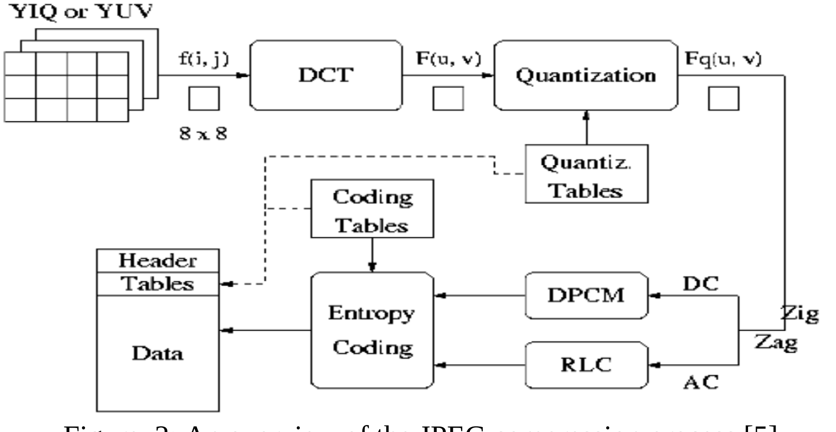

Figure. 2: An overview of the JPEG compression process [5]

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- **Color space conversion.**

The YUV color coordinate identifies the luminance (Y) and chrominance (Cb, Cr) components of a color image, allowing for more efficient processing and transmission of color signals in RGB primary displays. This approach, which combines luminance and chrominance attributes, is crucial for various applications. Where the component (Y) refers to the luminance and (Cb, Cr) refers to chrominance, which can be calculated as follows [8]:

$$\begin{pmatrix} Y \\ Cb \\ Cr \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.334 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} + \begin{pmatrix} 0 \\ 128 \\ 128 \end{pmatrix} \ldots\ldots \ldots.(1)$$

- **Discrete cosine transforms (DCT)**

In this stage, the original image, which is divided into blocks of 8 × 8, will be converted to a frequency domain by using a discrete cosine transform. For instance, an 8-bit sub-image of an 8 × 8 block can be represented as follows:

$$\begin{pmatrix} 52 & 55 & 61\ 66 & 70\ \ 61 & 64 & 73 \\ 63 & 59 & 55\ 90 & 109\ 85 & 69 & 72 \\ 62 & 59 & 68113 & 144104 & 66 & 73 \\ 63 & 58 & 71122 & 154106 & 70 & 69 \\ 67 & 61 & 68104 & 126\ 88 & 68 & 70 \\ 79 & 65 & 60\ 70 & 77\ \ 68 & 58 & 75 \\ 85 & 71 & 6459 & 5561 & 65 & 86 \\ 87 & 79 & 6968 & 6576 & 78 & 94 \end{pmatrix}$$

Then, before computing the DCT of the 8 × 8 block, its values are shifted from a positive value to one centered around zero. This leads to reducing the dynamic values in the process of DCT, and the result will be as follows [5]:

$$g = \overset{x}{\begin{pmatrix} -76 & -73 & -67-62 & -58-67 & -64 & -55 \\ -65 & -69 & -73-38 & -19-43 & -59 & -56 \\ -66 & -69 & -60-15 & 16\ -24 & -62 & -55 \\ -65 & -70 & -57\ -6 & 26\ -22 & -58 & -59 \\ -61 & -67 & -60-24 & -2\ -40 & -60 & -58 \\ -49 & -63 & -68-58 & -51-60 & -70 & -53 \\ -43 & -57 & -64-69 & -73-67 & -63 & -45 \\ -41 & -49 & -59-60 & -63-52 & -50 & -34 \end{pmatrix}} \quad y$$

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DCT will separate the image into parts of different frequencies. Then, in the quantization step, less important frequencies will be discarded, and the decompression step will utilize the important frequencies to reconstruct the image [8]. This equation gives the forward 2D_DCT transformation:

$$F(u,v) = \frac{2}{N} C(u)C(v)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} f(x,y)\cos\left[\frac{\pi(2x+1)u}{2N}\right]\cos\left[\frac{\pi(2y+1)v}{2N}\right]$$

for u=0….,N-1 and v=0,….,N-1

Where N=8 and $C(k) = \begin{cases} 1/\sqrt{2} & \text{for } K=0 \\ 1 & \text{Otherwise} \end{cases}$ ……………………..…….(2)

And this equation gives the invers 2D_DCT transformation:

$$f(x,y) = \frac{2}{N}\sum_{y=0}^{N-1}\sum_{v=0}^{N-1} C(u)C(v)F(u,v)\cos\left[\frac{\pi(2x+1)u}{2N}\right]\cos\left[\frac{\pi(2y+1)v}{2N}\right]$$

For x=0,…..,N-1 and y=0,……,N=1 where N=8 ……………...….(3)

DCT converts the spatial domain to the frequency domain. It converts the image into a suitable format, as follows:

$$G=\overset{u}{\begin{pmatrix} -145.38 & -30.19 & -61.20 & 27.24 & 56.13 & -02.10 & -2.39 & 0.46 \\ 4.47 & -21.86 & -60.76 & 10.25 & 13.15 & -7.09 & -8.54 & 4.88 \\ -46.83 & 7.37 & 77.13 & -24.56 & -28.91 & 9.93 & 5.42 & -5.65 \\ -48.53 & 12.07 & 34.10 & -14.76 & -10.24 & 6.30 & 1.83 & 1.95 \\ 12.12 & -6.55 & -13.20 & -3.95 & -1.88 & 1.75 & -2.79 & 3.14 \\ -7.73 & 2.91 & 2.38 & -5.94 & -2.38 & 0.94 & 4.30 & 1.85 \\ -1.03 & 0.18 & 0.42 & -2.42 & -0.88 & -3.02 & 4.12 & -0.66 \\ 0.17 & 0.14 & -1.07 & -4.19 & -1.17 & -0.10 & 0.50 & 1.68 \end{pmatrix}} v$$

DCT does not compress the image, so the compression occurs in the form of quantization [5].

- **Quantization**

The quantization step is used to remove data from the transformed image DCT matrix by dividing it by the used quantization matrix. Quantization reduces high-frequency DCT coefficients to zero, resulting in more compression and lower frequencies for image reconstruction due to human eye sensitivity. Here are the quantization matrices one for luminance and the other for the chrominance component [8].

$$Q_y = \begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 75 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}$$

$$Q_c = \begin{bmatrix} 17 & 18 & 24 & 47 & 99 & 99 & 99 & 99 \\ 18 & 21 & 26 & 66 & 99 & 99 & 99 & 99 \\ 24 & 26 & 56 & 99 & 99 & 99 & 99 & 99 \\ 47 & 66 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \\ 99 & 99 & 99 & 99 & 99 & 99 & 99 & 99 \end{bmatrix}$$

Using the above quantization matrix along with the DCT coefficient matrix from the above results, we will get the resultant matrix as follows [5]:

$$\begin{bmatrix} -26 & -3 & -6 & 2 & 2 & -1 & 0 & 0 \\ 0 & -2 & -4 & 1 & 1 & 0 & 0 & 0 \\ -3 & 1 & 5 & -1 & -1 & 0 & 0 & 0 \\ -4 & 1 & 2 & -1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

- **Ac and DC Coding With Zigzag Sequence.**

The process involves lossless compression by encoding quantized DCT coefficients, resulting in a DC coefficient separate from 63 AC coefficients. The DC coefficients, crucial for image energy, are encoded as a difference between 8 × 8 blocks [5]. After encoding the DC coefficient, the zigzag sequence sorts all the quantized coefficients as illustrated in Figure 3.

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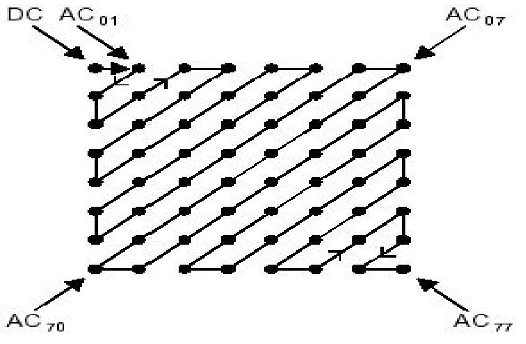

Figure3: Zigzag Sequence

Foremost, the zigzag sequence encodes coefficients with lower frequencies that have higher values then it encodes coefficients with higher frequencies that have zeros or approximately zero. therefore, the result will be a sequence of similar data bytes. This allows us to do efficient entropy encoding [8]. The zigzag sequence that we have got in Figuer 3, will be shown as follows [5]:

-26							
-3	0						
-3	-2	-6					
2	-4	1	-3				
1	1	5	1	2			
-1	1	-1	2	0	0		
0	0	0	-1	-1	0	0	
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	
0	0	0	0	0	0		
0	0	0	0	0			
0	0	0	0				
0	0	0					
0	0						
0							

- **Entropy Coding.**

The process of achieving lossless compression in JPEG involves using Huffman and arithmetic coding techniques. Huffman coding uses predefined tables for compression and decompression, while arithmetic coding adapts to image statistics but is more complex [5].

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- **Image Decompression.**

The compression process involves restoring Huffman tables, decompressing Huffman tokens, decomposing blocks using DCT values, filling in zeros, and combining zigzag sequences. The inverse (IDCT) checks the contribution of 64 frequency values to each pixel [8].

2.2.2 JPEG 2000 (Joint Photographic Experts Group).

This type of format is designed to overcome the disadvantages of the JPEG format and produce high-quality images. JPEG 2000 is a compression standard based on discrete wavelet transform (DWT).
In the year 2000, this formatting standard was created to replace the original JPEG format, which is based on the discrete cosine transform (DCT) that was created in 1992 [9].
The JPEG 2000 format offers a 10%–30% image compression ratio and a smoother image appearance, making it suitable for various applications like the internet, remote sensing, mobile applications, medical treatment, digital libraries, and e-commerce. It supports progressive transmission, making it the mainstream static image compression format in the 21st century [4].

a) Process of JPEG 2000 compression Algorithm.

The JPEG 2000 compression steps are shown in this section as follows:

- **Color space conversion.**

The first stage involves converting RGB to YUV or RCT, a lossless compression method similar to the JPEG method, using a formula.

$$G = Y_r - \left[\frac{U_r + V_r - 2}{4}\right] \quad , Y_r = \left[\frac{R + G + B}{4}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$R = U_r + G U_r = R - G$

$R = V_r + G V_r = B - G$

- **Tiling.**

In this stage, we divide the image into blocks. Then each block is compressed separately. This step is significant because it only

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restores specific parts of the image, not the whole image if desired [9].

- **Discrete Wavelet Transform (DWT)**

The discrete wavelet transform converts pixel information from the spatial to the frequency domain using cascaded filters. The input image X is fed into low and high pass filters, subsampled, and reconstructed using synthesis filters L and H, as shown in Figure 4.

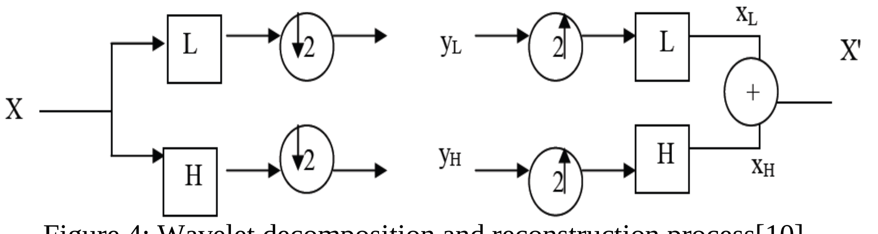

Figure 4: Wavelet decomposition and reconstruction process[10]

The 2D implementation of the discrete wavelet transform involves performing one-dimensional DWT in a row and column direction, with L representing the rough image and LH, HL, and HH representing the detailed information as shown in Figure 5.

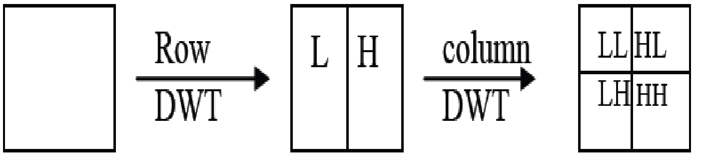

Figure 5:2D row and column computation of DWT[10]

Further computation of DWT can be performed as the level of decomposition increases. The concept is illustrated in Figure 6. The second and third-level decompositions based on the principle of multiresolution analysis show that the LL1 subband shown in Figure 6 is decomposed into four smaller subband: LL2, LH2, HL2, and HH2 [10].

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Figure 6: second and third level row and column decomposition[10]

- **Region of Interest (ROI).**

PEG 2000 allows for the definition of regions of interest in an image, which are coded with better quality by scaling up or DC shifting coefficients, placing these bits in a higher bit plan and decoding them first [11].

- **The quantization of DWT results.**

The main objective of this step is to reduce the frequencies with high coefficients to zeros, as in the JPEG.

- **Entropy Coding.**

The final step in the algorithm involves a bit-plane coding technique, based on the embedded block code with the optimized truncation (EBCT) algorithm implemented independently in each code block [9].

3. Methodology

This research is conducted using two lossy compression algorithms, which are JPEG using DCT and JPEG 2000 using DWT. They are implemented using Matlab software and a wavelet toolbox for DWT decomposition and synthesis. Particularly, the Harr wavelet is used in this research.
Furthermore, both algorithms have been executed by choosing the Lenna image in BMP format, and the image size is 512 × 512 × 3.

4. Results and Discussion

In this section, results obtained from the two algorithms will be presented and discussed.

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4.1Results of JPEG using DCT

Based on the results in Table 1 and the compressed images" a-e" in figure 7, it can be said that quality levels can be selected in the range of 1 to 100. Where level 1 gives the poorest quality and highest compression ratio as given in image "c", while level 100 gives the best quality and lowest compression ratio as seen in image "e".

Table1: JPEG compression ratio using DCT

Compression Level	Original image size	Compressed image size	Compression Ratio
Level 1	769 KB	9 KB	85.4%
Level50	769 KB	28 KB	27.4%
Level 100	769 KB	418 KB	1.8%

Figure 7: different compression levels. (a) Original image. (b)Converting RGB to YCbCr. (c) Compressed image at level 1.(d) Compressed image-level 50. (e) Compressed image-level 100.

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Consequently, the quality-to-compression ratio can be selected to meet different applications. The study in [6] has mentioned that the algorithm's ability to adjust the compression rate is one of its distinguishing features, which adds to its flexibility. When we compress an image heavily, more information is lost, but the final image size is reduced. Better quality is obtained with less compression, but the final image will be larger in size.
The JPEG committee suggests a matrix with a quality level of 50 as a standard matrix [11].
After generating all compressed images, the compression ratio (CR) is calculated by the following formula:

CR= Original image size / Compressed image size.

4.2 Results of JPEG 2000 using DWT

It can be seen from the results shown infigures (8, 9 and10) and Table2 that compressed images have various levels of value. As the level value increases, the blurring of the image continues to increase.
There are various parameters for image quality calculation, including peak signal-to-noise ratio and mean squared error, which are calculated using the following relations [6]:

$$\text{MSE} = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(x(i,j) - y(i.j))^2 \quad \text{……………………..(5)}$$

The peak error between the actual and compressed image is measured by the PSNR as follows:

$$\text{PSNR (dB)} = 10\,\log_{10}\left(\frac{255^2}{MSN}\right) \quad \text{…………………………...….(6)}$$

i(x,y) denotes the actual picture, z(x,y) denotes its approximate representation (which is the decompressed image), M and N denote the size of the images. A lower MSE value indicates fewer mistakes, and since the MSE and PSNR have an inverse relationship, this results in a higher PSNR value [6].
It is very clear that as PSNR increases, the compression ratio will increase, and the quality of the compressed image will increase,as given in Table2.

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Table2: Compression ratio and PSNR of JPEG 2000

Compression level	Compression ratio	PSNR
Level1	61.21%	23.16
Level 4	1.19 %	21.42
Level 5	0.35 %	20.23

Therefore, DWT performs better than DCT in the context of avoiding blocking artifacts that degrade reconstructed images. According to study in [1], comparing DCT to Haar wavelet, DCT has a lower compression ratio and PSNR. Better image quality is indicated by a greater PSNR. A high-frequency sub band with improved resolution is used to adaptively quantize them. Moreover, a study in [11] indicated that, according to findings comparing JPEG-2000 to traditional JPEG [61], there is a 20–30% improvement in compression for the same quality at about a 2dB improvement in image quality (measured using PSNR) at the same bit rate. JPEG-2000's superiority is most notable at low bit rates (for example, compression ratios > 10:1). On the other hand, DWT requires longer computation time to compress the image.

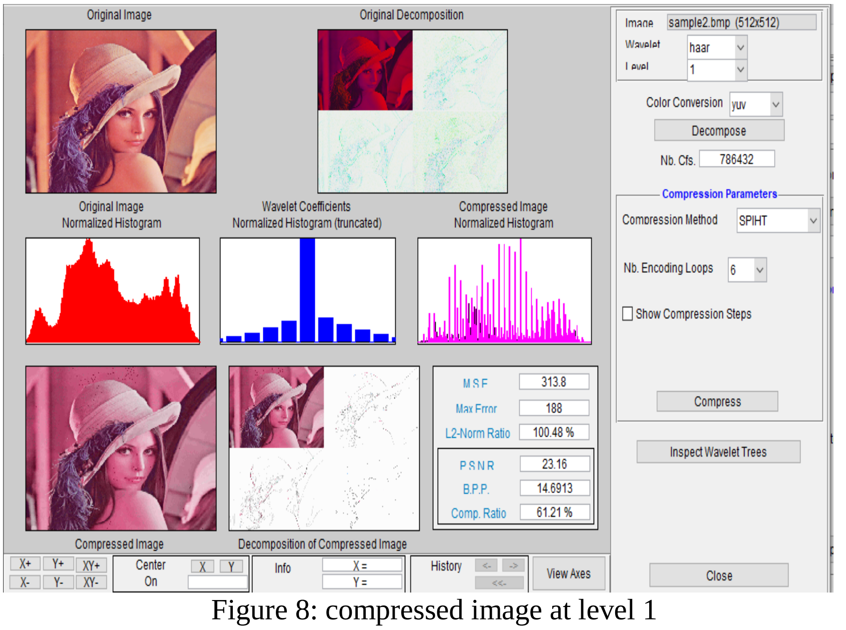

Figure 8: compressed image at level 1

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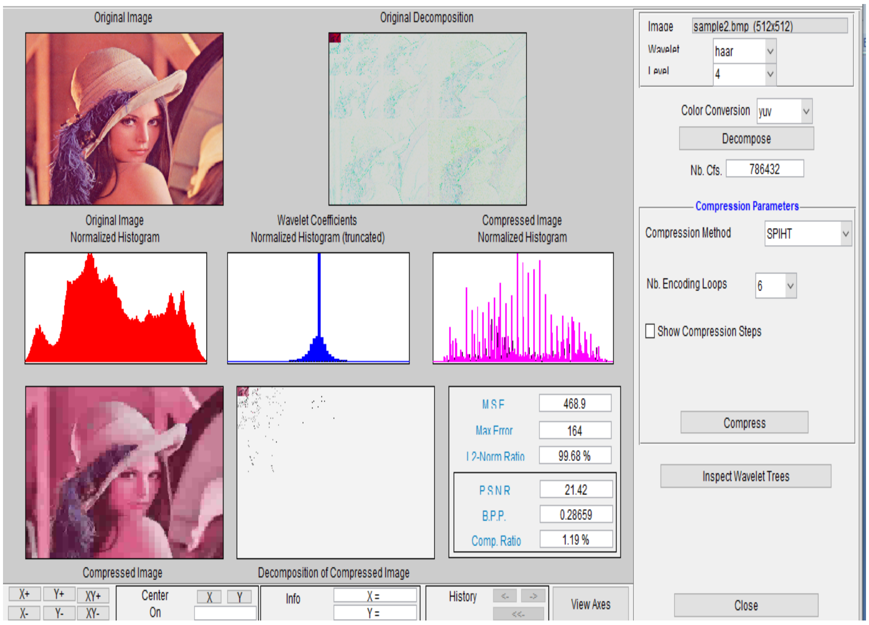

Figure 9: Compressed image at level 4

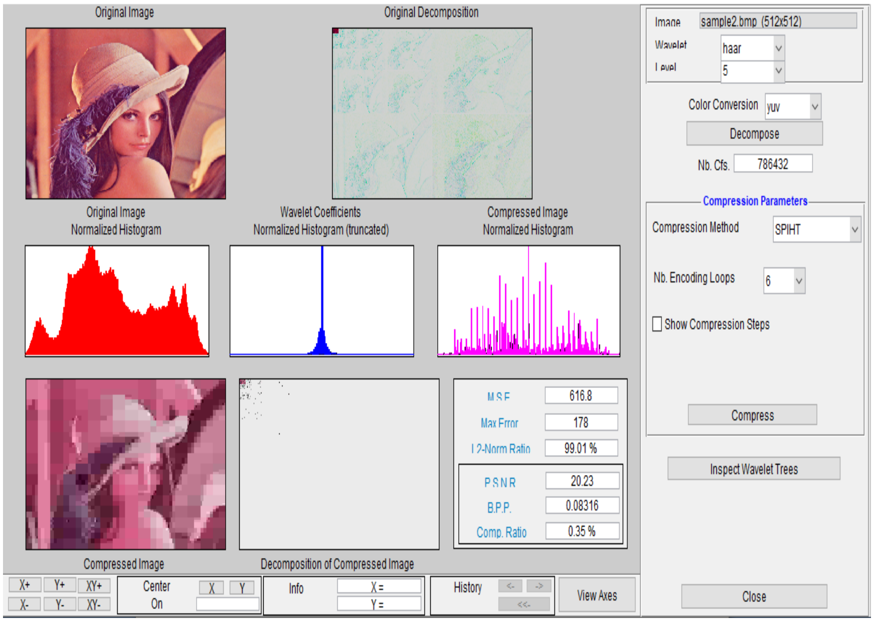

Figure 10: Compressed image at level 5

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5. Conclusion

It is evident, in conclusion, that JPEG 2000 using DWT and JPEG utilizing DCT were both introduced. The two approaches were then compared to see which produced better results in terms of compression ratio and image quality. DWT is superior to DCT in preventing blocking artifacts that degrade the reconstructed images. The image quality of JPEG 2000, as assessed by PSNR at the same data rate, is also better than that of regular JPEG, according to the results.

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