International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 23 (2017) pp. 13951-13958

Implementation of Image Compression Using Discrete Cosine Transform (DCT) and Discrete Wavelet Transform (DWT)

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Abstract

This research is research on the application of discrete transformation cosine (DCT), discrete wavelet transformation (DWT), and hybrid as a merger of both previous transformations in the process digital image data compression. Compression process done to suppress the source consumption memory power, speed up the transmission process digital image.

Image compression is the application of Data compression on digital images. The Discrete Cosine Transform (DCT) is a technique for converting a signal into elementary frequency components. It is widely used in image compression. Discrete Wavelet Transform (DWT) algorithm can compact the energy of image into a small number of coefficient, give combination information of frequency and time, so that more accurate to reconstruct of image.

Keywords: Compression, DCT, DWT, Converting, Algorithm, Coefficient

INTRODUCTION

Image compression means reducing the size of the image by encoding it using fewer bits and it is used to minimize of memory needed to represent this image. Image compression is extremely important for transmission of images and video over the communication channels to minimize the required channel bandwidth by reducing data that represent the image or video, and it is used to minimize the consuming of expensive storage devices such as hard disk space. For the compression algorithm to be effective, it must fulfill low bit rate in the quality of image.

FUNDAMENTAL OF DIGITAL IMAGE

The image can be defined as a visual representation of an object or group of objects. When using a computer or another digital equipment to deal with the photographic image(capture, modify, store and view), it must be converted firstly to a digital image by a digitization process, which converts the image to an array of numbers, because the computer is very efficient in storing and operating with numbers. Therefore, when image is converted to digital form, it can be easily examined, analyzed, displayed, or transmitted. The digital an approximation image is formed by measuring the color of this image at many numbers of points (or pixels). From these numbers the original image is reconstructed. In a digital image, the array of pixels is arranged in a regular shape of rows and columns, which is usually called a bitmap. This array consists of N rows and M columns, and usually N=M. Typical values of N and M are 128, 256, 512and 1024 etc [13-14].

THE NEED FOR IMAGE COMPRESSION

Image compression is the technique that is used to solve the problem of large size of a digital image by minimizing data that required to represent this image. The key concept of the size reduction is removing redundant data. This redundancy occurs, when the two dimensional array pixel is transformed to a statistically uncorrelated set of data. The image is decompressed at the receiver to be able to reconstruct the original image (in case of lossless compression) or an approximation to it (in the case of lossy compression).

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 23 (2017) pp. 13951-13958
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THE PRINCIPLES OF IMAGE COMPRESSION

The main principles of image compression is to remove the redundant data in the image, where most of images have their neighboring pixels correlated to each other and this correlated pixels include less information, so this correlated data can be removed by using some form of image compression techniques [15].

In fact, any image compression system depends on removing the redundant data and removing the duplication from the original image, where the part of the image that cannot noticed by the image receivers like Human Visual System (HVS) is omitted. This redundancy is divided into three types, they are [16]:

- Spatial Redundancy are obtained from the correlation between adjacent pixel values.
- Spectral Redundancy are obtained from the correlation between the spectral bands.
- Temporal Redundancy are obtained from correlation between adjacent frames in a sequence of images (in video applications).

Compression is done by removing the spatial and spectral redundancies (in image compression) and temporal redundancy in (video compression) as much as possible, because this reduces of bits required to represent the image [16].

LOSSLESS AND LOSSY COMPRESSION

Lossless compression is an algorithm, where the original image can perfectly reconstructed without any loss. Lossless compression is very important in applications that required the reconstructed image to same as original image as in the medical images. The images in file formats like .png and .gif must be in lossless compression formats. On the contrary, in the lossy compression algorithm, the original image cannot be reconstructed and the reconstructed image slightly differs than the original image, because in lossy compression the redundancies in the original image are neglected. The advantage of the lossy compression is its high compression ratio [14].

LOSSY IMAGE COMPRESSION

The lossy image compression consists of three main steps as shown in Figure 1 they are [14]:

- Transformation: where the original image are transformed linearly from the image domain to another domain.
- Quantization: where the transformed image coefficients is quantized using the quantization matrix.
- Encoding: after the quantization stage, the encoding is done to give the compressed image.

In the reconstruction process, the reverse steps of compression process are done where the compressed image is decoded, and then dequantized and finally an inverse transformation process is performed to give the reconstructed image as shown in Figure 1.

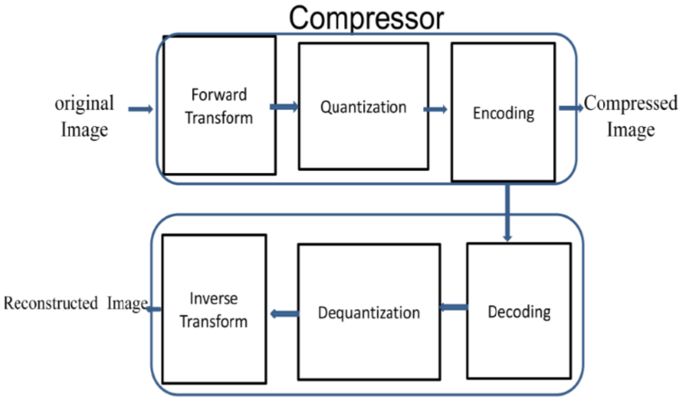


Figure 1: The architecture of a lossy image compression system [14].

IMAGE TRANSFORMATION

In a linear transformation, the image is transformed from spatial domain to another domain, where the representation of the data is more compact (energy compaction) and less correlated. A significant number of linear transformations has been used in the recent years. Some popular transformation used in image compression are discussed below. One-dimensional signal is useful for sound/audio waveform. As for the image/video frame which is a two dimensional signal. Therefore, this section will present about two dimensions

Discrete Cosine Transform (DCT)

Discrete Cosine Transform (DCT) is considered as important transformations used in data compression technology. [18-19].

1. 2D DCT

The forward and inverse 2D DCT are given by Equations:

$$Gij = \sqrt{\frac{2}{m}}\sqrt{\frac{2}{n}}CiCj\sum_{x=0}^{n-1}\sum_{y=0}^{m-1}Pxy\cos\left[\frac{(2y+1)j\pi}{2m}\right]\cos\left[\frac{(2x+1)i\pi}{2n}\right]$$

For $0 \le i \le n-1$ and $0 \le j \le m-1$ and

$$Cf = \begin{cases} 1/\sqrt{2}, & for\ f = 0 \\ 1, & for\ f > 0 \end{cases} \quad for\ f = 0,1,\dots,n-1$$

Where P is the input pixel value, n is number of the input data set, Cf is a constant, and the output is a set of n DCT transform coefficients (Gf).

The first coefficient G_{ij} is called the DC coefficient, and the rest are called the AC coefficients.

$$Pxy = \sqrt{\frac{2}{m}}\sqrt{\frac{2}{n}}\sum_{x=0}^{n-1}\sum_{y=0}^{m-1} CiCjGij\cos\left[\frac{(2x+1)i\pi}{2n}\right]\cos\left[\frac{(2y+1)j\pi}{2m}\right]$$

For $0 \leq i \leq n-1$ and $0 \leq j \leq m-1$ and

$$Cf = \begin{cases} 1/\sqrt{2}, & for\ f = 0 \\ 1, & for\ f > 0 \end{cases} \quad for\ f = 0,1,\dots,n-1$$

For the image compression by DCT, firstly, the image is divided into K blocks, each block has a size of 8×8 (or 16×16) pixels, The pixels are denoted by Pxy , where x refers to the row number and y the column number. If the number of rows in the image is not divisible by 8 (or 16), the bottom row is duplicated as many times as needed and if the number of column is not divisible by 8 (or 16), the right most column is also duplicated.

Discrete Wavelet Transform

Discrete Wavelet Transform (DWT) is one of the methods used in digital image processing. DWT can be used for image transformation and image compression. In addition to image processing (drawing), the DWT method can also applied to steganography.

The process of wavelet transform is a simple concept. The original transformed image is divided into 4 new sub-images to replace it. Each sub-image is ¼ times the original image. The sub-image on the top right, the bottom left and the bottom right will look like a rough version of the original image as it contains the high frequency components of the original image. As for the upper left sub-image looks like the original image and looks smoother as it contains the lower frequency components of the original image. Because it is similar to the original image, the upper left sub-image can be used to approximate the original image. While the pixel value (coefficient) 3 other sub-image tend to be low value and sometimes zero (0).

1. 2D DWT

The 1D DWT illustrated in the previous section can be extended to the 2D image of (M×N) dimensions. In this case, it is called 2D DWT [15]. When the 2D DWT is applied on an image, first 1D filtering is applied along rows and columns of the image. The output from this decomposition is four sub-components LL, HL, LH, and HH, where L refer to the low pass filter and H refer to the high pass filter, and this case is considered one level decomposition.

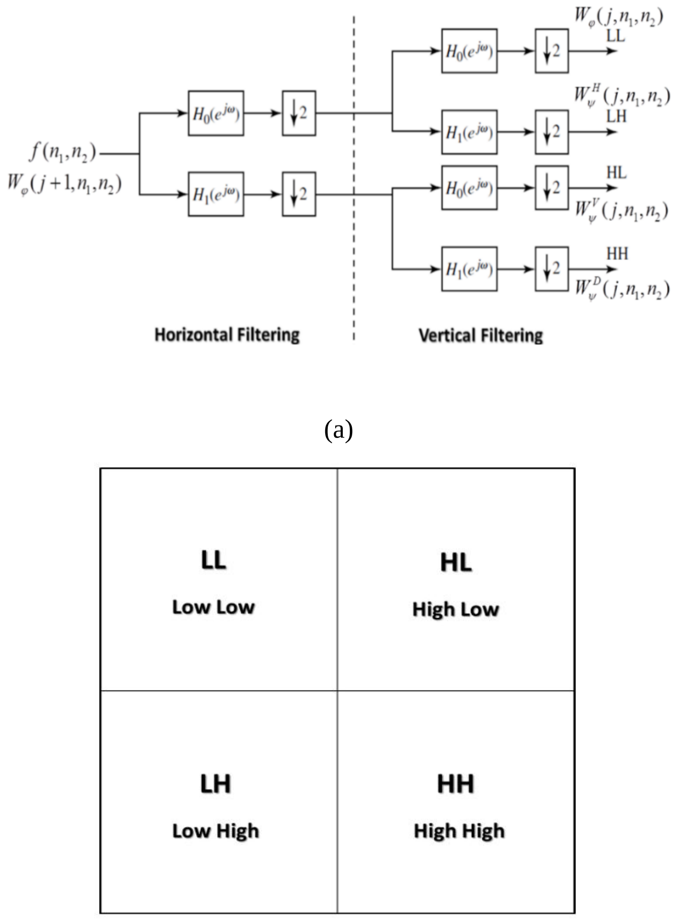


Figure 2: Decomposition of image into four sub-bands: (a) basic scheme; (b) sub-bands for 1-level decomposition.

In order to obtain multi-level wavelet decomposition, the Figure 2(a) is applied again to the LL sub–component to produce four sub-components. This operation can be repeated many times according to the required wavelet decomposition level. The cascade filter bank achieve two-level wavelet decomposition in Figure 3.

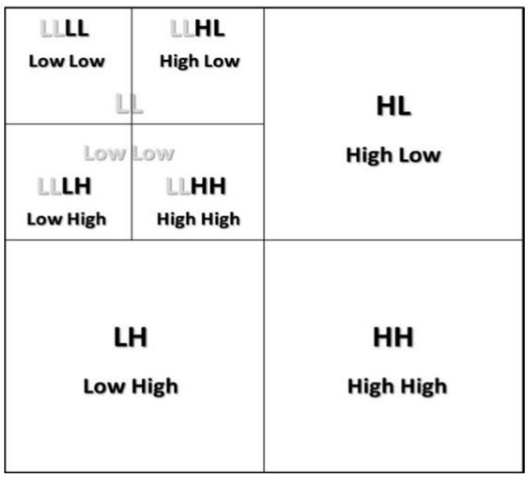


Figure 3: Decomposition of image into seven sub-bands: sub-bands for 2-level decomposition.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 23 (2017) pp. 13951-13958

Quantization

Quantization is considered the major source of compression process, because it reduces the bits to be able to store the transformed coefficient. Since the quantization is many to one mapping, and so the accuracy of the transformed coefficient values is minimized by the quantizer. The quantizer has two main types:

- Scalar Quantization (SQ), the quantization are done on each coefficient.
- Vector Quantization (VQ), the quantization are done on group of coefficients, simultaneously.

Scalar Quantization (SQ) and Vector Quantization (VQ) can used according to the problem at the hand [18].

Encoding

Encoding is the last process that occurs in the encoder of the compression scheme, where the quantized values are compressed to produce the best compression results. At the encoder, the probabilities of occurrence of the quantized values are precisely determined to give convenient code to make the output code stream smaller than the input one.

Encoding is considered a lossless process, because it reduces bit rate without loss in precision. This lossless coding scheme is known as entropy coding. Entropy coding is commonly the last stage in any compression system. In this stage, the output from the previous coding stages is converted to a binary code word stream. Each code word length in the output bit stream expresses the probabilities of occurrence of each symbol, where the symbol of high probability takes short length and the other with low probability takes long length [17].

This section presents some of the most common lossless symbol coding such as Huffman coding and run-length coding (RLE).

1. Huffman Coding

Huffman coding is an important for data compression system. Huffman coding mainly depends on probability of the data occurring in the sequence, where the symbols with high occurrence probability take fewer bits than the symbols with low probability [15-16].

Example for Huffman coding

An example of the Huffman coding is explained in this section, where Figure 5 [14] shows a pixel symbol sequence consist of 6 pixels and their probabilities.

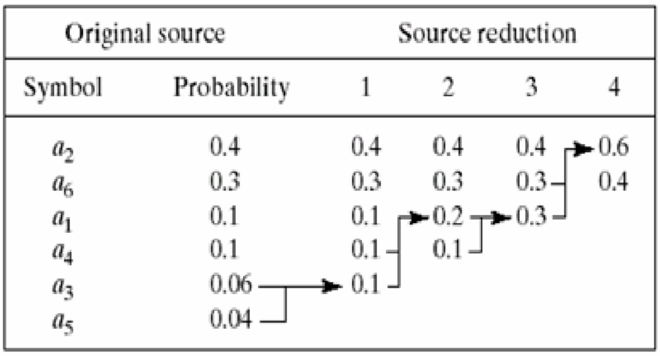


Figure 4: Example of Huffman code assignment.

Initially, the probabilities of occurrence are arranged in ascending order, and then the Huffman code sums the two lowest probability into a new pixel with a new probability, by repeating this operation until there are 1. The binary 0 and 1 are given to the source on the right, then we go back with the same path, adding 0 and 1 to the source. Figure 5 shows the final code for each symbol [14]

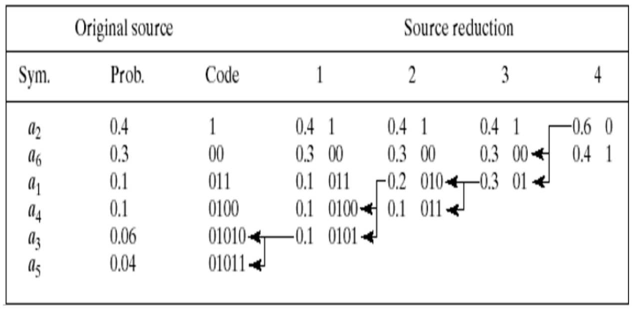


Figure 5: Huffman Coding (final code).

As can be shown from Figure 5, the symbol with high probability of occurrence has only the code with only 1 bit, and the symbol with low probability of occurrence has the code with 5 bits. Implementation details of Huffman encoding and decoding algorithms can be found in [15].

2. Run-Length Coding

Run length coding technique depends on the inter-pixel redundancy that exists in images [14][19]. In image compression system, the run length coding looks for gray levels repeated along each row of the image. A 'run' of pixels whose gray level is identical is replaced with two values; the length of the run and the gray pixels in the run, for example the sequence (50, 50, 50, 50) becomes (4, 50). Run length coding can be applied on a row-by-row of the image, where the image is considered as a one-dimensional data stream in which the last pixel in a row is adjacent to the first pixel in the next row, if the right and left–hand sides of similiar image, the compression ratio becomes higher.

In the case of binary images (with all values as zeros and ones), there is no need to record the value of the run except the first run in the first row, because the pixels values in the binary image are only 0 or 1, and if the first run has one of these values, the second run must have the other values, and surely the third run has the same value as the first, and so on. Note that if the run is of length 1, the run length coding will replace one value with a pair of values and this will increase the size of the dataset in the compressed image. This may occur for noisy or uncorrelated images.

JPEG

Joint Photographic Experts Group (JPEG) are an international standard for image compression. JPEG is presently a universal standard for digital image compression.

Figure 6 shows the basic architecture for the encoder and the decoder in the JPEG compression system. The JPEG encoder as shown in this figure consists mainly of three units; transformation, quantization and encoding. Firstly, the image are cut into blocks, each block has a 8x8 pixels size, the 2-D DCT is applied on each block and insignificant information is discarded and thrown away. At the last step, the quantized coefficients are compressed using an entropy coding method like Huffman coding to reduce the image size with good quality.

In the transformation stage in the JPEG encoder, the 2-D Discrete Cosine Transform are used to transform an image from image domain to frequency domain, where the low frequency is more important and influential in the image than the high frequency.

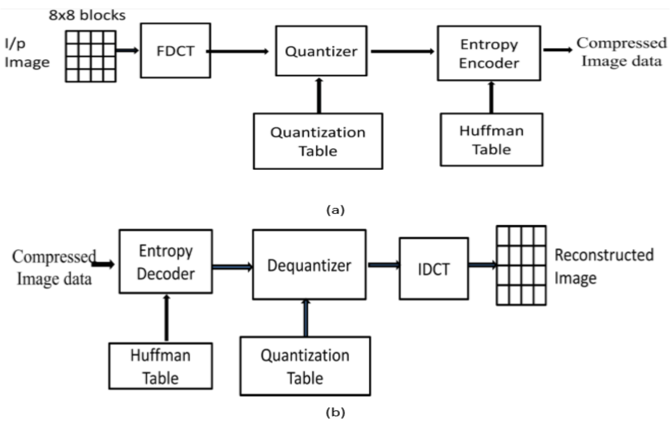


Figure 6: Architecture for a JPEG compression system (a) Encoder and (b) Decoder [17].

Quantization is the next stage after transformation step. In this stage, each element of coefficient is divided by corresponding element in to an 8×8 matrix, and then the result is rounded. A quantization matrix is required for the image component.

The quantized coefficient is determined by Equation:

$$Xq[m,n] = \left[\frac{X[m,n]}{q[m,n]}\right] Round$$

Where X[m,n] is DCT coefficient and q[m,n] is quantization matrix coefficient. Note, that the first coefficient in the DCT matrix is called the direct current (DC), the other coefficients is called alternating current (AC).

Quantization is considered as the main reason that makes the coding lossy. After quantization stage, the quantized DCT coefficients array (with majority of numbers as zero) is scanned in a zigzag method as shown in Figure 7. This scanning method makes the DCT coefficients increasing spatial frequency, start with low frequency coefficients and end with the high frequency ones to concentrate the zeros together to be encoded efficiently with a suitable encoder (such as the Huffman coder) as the final stage in the JPEG encoder system.

8 x 8

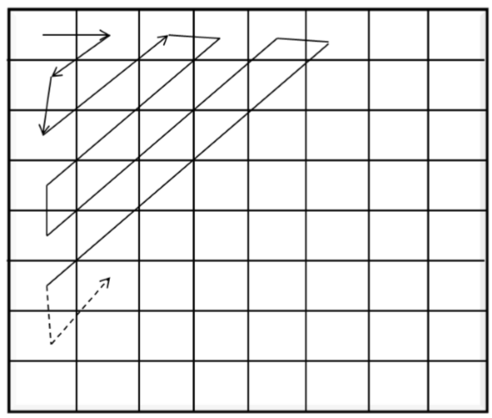


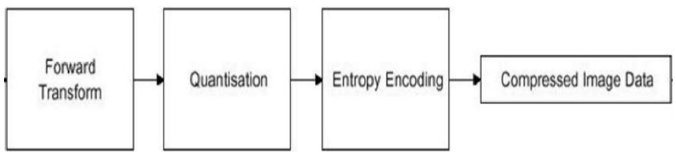
Figure 7: Zigzag scan procedure [10].

JPEG 2000

JPEG 2000 is an image coding algorithm, which a modified of JPEG that uses DWT instead of DCT in the JPEG compression technique. The status of the Parts is available at the official website [16]. An overview of the JPEG 2000 Part 1 is provided below.

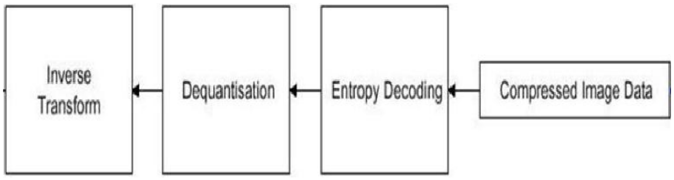
The 2-D DWT images are based on tree structure, which can be achieved using a suitable bank of low pass filters and high pass filters. Figure 8 shows the block diagram of JPEG 2000.

Source image data



(a)

Store or Transmit



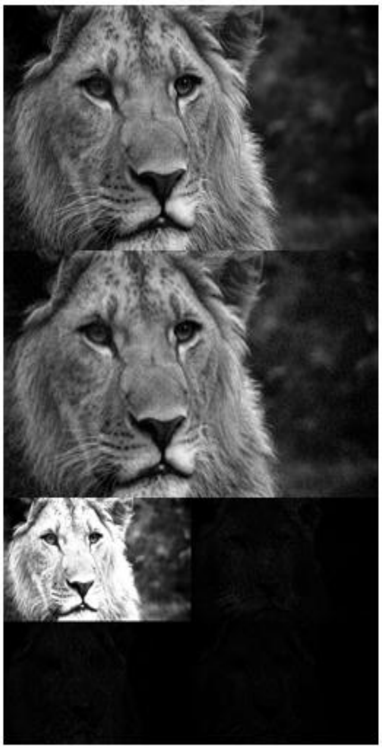
(b)

Reconstructed image data

Figure 8: JPEG2000 (a) Encoder and (b) Decoder [14].

The blocks HL, LH and HH in each level contain many small coefficients, because the blocks is obtained by applying high pass filter to the image of previous level.

SIMULATION RESULT



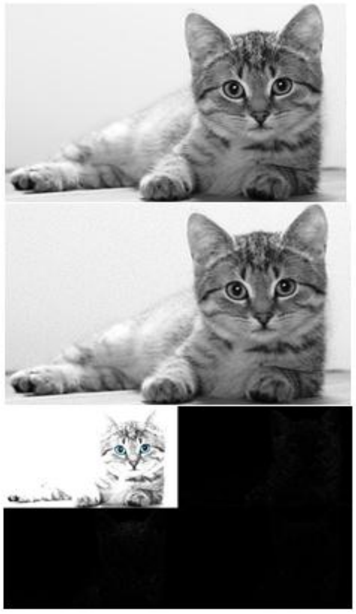
(a) Original Image

(b) Compressed with DCT

(c) Compressed with DWT

Figure 9: Lion.jpg (a) Original and (b) Compressed DCT (c) Compressed DWT.

In figure 10, the image lion.jpg has size 111 KB in original (a). Then with DCT Compression the size is 82.5 KB and 73.6 KB with DWT Compression. It show the compression ratio with DCT compression is 25.67% and 33.69% with DWT Compression.



(a) Original Image

(b) Compressed with DCT

(c) Compressed with DWT

Figure 10: Cat.jpg (a) Original and (b) Compressed DCT (c) Compressed DWT.

In figure 11, the image cat.jpg has size 61 KB in original (a). Then with DCT Compression the size is 55.2 KB and 34.2 KB with DWT Compression. It show the compression ratio with DCT compression is 9.50% and 43.93% with DWT Compression.

(a) Original Image

(b) Compressed with DCT

(c) Compressed with DWT

Figure 11: Wolf.jpg (a) Original and (b) Compressed DCT (c) Compressed DWT.

In figure 12, the image wolf.jpg has size 68 KB in original (a). Then with DCT Compression the size is 61.3 KB and 42.1 KB with DWT Compression. It show the compression ratio with DCT compression is 9.85% and 38.08% with DWT Compression.

COMPRESSION RESULT

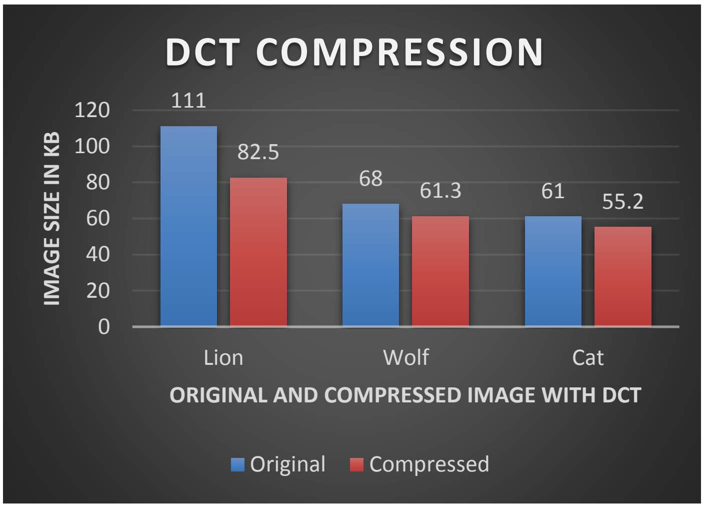


Figure 12: DCT compression

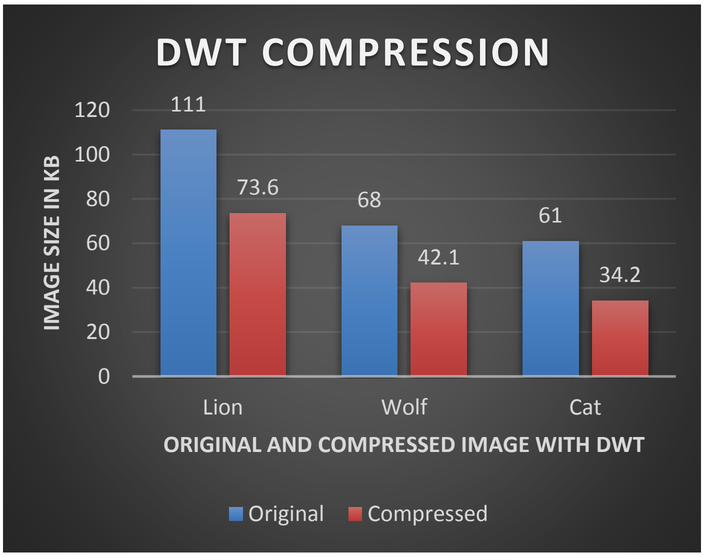


Figure 13: DWT compression.

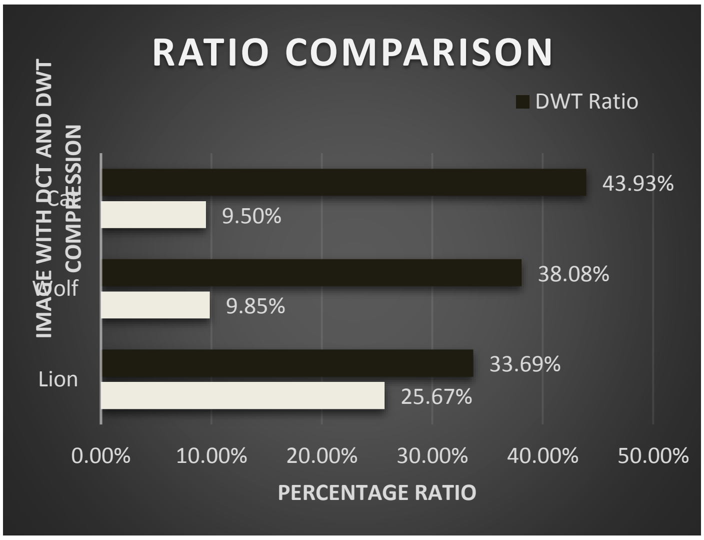


Figure 14: Comparison of DCT and DWT compression.

CONCLUSIONS

From the experimental results, we can see that the compression ratio using DWT is greater. Which means compression by using DWT method is smaller. However, we can get a better image with DCT method.

DCT (Discrete Cosine Transform)

- Concentrate image energy into a small number of coefficients (energy compaction).
- Minimizes interdependencies among coefficients (decorrelation).
- Not resistant to changes in an object
- DCT calculates the quantity of bits of image where the message is hidden inside.

DWT (Discrete Wavelet Transform)

- Inserting the watermark image into the original image using DWT by inserting the watermark image into the wavelet coefficient of the original image.
- Decomposition of digital images using Discrete Wavelet Transform is done by taking the wavelet coefficient of the image, wavelet coefficient also used to reconstruct the image again using IDWT.
- Extraction of watermarks inserted using DWT is done by taking the watermark of the wavelet coefficient of the image.

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