PERFORMANCE ANALYSIS OF VECTOR QUANTIZATION BASED LOSSY IMAGE COMPRESSION

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ABSTRACT *— This paper presents a Lossy image compression technique which is combination of discrete wavelet transform (DWT), Thresholding, Vector Quantization (VQ) and Huffman coding. Proposed method is as follows, First, DWT is performed on the original image then Globle Thresholding technique is applied and resulting coefficients are then vector quantized. VQ indices are Huffman coded to increase the compression ratio. There are many lossy techniques exists for image compression in digital domain, among this wavelet transformation based image compression by using vector quantization (VQ) provides good picture quality and better image compression ratio compared to all other techniques. Vector quantization (VQ) has the potential to greatly reduce the amount of information required for an image because it compresses in vectors which provides better efficiency than compressing in scalars. The objective is to generate the standard codebook by using some standard training set which is capable of successfully coding images outside of the training set. Vector quantization (VQ) based coded images then encoded for transmission by using Huffman encoding. A SSIM (Structural similarity index measurement) is used to check the image quality result are measured in terms of Compression Ratio (CR), peak signal to noise ratio (PSNR) of the reconstructed image and Root Mean square error (RMSE) The proposed Lossy image compression techniques gives higher Compression Ratio with better image quality in terms of PSNR, SSIM, compared to other DWT and VQ based image compression techniques. The proposed method of image compression is useful for various applications criminal investigation, medical imaging, etc*

Index Terms— Discrete Wavelet Transform (DWT), Vector Quantization (VQ), Peak Signal to Noise Ratio (PSNR), Root Mean Square Error (RMSE), Structural Similarity Index Measurement (SSIM).

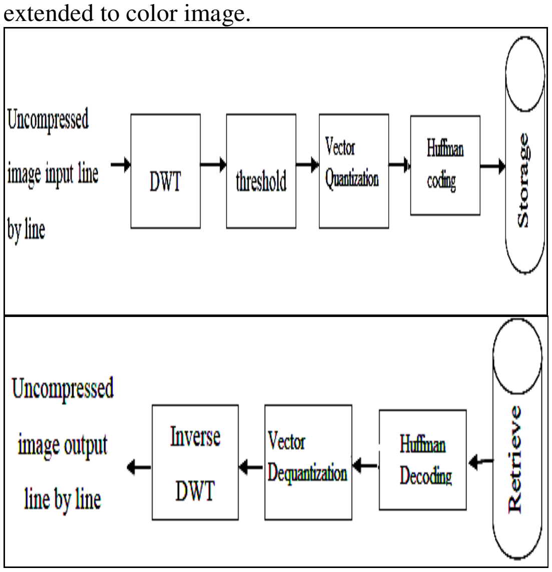
1. INTRODUCTION

Image compression has become an important research area for many years due to increasing demand on transfer and storage of data [1]. Image compression defines as reducing the amount of data required to represent digital image. However, image information contains a large of information, which brings a lot of difficulties for storage, processing and transmission. Thus image compression is very importance and necessity. There are two way to image compression (1) lossless compression and (2) lossy compression. Lossy image compression algorithms are applicable whenever the exact reconstruction of an image is not expected. These algorithms are usually based on transform methods. In recent years, a considerable effort have been made to design image compression method in which the main goal is to obtain good quality of decompressed images even at very low bit rates.

The basic aim of image compression is to reduce the storage requirement while maintaining acceptable image quality. Wavelet transform based vector quantization is (VQ) is one of the popular lossy image compression techniques for its simpler decoding structure and it can achieve high compression ratio while maintaining acceptable value of SSIM,FSIM and peak signal to noise ratio [1].

In this paper lossy compression technique is used. A Discrete wavelet representation provides access to a set of data at various levels of detail. However, wavelet analysis differs from Fourier analysis such that the different signal frequencies are described by individual wavelet basis functions are localized rather than global. Advantages of wavelet analysis include the following: very good image approximation with just a few coefficients [2]; it can be used to extract and encode edge information [2], which provide important visual cues in differentiating images. Moreover, the coefficients of wavelet decomposition provide information that is independent of the original image resolution. Thus, a wavelet based scheme allows us to easily compare images of different resolutions. Finally, wavelet decompositions are fast and easy to computer requiring linear time in the size of the image [2]. Transform does not reduce the amount of data present in the image. It is simply a different form of representation of the image. Vector quantization (one form of lossy compression technique) on the other hand can reduce the amount of data in the image.

In this work, a combined approach of image compression, based on the wavelet transform [2] [3] and Vector quantization [4] is presented. This proposed Lossy image compression techniques gives superior results which are in general applicable to any images. This proposed method of image compression is applicable to those areas of digital images where higher compression ratio with better reconstructed image is required like criminal investigations, medical imaging, etc. This method is tested on gray scale test images, but it can be easily extended to color image.



1.1 Algorithmic Steps:

The steps needed to compress an image are as follows:

1. Decompose the signal into a sequence of wavelet coefficients w.
2. Use threshold to modify the wavelet coefficients from w to another sequence w'.
3. Use Vector Quantization to convert w' to a sequence q.

4. Apply entropy coding to compress q into a sequence.

DWT can be used to reduce the image size without losing much of the resolution. For a given image, you can compute the DWT of, say each row, and discard all values in the DWT that are less than a certain threshold. We then save only those DWT coefficients that are above the threshold for each row and when we need to reconstruct the original image, we simply pad each row, with as many zeros as the number of discarded coefficients, and use the inverse DWT to reconstruct each row of the original image. We can also analyze the image at different frequency bands, and reconstruct the original image by using only the coefficients that are of a particular band. The steps needed to compress an image are as follows: [1]

In certain signals, many of the wavelet coefficients are close or equal to zero. Through a method called threshold, these coefficients may be modified so that the so sequence of wavelet coefficients contains long strings of zeros. Through a type of compression known as entropy coding these long strings may be stored and sent electronically in much less space. There are different types of threshold. In hard threshold, a tolerance is selected. Any wavelet whose absolute value falls below the tolerance is set to zero with the goal to introduce many zeros without losing a great amount of detail. There is not a straightforward easy way to choose the threshold.For each phase a new smaller threshold is defined. This threshold determines which of the wavelet coefficients should be classified as important. Since the threshold decreases, essentially the group of important coefficients widens from one phase to the next.

The fourth step of the process, known as Vector Quantization, which is a powerful tool for digital image compression. It is a classical quantization technique from signal processing and image compression which allows the modeling of probability density functions by the distribution of prototype vectors. It was originally used for data compression. It works by dividing a large set of points (vectors) into groups having approximately the same number of points closest to them. Each group is represented by its centroid point, as in k-means and some other algorithms [7] The wavelet coefficients are quantized during a number of iterations of what is called the “quantization loop.” This loop generates the quantization code. Whenever the stopping condition is met the loop is terminated (possibly in a middle of a phase) and with it the whole process. Each phase of the quantization loop creates two pieces of code: The first maps the locations of the wavelet coefficients that are labeled important (the notion “important” will be explained later) in the current phase. This is later called “the classified map.” The second describes the quantized value of each one of the significant chosen wavelet coefficients.

After Vector quantization, the discrete values are entropy encoded using Huffman coding. We map the set of quantized coefficients to a set of symbols so that the total number of bits per symbol gets minimized. The encoding process works with the probabilities of the quantized coefficients. We assume that these coefficients have stationary statistics. Then, Huffman coding encoding is used.

Reconstruction of compressed image is done by the reverse process of the above compression process. But we cannot get exactly original image because of there is some error due to quantization and threshold. Though in DWT, we get very high compression ratio, we lose minimum amount of information. But if we do more than one level then we get more compression ratio but the reconstructed image is not identical to original image. MSE is greater if DWT apply more than one level.

2. PRINCIPLE OF WAVELET TRANSFORM

Image wavelet transform adopts the fast algorithm of two dimensional wavelet transform. The original image is decomposed into four sub-bands after passing a high- pass filter and low- pass filter [5]. The four sub-bands are LL, HL, LH and HH respectively. LL is a low frequency sub-band of the approximate image. HL is a high frequency sub-band of the horizontal details of the image. LH is a high frequency sub-band of the vertical details of the image. HH is a high frequency sub-band of the diagonal details of the image. The process is called the first level of wavelet decomposition. The low frequency sub-band can be continually decomposed into four sub-bands. The decomposition can be infinitely repeated in theory. But people must take the quality of the reconstructed image into consideration. Thus, people don't decompose image beyond the fifth level. Researchers usually use the third level. The model of wavelet decomposition of the third level is shown in Fig.1. Image information does not reduce and can't realize image data compression after the wavelet transform. But the energy of whole image is redistributed after this transform. The image of low frequency sub-band contains major information. The values of high frequency sub-band approximate zero, the more high frequency the more obvious this situation. For image, the part of the low frequency is primary part which can represent the image information. So researchers take full advantage of the characteristic after wavelet transform and employ proper method to process the image coefficients for achieving effective compression.

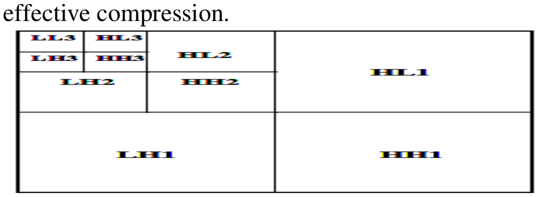
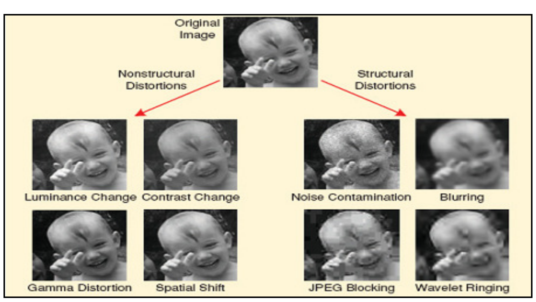


Fig.1 [3 Level wavelet decomposition][16]



In certain signals, many of the wavelet coefficients are close or equal to zero. Through a method called threshold, these coefficients may be modified so that sequence of the wavelet coefficients contains long strings of zeros. Then by using entropy encoding compression technique these long strings may be stored and sent electronically in much less space. There are different types of threshold. In hard threshold some tolerance is selected. Any wavelet whose absolute value falls below that selected tolerance is set to zero with the goal to introduce many zeros without losing the great amount of details. There isn‟t another straightforward way to choose the threshold value. Although the larger the threshold chosen the more error introduces into the process.

The fourth step of the process known as vector quantization (VQ) converts a sequence of floating numbers "w" to a sequence of integers "q". The simplest form is to round the nearest integers. Another option is to multiply each number by a constant "k", and then rounding it to the nearest integer. This quantization process is called Lossy because it introduces an error into the process, since the conversion of "w" to "q" is many-to-one function. Reconstruction of compressed image is done by the reverse process of the above compression process. But we cannot get exactly original image because of there is some error due to quantization and threshold. Though in DWT we achieve very high compression ratio by losing minimum amount of information and if we increases the levels then we get more compression ratio but the reconstructed image is not identical to the original image. MSE also increases if the level of DWT increases [6]

3. VECTOR QUANTIZATION

Vector quantization is a powerful tool for digital image compression. The vector quantization is a classical quantization technique from signal processing and image compression which allows the modeling of probability density functions by the distribution of prototype vectors. It was originally used for data compression. It works by dividing a large set of points (vectors) into groups having approximately the same number of points closest to them. Each group is represented by its centroid point, as in k-means and some other algorithms [7]

3.1 Principle of Vector Quantization

Vector Quantization assist to project a continuous input space on a discrete output space, while minimizing the loss of information [8]. To define zones in the space, the set of points contained in each zone being projected on a representative vector.

3.2 Use of Vector Quantization in Image compression

The methodology of vector quantization is also called "block quantization" or "pattern matching quantization" is often used in lossy image compression. It works by encoding values from a multidimensional vector space into a finite set of values from a discrete subspace of lower dimension [7]. The lower-space vector requires less storage space, so the image can be easily compressed. Due to the density matching property of vector quantization, the compressed data have errors that are inversely proportional to their density. The renovation is usually done by projection or by using a codebook [9]. In some cases, the codebook can be also used to entropy code the discrete value in the same step, by generating a prefix coded variable-length encoded value as its output.The set of distinct amplitude levels is quantized jointly rather than each sample being quantized separately.

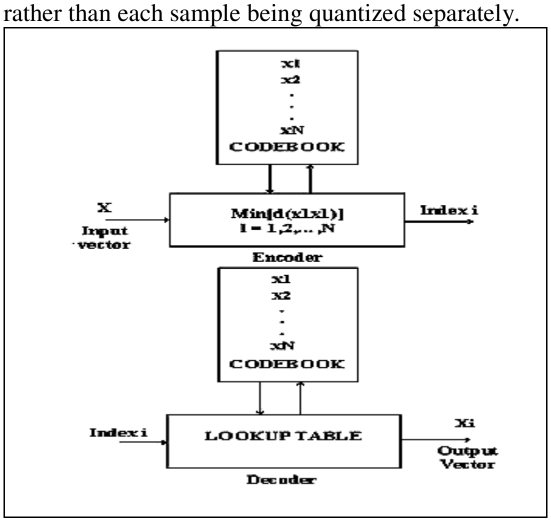


Fig.2 [Basic Block Diagram of VECTOR QUANTIZATION]

Compression is achieved by transmitting codebook indices instead of transmitting the image pixels. So, if the codebook is of size 128, then it will only require 7 bit to transmit the codebook indices. Vector quantizer also requires the same codebook at the decoding end. The decoder just receives the codebook indices and reconstruct the pixels of the image.

4. SSIM INDEX

Digital images and videos are prone to different kinds of distortions during different phases like acquisition, processing, compression, storage, transmission, and reproduction [13]. This degradation results in poor visual quality. There are several metrics which are widely used to quantify the image quality like FSIM, SSIM, bitrates, PSNR and MSE [14, 12, 15, and 16]. This work is primarily focus on metrics like SSIM and bitrates. The other conventional metrics like PSNR and MSE will not be measured as they are directly dependent on the intensity of an image and do not correlate with the subjective fidelity ratings [14]. MSE cannot model the human visual system very accurately [18].

SSIM is the quality assessment of an image based on the degradation of structural information [14]. The SSIM takes an approach that the human visual system is adapted to extract structural information from images [16]. Thus, it is important to retain the structural signal for image fidelity measurement. Figure 2 shows the difference between nonstructural and structural distortions. The nonstructural distortions are changes in parameter like luminance, contrast, gamma distortion, and spatial shift and are usually caused by environmental and instrumental conditions occurred during image acquisition and display [16]. On the other hand, structural distortion embraces additive noise, blur, and lossy compression [16]. The structural distortions change the structure of an image [16]. Figure 3 explains the measurement system used in the calculation of SSIM. Difference between non-structural & structural distortion[16]SSIM is based on the evaluation of three different metrics like luminance, contrast, and structure which are described mathematically by equations (1), (2), and (3) respectively [20].

$$l(x,y) = \frac{2\mu_x\mu_y + C_1}{\mu_x^2 + \mu_y^2 + C_1} \quad \ldots\ldots\ldots\ldots..(1)$$

$$c(x,y) = \frac{2\sigma_x\sigma_y + C_2}{\sigma_x^2 + \sigma_y^2 + C_2} \quad \ldots\ldots\ldots\ldots(2)$$

$$s(x,y) = \frac{\sigma_{xy} + C_3}{\sigma_x\sigma_y + C_3} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where, μ_x and μ_y are local sample means of x and y respectively, σ_x and σ_y are local sample standard deviations of x and y respectively, σ_{xy} is local sample correlation coefficient between x and y and C_1, C_2, and C_3 are constants that stabilize the computations when denominators become small.
General form of SSIM index can be obtained by combining equations (1), (2) and (3) [20]

$$\mathrm{SSIM}(x,y) = [l(x,y)]^\alpha \cdot [c(x,y)]^\beta \cdot [s(x,y)]^\gamma \quad ..(4)$$

Here, α, β, and γ are parameters that mediate the relative importance of those three components.
Using α = β = γ = 1. We get [20],

$$\mathrm{SSIM}(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \quad \ldots(5)$$

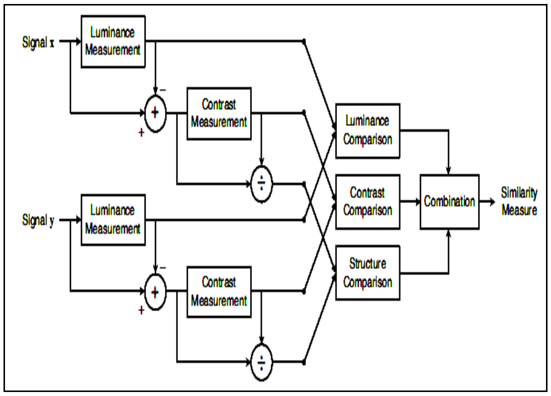


Fig.3 [Block diagram of SSIM measurement system] 15]

5. EVALUATION OF IMAGE COMPRESSION TECHNIQUE

Essential criteria: the obtained compression ratio CR and the quality of the reconstructed image, PSNR.

5.1 Compression Ratio

The Compression ratio (CR) is the ratio between the size of the original image and the size of the compressed image.

$$CR = \frac{n1}{n2}$$

5.2 Distance Measure

Mean Square Error (MSE) is used to measure the rate of distortion in the reconstructed image.

$$MSE = \frac{1}{M * N} \sum_{x=1}^{M} \sum_{y=1}^{N} [f(x,y) - f'(x,y)]^2$$

Where, x (m, n), y (m, n) are, respectively, the original and recovered pixel values at the m^{th} row and n^{th} column for the image of size MXN. PSNR is normally quoted in decibels (dB), which measure the ratio of the peak signal and the difference between two images (error image). Logically, a higher value of PSNR is good because it means that the ratio of Signal to Noise is higher. So, if we find a compression scheme having a high PSNR, we can organize that it is a better one. For an 8-bit grayscale image, the peak signal value is 255. Therefore, the PSNR of 8-bit grayscale image and its reconstructed image is calculated.

5.3 PSNR

It is used as an approximation to human perception of reconstruction quality. PSNR has been accepted as a widely used quality measurement in the field of image compression.

$$PSNR = 20 \log_{10} \frac{MAX}{MSE}$$

A high PSNR would normally indicate less Distortion and high reconstruction quality.

5.4 Structural Similarity Index Measurement

$$\mathrm{SSIM}(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)}$$

When both images is same SSIM is 1 so a value nearer to 1 would normally indicate high reconstruction quality [20].

6. RESULTS AND DISCUSSION

In this Paper we have shown the result of proposed method analyzed on wavelet based vector quantization for the evaluation of the test image cameraman (256 X 256) with global thresholding technique and Huffman coding. The result are shown in table I to III, and the parameters are PSNR (Peak Signal to Noise Ratio) and CR (Compression Ration), RMSE (Root Mean Square Error) and SSIM for bi-orthogonal Wavelet with different Cluster size and Number of level of Vector Quantization.

Table I to III shows that RMSE and PSNR value vary inversely. Proposed method will comply with JPEG techniques and Result of Table III show that for compression ratio of 64 PSNR is 16.9 but our method give the compression ratio 63.72 at PSNR of 20.03 which is better that standard technique. Table III also state that reference paper [20] will provide Compression ratio 20 and PSNR 24.83, where proposed method will give the result of higher compassion ratio at the almost same amount of PSNR which is compression ratio of 27.02 at PSNR 24.17. Table I and II shows that If quality of image is an issue than it can be improved by increasing the quantization levels(8,16,32,64)per cluster size at the cost of compression ratio but anyone want to achieve higher compression ratio it can be achieved by increasing the threshold value, which can loss valuable information but our method also provide a optional solution that is nothing but the increasing the cluster size and decreasing the number of bit for homogenous image. Figure 4 Shows that at higher compression ratio proposed method will give challenge to the JPEG technique.

By comparing figure 6 and figure 7 it is concluded that figure 6 have higher compression ratio than figure 7 but SSIM value of figure 6 is 0.9422 which indicate quality of image is poor than figure 7 with SSIM value of 0.9945.

Table-I Cameraman Test Image (Cluster Size (4x4))

Parameter/ Level	8	16	32	64
CR	78.74	60.24	46.29	31.25
PSNR	17.49	19.38	19.95	20.93
RMSE	34.04	35.29	25.63	22.90
SSIM	0.84	0.90	0.91	0.93

Table–II Cameraman Test Image (Cluster Size (8x8))

Parameter/ Level	8	16	32	64
CR	84.03	60.24	60.53	60.38
PSNR	13.86	15.00	15.28	15.25
RMSE	51.65	45.29	43.86	44.39
SSIM	0.77	0.61	0.84	0.840

Table-III Result Comparison of cameraman with other

P1 [19]		**JPEG [18]**		**P2[18]**		**Proposed method**	
CR	PSNR	CR	PSNR	CR	PSNR	CR	PSNR
2	45.94	8	33.19	15.28	29.46	2.1	41.53
5	37.05	32	24.3	29.25	25.78	8.1	27.45
10	30.87	64	16.9	55.36	22.62	27.02	24.17
20	24.83					49.32	21.46
						63.72	20.03
						78.74	17.49

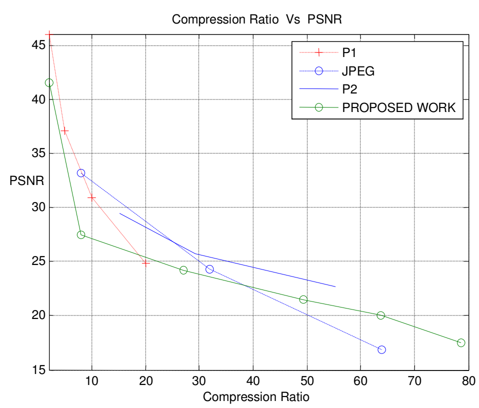


Fig. 4 [Compression Ratio vs. PSNR for different techniques.]

Fig.5 Original Image

CLUSTER SIZE (4X4), H=8

CR= 98.2237, PSNR=21.8202
SSIM=0.9422

Fig. 6

CLUSTER SIZE (4X4), H=512

CR=83.67, PSNR=31.80
SSIM=0.9945

Fig**. 7**

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