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Vector Quantization Based Image Compression

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***Abstract**: An image compression method combining discrete wavelet transform (DWT) and vector quantization (VQ) is presented. First, a three-level DWT is performed on the original image resulting in ten separate sub bands. These sub bands are then vector quantized. VQ indices are Huffman coded to increase the compression ratio. Lloyd extended scalar quantization technique is used to design memory less vector quantization. A novel iterative error correction scheme is proposed to continuously check the image quality after sending the Huffman coded bit stream of the error codebook indices through the channel so as to improve the peak signal to noise ratio (PSNR) of the reconstructed image. The sub band of the wavelet transformed image is also generated for the error correction scheme using the difference between the original and the reconstructed images in the wavelet domain. The proposed method shows better image quality in terms of PSNR at the same compression ratio as compared to other DWT and VQ based image compression. The proposed method of image compression is to obtain the best possible fidelity for given rate.*

***Index Terms**: Vector Quantization, Wavelet Transform, Compression Ratio.*

I. INTRODUCTION TO DISCRETE WAVELETTRANSFORM

In numerical analysis and functional analysis, a discrete wavelet transform (DWT) is any wavelet transform for which the wavelets are discretely sampled. As with other wavelet transforms, a key advantage it has over Fourier transforms is temporal resolution: it captures both frequency and location information.

1.1.One level of the transform

The DWT of a signal x is calculated by passing it through a series of filters. First the samples are passed through a low pass filter with impulse response g resulting in a convolution of the two:

$$Y[n] = (x * g)[n] = \sum_{k=-\infty}^{\infty} x[k]g[n-k] \text{-----}(1)$$

The signal is also decomposed simultaneously using a high-pass filter h. The outputs giving the detail coefficients (from the high-pass filter) and approximation coefficients (from the low-pass). It is important that the two filters are related to each other and they are known as a filter.

However, since half the frequencies of the signal have now been removed, half the samples can be discarded according to Nyquist's rule.

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The filter outputs are then sub sampled by 2 .

$$y_{low}[n] = \sum_{k=-\infty}^{\infty} x[k]g[2n-k] \text{-------}(2)$$

$$y_{high}[n] = \sum_{k=-\infty}^{\infty} x[k]h[2n+1-k] \text{----}(3)$$

This decomposition has halved the time resolution since only half of each filter output characterizes the signal. However, each output has half the frequency band of the input so the frequency resolution has been doubled.

Figure [1] shows the filter analysis

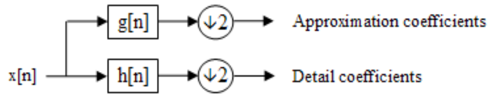

Figure 1 Wavelet decomposition

With the sub sampling operator ↓

$(y\downarrow k)[n] = y[kn]$---------(4)

the above summation can be written more concisely.

$$y_{low}[n] = (x*g)[n] \text{-------}(5)$$

$$y_{high}[n] = (x*h)[n] \text{------}(6)$$

However computing a complete convolution $x * g$ with subsequent down sampling would waste computation time. The Lifting scheme is an optimization where these two computations are interleaved.

1.2 Cascading and Filter banks

This decomposition is repeated to further increase the frequency resolution and the approximation coefficients decomposed with high and low pass filters and then down-sampled. This is represented as a binary tree with nodes representing a sub-space with different time-frequency localization. The tree is known as a bank. A 3 level filter bank shown in figure 2.

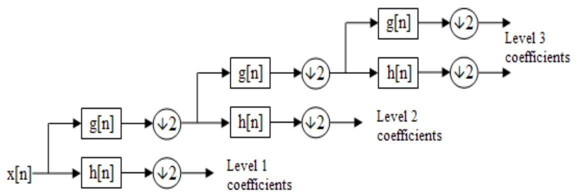

Figure 2 Three level filter bank

At each level in the above diagram the signal is decomposed into low and high frequencies. Due to the decomposition process the input signal must be a multiple of 2^n where n is the number of levels.

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II.VECTOR QUANTIZATION BASED ENCODER AND DECODER

Data compression is the process of converting data files into smaller files for efficient storage and transmission. In this paper lossy compression technique is used. 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. 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 compute, requiring linear time in the size 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 and Vector quantization is presented. This proposed method gives superior results which are in general applicable to any images.

2.1. Principle of vector quantization

A vector quantize (VQ) is defined as a mapping Q of K dimensional Euclidean space RK in to a finite subset Y of RK shown in the following equation: Q: RK → Y, where Y = [yi; for i = 1, 2,.., N], is the set of reproduction vectors and is called a vector quantize codebook, and N is the number of vectors in Y. SOFM algorithm is used in the proposed method. SOFM is a neural network model consists of one input and one output layer. Each input node is connected with output node by adaptive weights as shown Figure3.SOFM produces codebook for vector quantization through modifying the weights between input nodes and output nodes. The schematic diagram of a full search vector quantize is shown in Figure3.

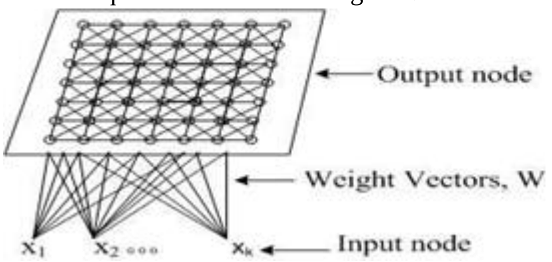

Figure 3 SOFM algorithm

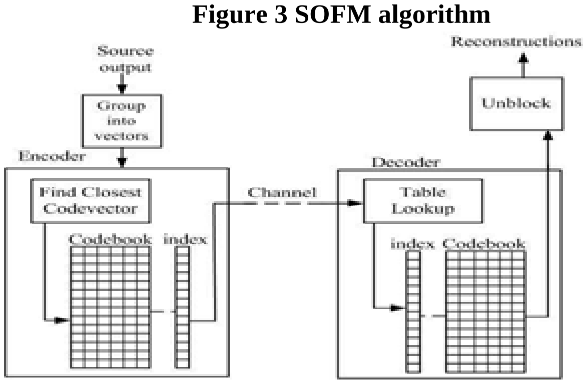

Figure 4. Schematic diagram of vector quantization.

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 reconstructs the pixels of the image.

2.2.Memoryless Vector Quantizer

Mathematically vector quantization consists of two mappings, an encoder V, which assigns to each input vector $x=(x_0, x_1, \ldots x_{k-1})$ a channel symbol V(x).This vector quantization is called as memoryless vector quantization because output does not depend on previous inputs.

2.3. Principle of wavelet transforms

Wavelet analysis is a technique to transform an array of N numbers from their actual numerical values to an array of N wavelet coefficients. Each wavelet coefficient represents the closeness of the fit (or correlation) between the wavelet function at a particular size and a particular location within the data array. By varying the size of the wavelet function (usually in powers-of-two) and shifting the wavelet so that it covers the entire array, one can build up a picture of the overall match between the wavelet function and the data array. Wavelet transform decomposes an image into a set of different resolution sub-images, corresponding to the various frequency bands. Wavelets are a class of functions used to localize a given signal in both space and scaling domains. Wavelets automatically adapt to both the high-frequency and the low frequency components of a signal by different sizes of windows. Wavelets are functions generated from one single function ψ (as shown in the following equation), which is called mother wavelet, by dilations (a) and translations (b)

$$\psi_{a,b}(x) = |a|^{-\frac{1}{2}}\,\psi\left(\frac{x-b}{a}\right) \quad \text{-----(7)}$$

Where ψ must satisfy the following conditions.

$$\int_{-\infty}^{\infty} \psi(x)dx = 0 \quad \text{-------(8)}$$

$$\int_{-\infty}^{\infty} |\psi(x)|^2 dx = 1 \quad \text{----(9)}$$

Wavelet transform is the representation of any arbitrary signal x (t) as a decomposition of the wavelet basis or write x(t) as an integral over a and b of ψ a,b. In this work Discrete Wavelet Transform (DWT) is used.

It is the discretized version of the continuous wavelet transforms (as defined by equation), for efficient computer implementation.

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III. PROPOSED IMAGE COMPRESSION METHOD

A combined approach of image compression, based on the wavelet transform and vector quantization is presented. This proposed method gives superior results over other Wavelet Transform and Vector Quantization based image compression methods. Moreover if a user needs a better quality image just has to inform the transmission end to transmit an image of that quality.

The information source {Xn :n=0,1,2,....} is a sequence of channel symbols{Un: n=0,1,2,...} is delivered to the receiver by the channel as shown in the figure 5.

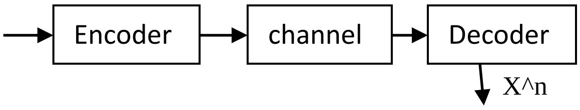

Figure5.Vector quantization compression system.

The decoder maps this sequence of vectors {Un :n=0,1,2........}.

This method is tested on gray scale images, but it can be easily extended to color images by processing the three color matrices separately. In this paper 3-level 2-D DWT is firstly applied to the test image (i.e. the image to be compressed) and then VQ is used to different sub bands for compression. Ten sub bands are created after the application of 3-level 2-D DWT using SOFM, and thus all these codebooks are used for this all sub bands individually. 3-level 2-D DWT is applied to images because the low frequency sub band, which contains the maximum energy content of the original image, becomes of smaller size so that in case of vector quantization this sub band is treated with a codebook size of 7-bits only. These vector indices are subjected to Huffman coding for improving the compression ratio of the transmitted data. Whole compression process of this work is divided into three steps such as Codebook generation, encoding of the original image and decoding of the image.

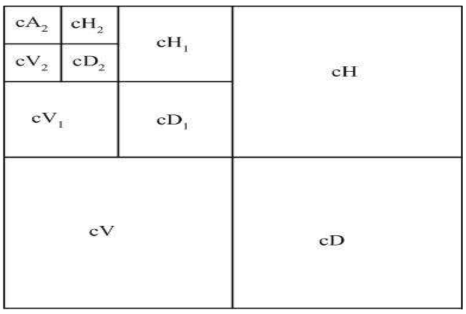

Figure 6 3-Level wavelet 10 sub bands

Figure 7 3-Level wavelet 10 sub bands

3.2 Code book generation

A vector is formed using a block of 4*4 pixels forms a vector. For an image size 128*128, the total number of vectors is 1024.out of these every fourth vector is used. This selection is random. Thus, the number of vectors in the initial codebook is 256.T1, T2,....is the input training image.C1,C2, is the codebook. Out of the input vectors, best match is found with the code vectors. The squared distortion is the measure used for this purpose.

3.3.Lloyd Algorithm

Step 1: Begin with an initial codebook C1, set m=1.

Step 2: Given the codebook, C_m , perform the Lloyd iteration to generate the improved codebook $C_{m+1.}$

Step3: Compute the average distortion for $C_{m+1.}$If it has changed by a small enough amount since the last iteration, stop. Otherwise Set m+1 m and go ~~to step~~ 2.

Lloyd iteration for codebook improvement with known statistics:

a)Given a codebook, C_m={$y_{i,}$ i=1,...N},find the optimal partition into quantization cells.

b)Using the centroid condition, find $C_{m+1=}${cent (R_i);i=1,......N}.

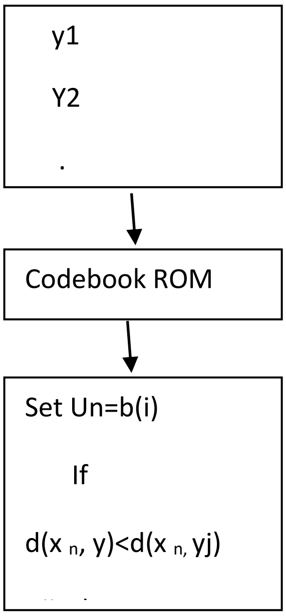

Figure 8.Codebook generation

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The proposed method uses a total of twenty codebooks, ten codebooks for original image reconstruction and other ten are used to reconstruct the error images. In the codebook generation step (i.e. the training stage) four different standard images are used to generate ten original codebooks and also ten error codebooks are generated in this step. In the ten original codebook generation step,3-level 2-D DWT is applied to each of these original training images. These generate ten wavelet sub bands for each of the original images. Similar sub bands of each image are then combined to form a single frame and this frame is then considered as a new image. The figure shows the wavelet sub bands of the image Lena, after applying 3-level 2-D DWT. Therefore there are ten separate images available at this stage. Using these ten separate images, ten separate codebooks are generated using SOFM.

3.4. Encoding process

The distortion between the input vector and each stored codeword is computed. The encoded output is then the binary representation of the index of the maximum distortion codeword. When the input vector 'X' is fed to the encoder, local mean 'm' of the input vector is removed and separately quantized by scalar quantize, using means codebook 'cm' and the residual portions. R=(X-m) is separately quantized by residual vector quantization using its vector codebook 'cy'. Separate indices 'i' and 'j' are transmitted from encoder. These correspond to the residual and the mean respectively.

Here, 3-level 2-D DWT is applied to the test image (i.e. the image to be compressed). Then each of these available ten sub bands is vector quantized using the original codebooks, so that separate codebook is used for different sub bands. The codebook indices of this VQ process are transmitted to the decoder after Huffman coding. At the encoder end image is reconstructed using the transmitted image indices and peak signal to noise ratio (PSNR) of this transmitted image is calculated to test the image quality.

Error codebook indices are also transmitted to the decoder after Huffman coding. The transmitted error image is reconstructed from the transmitted error codebook indices (at the encoder or transmission end). Then the reconstructed image errors (R.I.E) are added (algebraically) to the previously reconstructed image, and thus R.I. is modified. This iterative error correction process continues until the PSNR of the modified reconstructed image is larger than or equal to the desired PSNR or the maximum number of iteration (considering the case of infinite loop, the iteration process stopped by force at the third iteration) is reached.

3.5. Decoding process

At the receiving end , indices 'i' and 'j' are fed to reproduce the original vector X. The reproduction X^ is given by X^=m^ + R, where m^ and R^ are the quantized mean and the residual vectors respectively. The decoder first receives the Huffman coded bit-stream of the VQ indices corresponding to the original

Wavelet coefficients from the channel. It then reconstructs the codebook indices of the different wavelet sub bands. In the initial stage the receiver receives the reconstructed image and successively in the later steps the receiver receives image errors (actually it receives Huffman coded image errors, and reconstructs the image error coefficients from these Huffman coded indices). The receiver adds (algebraically) the received errors of each sub band. In the final step the image is reconstructed using 3-level inverse 2-D DWT.

IV. RESULTS AND DISCUSSION

For simulating the proposed method, we are using mat lab 7.9 Image Processing Tool Box. The 'Lena.jpg' image of size 256*256 is taken for this paper and the original image is displayed in the figure 9.

Figure 9.Original Lena Image before Compression

This is image is taken for first level decomposition, second level decomposition, third level decomposition. If we apply wavelet transform for this image we get 4 sub bands. So the number of bits used to represent the original component still decreases. Figure10. Shows all the 10 sub bands obtained due to 3-level wavelet decomposition. The approximated component obtained at the end of 3 level decomposition will have size 32*32.

Figure 10 2-Level Decomposition of original Image 10 sub bands

Here the encoder is designed for first level wavelet decomposition. So we consider the approximated component first which is given in figure 11.all the steps are followed for which is available in encoder design. Figure 12.

Shows the reconstructed image in the first step is given. Then figure 13.shows the image error. Then figure 14 shows the new reconstructed image for the approximated component.

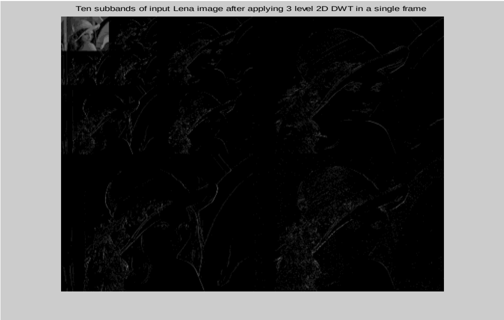


Figure 11. Approximated first level component

Figure 12. Reconstructed approximated first level component

Figure 13. Image Error Approximated first level component

Figure 14 New Reconstructed Approximated first level component

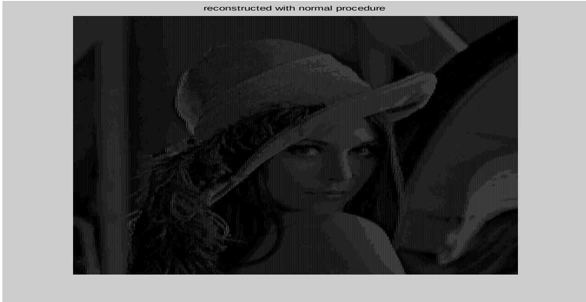


Figure 15 Reconstructed Image with first step

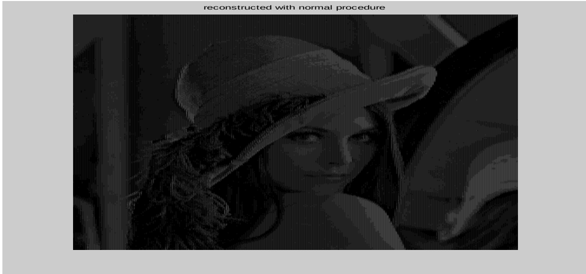
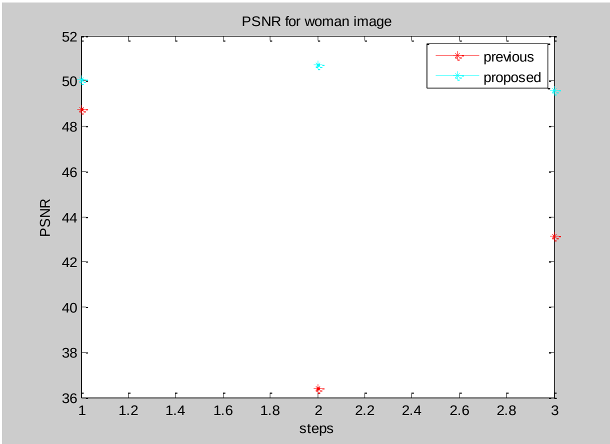


Figure 16 New Reconstructed Image with three steps

The overall PSNR achieved after reconstruction is 50.7074. This can be further improved with the increase in number of decomposition levels.

Figure17. PSNR comparison for Lena Image



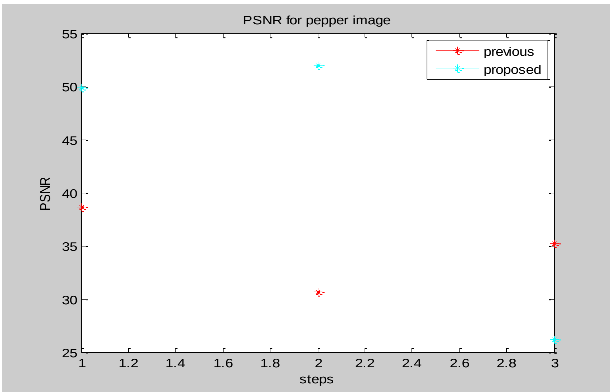


Figure 18. PSNR comparison for pepper Image

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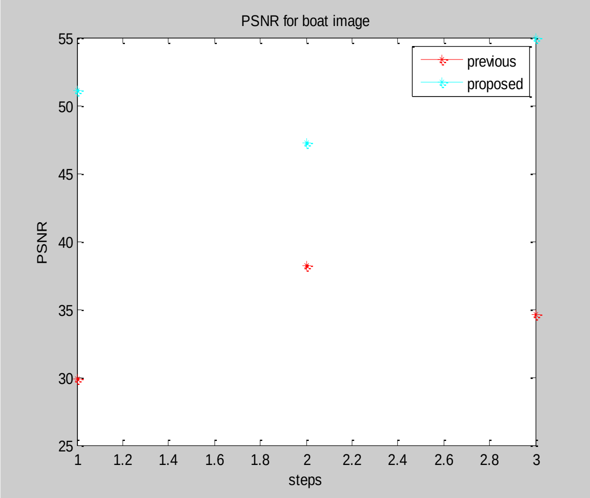

Figure 19. PSNR comparison for boat Image

From Figures 17, 18, 19 we can conclude the PSNR value for the proposed method is high when compared to previous method.

V.CONCLUSION

In this paper a technique of digital image compression as well as decompression based on multi resolution analysis using wavelet transform and vector quantization is proposed. It is clear that inclusion of the error correction scheme resulted in a great improvement on the overall image compression process. It reduce the compression ratio a little bit, but increases the PSNR of the image drastically, which ultimately assures the purpose of the method for those area of image compression which requires high quality image. The proposed method provides satisfactory image quality with high compression ratio. The result of Huffman code is that better performance can be always be achieved by coding vectors instead of scalars.

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