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Performance Analysis of Vector Quantization based Lossy Image Compression using SSIM

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Abstract: This paper presents Vector quantization and LZW coding based Lossy image compression technique. VQ is a powerful and classical quantization technique for lossy image compression. VQ is an irreversible process and reduces the psycho-visual redundancies. In this technique, first it divides the input image into P × Q blocks. Where P and Q are number of pixels in X and Y dimensions of Blocks and both are power of 2. After this, it takes each pixel value within the block from left to right, top to bottom to construct a vector. This vector calculates the Euclidean distance with all code words in the codebook. VQ indices are coded using LZW coding to increase the compression ratio. After the decompression, quality of retrieved image is evaluated using SSIM. The aim of the present study is to obtain best quality decompressed images at very low bit rates and higher compression ratio, which in turn can save the storage as well as transmission bandwidth over the internet. Experimental results are measured in terms of Compression Ratio (CR), Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE) and Structural Similarity Index Measurement (SSIM) for image quality assessment.
Keywords: Vector quantization (VQ); Peak signal to noise ratio (PSNR); Mean square error (MSE), Structural Similarity Index Measurement (SSIM).

I. INTRODUCTION

Image compression has been a significant research area for many years due to its continuously increasing demand in transfer and storage of data [2]. The aim of image compression is to reduce the amount of data required to represent a digital image. Thus, image compression is quite necessary. There are two types of image compression: (1) Lossless compression and (2) Lossy compression. Out of these two, the lossy technique is applicable, when we don't require the exact reconstruction of an image.
Discrete Cosine Transforms (DCT), Vector Quantization (VQ) [13], Short Time Fourier Transforms (STFT) and Discrete Wavelet Transforms (DWT) are widely used methods for image compression. DCT is an image compression algorithm that samples an image at regular intervals, analyzes the frequency components present in the sample, and discards those frequencies which do not affect the image as the human eye perceives it. DCT presents blocky artifacts in the reconstructed image, which are not necessary and pleasing to the eyes. In STFT once window is selected, it remains uniform for all frequencies. So, it gives a constant resolution at all frequencies. Compared to other techniques wavelet based compression gives better performance. The basic aim of image compression is to reduce the storage requirement while maintaining acceptable image quality [2]. Wavelet Transform and Vector quantization (VQ) is one of the popular image compression techniques for its simpler decoding structure and it can achieve high compression ratio while maintaining acceptable value of MSE and PSNR [1]. Lossy image compression algorithm gives higher compression ratio with better picture quality. It also overcomes problems of low resolution and high computational complexity for different satellite and medical images. In Vector Quantization, by selecting proper value of cluster size and codebook, proposed technique can improve the performance of lossy image compression algorithm. When codebook and cluster size in Vector Quantization are increased, the compression performance improves but the quality of image deteriorates [1] and processing time is also increased. Proposed technique gives a huge improvement on the overall image compression. It increases the compression ratio drastically, but decreases the PSNR a little bit for the image, which ultimately assures the purpose of the method for that area of image compression which requires high quality image [1]. The proposed lossy image compression technique gives superior results, which are in general applicable to any images [1]. The proposed method of image compression is applicable to the areas of digital images where higher compression ratio with better image reconstruction is required like criminal investigations, medical imaging, etc. This method is tested on gray scale test images, but it can be easily extended to colored images [1].

II. PROPOSED APPROACH

This paper proposes an effective Lossy image compression algorithm to reduce the size of an image with the combination of Vector quantization and Source coding like Huffman coding and LZW coding. The proposed Lossy image compression technique is applicable to those areas of digital images where higher compression ratio with better reconstructed image is required e.g. criminal investigations, medical imaging, etc. [1] Image compression is achieved by reducing redundancy or eliminating irrelevancy. The proposed technique, first divides the input image into P × Q blocks. Where P and Q are number of pixels in X and Y dimensions of Blocks and both are power of 2. After this, it takes each pixel value within the block from left to right, top to bottom to construct a vector. This vector calculates the Euclidean distance with all codewords in the codebook. VQ indices are coded using LZW coding to lower the data size. VQ is a powerful and classical quantization technique for Lossy image compression [1]. VQ is irreversible process and reduces the psycho-visual redundancies.

VQ input image of size M × M pixels, where M is number of pixels in X and Y dimensions of input Image and it is power of 2. Then divide the input image into C × D blocks. Where C and D are number of pixels in X and Y dimensions of Blocks and both are power of 2. After this, it takes each pixel value within the block from left to right, top to bottom to construct a vector. [1] This vector calculates the Euclidean distance with all codewords in the codebook. The calculation of Euclidean distance is shown in Eq. (1) as follows, where d is Euclidean distance, B is block's vector, **Ci** is the i^{th} index codeword in the codebook, k is the dimension of vectors. Then we can find the closest or the shortest codeword, and use the index value of this codeword to represent this block, finally obtain an index table including 64 × 64 indices [1]. In the decompression phase, we can then use this index table to find out the codeword from the codebook, restore block vectors, and reconstruct the image according to equation (1).

$$\boldsymbol{d(B, C_i) = \sqrt{\sum_{j=0}^{k-1}(B_j - C_{i,i})^2}} \qquad \ldots (1)$$

After this, VQ generates N training vectors. Where N= ((M × M)/ C × D). Then fix the codebook size to n.[9] where, n is power of 2. Finally compute P = N/n and Select every Pth training vector as a code vector till the codebook of desired size is obtained. [1] After VQ discrete values are source encoded using LZW codes. [12]. Proposed technique maps the set of vector quantized coefficients to a set of symbols so that the total number of bits per symbol gets reduced.[1] This encoding process works with the probabilities of the quantized coefficients. In this proposed technique, LZW encoding is used, which reduces the coding redundancy as compared to other existing source coding techniques. Significant reduction of number of bits can be done by optimization of LZW codes.[4]

In image decompression, the input image is reconstructed from compressed image. First source decoding namely LZW decoding is applied on compressed image. The resultant image after source decoding is vector de-quantization, which is irreversible operation, so it introduces loss in reconstructed Image.

III.PERFORMANCE PAREMETERS

The obtained compression ratio CR and the quality of the reconstructed image, PSNR.[1]

A. Compression Ratio

The compression ratio (CR) is the ratio between the size of the original image (n1) and the size of the compressed image (n2).[1]

$$\mathrm{CR} = \frac{n1}{n2} \qquad \ldots (2)$$

B. Mean Square Error

Mean Square Error (MSE) is used to measure the rate of distortion in the reconstructed image. [6]

$$\mathrm{MSE} = \frac{1}{M*N}\sum_{x=1}^{M}\sum_{y=1}^{N}[f(x,y) - f'(x,y)]^2 \qquad \ldots (3)$$

Where, f(x,y), f'(x,y) are, respectively, the original and recovered pixel values at the m^{th} row and n^{th} column for the image of size MxN.[1]

C. Peak Signal to Noise Ratio

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. [1] 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 gray scale image, the peak signal value is 255. Therefore, the PSNR of 8-bit gray scale image and its reconstructed image is calculated. [1]

$$\mathrm{PSNR} = 20\log\log_{10}\frac{\mathrm{MAX}}{\mathrm{MSE}} \qquad \ldots (4)$$

A high PSNR would normally indicate less distortion and high reconstruction quality. [1]

D. Structural Similarity Index Measurement [3]:

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

Where, C_1 and C_2 are constant and equal to unity. When both images are same, SSIM is 1 so a value nearer to 1 would normally indicate high reconstruction quality.[3]

IV. RESULTS AND DISCUSSION

In this paper, we have shown the result of proposed technique based Vector Quantization and LZW coding for the evaluation of the test images cameraman (256 X 256) and Lena (256 X 256). The result is shown in Table 4.1 and 4.2, and the parameters are PSNR and CR, MSE and SSIM for different size of cluster and codebook of Vector Quantization.

TABLE I
RESULT COMPARISON OF CLUSTER SIZE (4X4) AND CLUSTER SIZE (8X8) USING MSE, PSNR, CR AND SSIM FOR CAMERAMAN IMAGE

Parameter	Cluster size (4x4)					Cluster size (8x8)				
	Codebook size					Codebook size				
	8	16	32	64	128	8	16	32	64	128
MSE	427.6	375	254.4	182.9	150	835.3	564.8	477.7	336.2	205.6
PSNR(db)	21.8	22.3	24.1	25.5	26.4	18.9	20.6	21.3	22.9	25
CR (%)	99.5	99.1	98	95.8	91.7	98.2	96.3	92.3	84.1	68.8
SSIM	0.94	0.95	0.97	0.98	0.98	0.88	0.92	0.94	0.96	0.97

Table I shows the results for performance parameter MSE, PSNR, CR and SSIM using cluster size (4x4) and cluster size (8x8) for CAMERAMAN image. These Tables are generated by varying codebook size based on vector quantization and LZW coding techniques. From these results it is concluded that proposed technique achieves variation in parameter as changes in the codebook size, cluster size and wavelet Families. As codebook size increases, the CR reduces, while PSNR and SSIM are increased as shown in the Table.

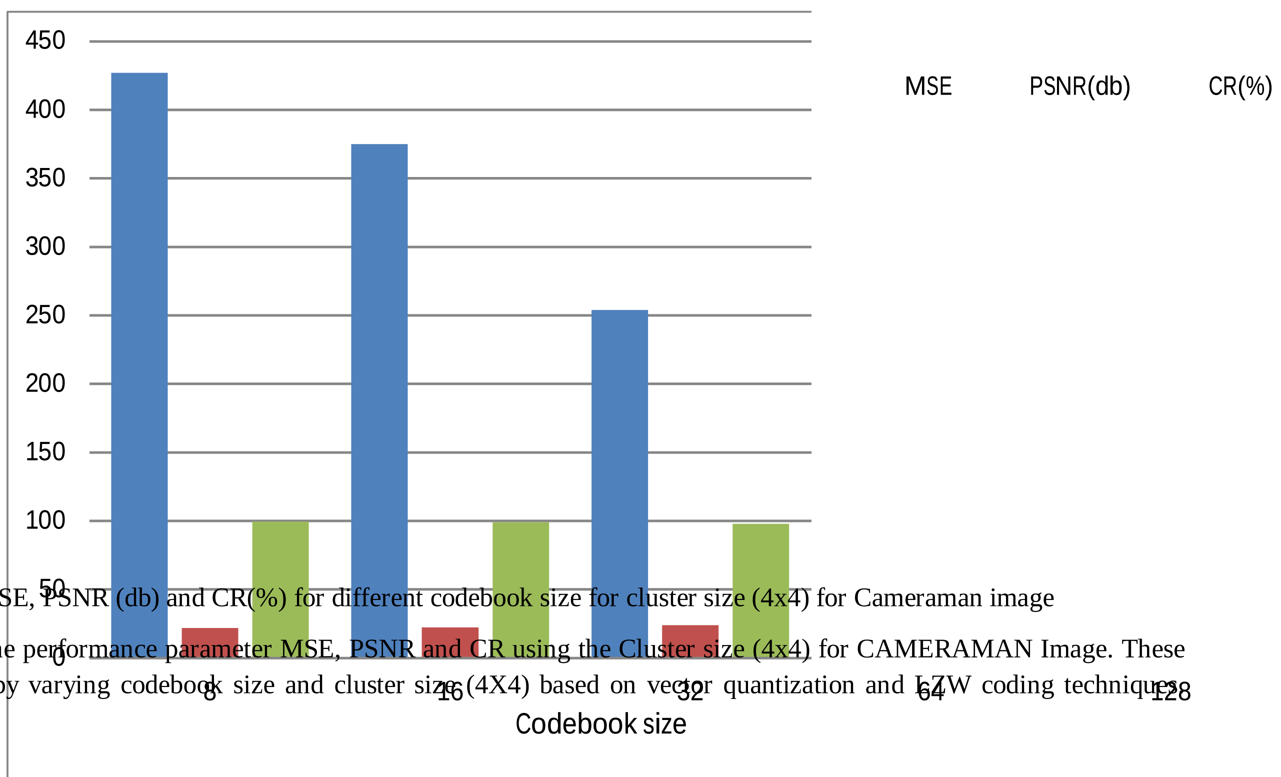

Fig. 1 MSE, PSNR (db) and CR(%) for different codebook size for cluster size (4x4) for Cameraman image

Figure 1 represents the performance parameter MSE, PSNR and CR using the Cluster size (4x4) for CAMERAMAN Image. These results are obtained by varying codebook size and cluster size (4X4) based on vector quantization and LZW coding techniques.

From these results it is observed that as codebook size increases, the CR reduces normally and Quality of reconstructed image is improved as PSNR and SSIM increases.

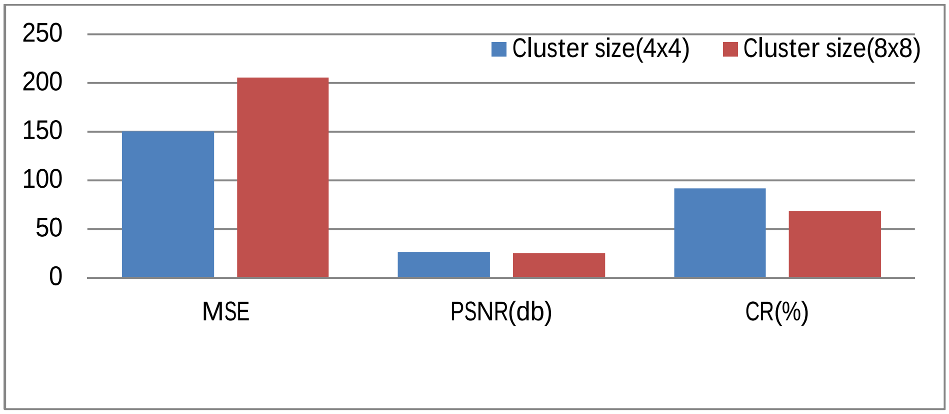

Fig. 2 Comparison of cluster size (4x4) and cluster size (8x8) for MSE, PSNR and Cr using codebook size of 128 for Cameraman image

Figure 2 represents the performance comparison of cluster size (4x4) and cluster size (8x8) using MSE, PSNR and CR using CAMERAMAN image. Codebook size 128 of vector quantization and LZW coding techniques are used to generate these results. It is concluded that as cluster size increases, the CR and PSNR reduce normally, but MSE increases.

TABLE II
RESULT COMPARISON OF CLUSTER SIZE (4X4) AND CLUSTER SIZE (8X8) USING MSE, PSNR, CR AND SSIM FOR LENA IMAGE

Parameter	Cluster size (4x4)					Cluster size (8x8)				
	Codebook size					Codebook size				
	8	16	32	64	128	8	16	32	64	128
MSE	379.8	206.8	160.6	122.6	90.7	677.1	428.6	304.4	230.1	153.6
PSNR(db)	22.3	24.9	26.1	27.2	28.5	19.8	21.8	23.3	24.5	26.3
CR (%)	99.5	99.	98.1	96.1	91.1	98.2	96.2	92.3	84.2	68
SSIM	0.91	0.95	0.96	0.97	0.98	0.83	0.90	0.93	0.95	0.97

The results mentioned in above Table II clearly depicts that proposed technique achieves variation in parameter as changes in the codebook size, cluster size and wavelet Families. As codebook size increases, PSNR and SSIM increases but the CR reduces as mentioned in Table.

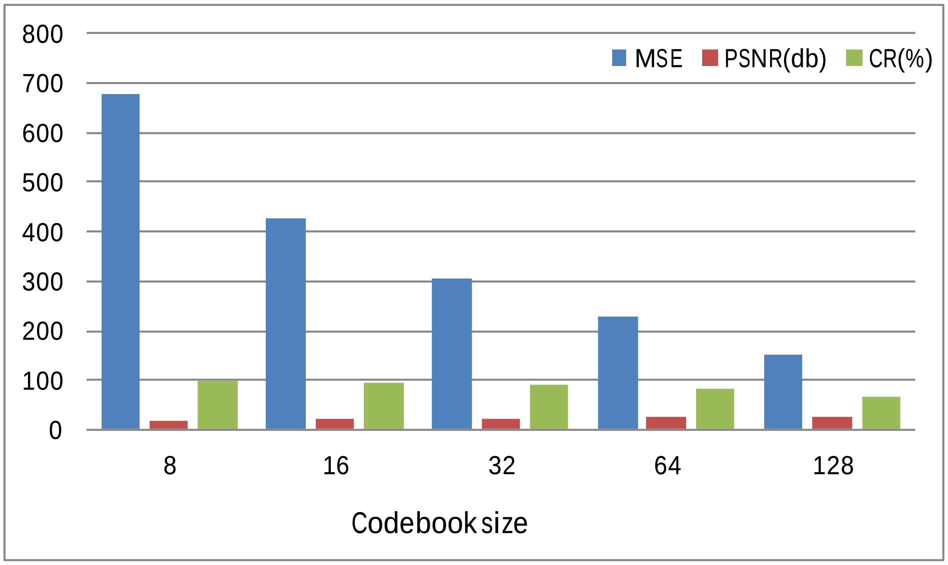

Fig. 3 Comparison of various codebook size for cluster size (8x8) using MSE, PSNR (db) and CR (%) for Lena image

Figure 3 represents the performance parameter MSE, PSNR and CR for LENA image using various codebook size and cluster size (8x8). These results are for codebook size and cluster size (8X8) of vector quantization and LZW coding techniques. From these results it is observed that as codebook size increases, the CR reduces normally and Quality of reconstructed image is improved as PSNR and SSIM increases.

V. CONCLUSION

In this paper, performance of proposed technique has been measured using the various parameters such as compression ratio, PSNR, MSE, and SSIM. It emphasizes on development of effective algorithm for the lossy compression for the 2D images. This simulation has achieved reasonable performance enhancement. If cluster size in Vector Quantization is increased, the compression performance improves but the quality of image deteriorates. Proposed technique gives great improvement on the overall image compression process. It increases the compression ratio drastically, but the PSNR is reduced a little bit, which ultimately assures the purpose of the method for that area of image compression which requires high quality image. The proposed method of Vector Quantization (VQ) with combination of LZW coding provides better quality with high compression ratio. Future work on this image compression may include the implementation of an effective codebook and the wavelet based tree structure, the computation time can be reduced more.

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