Image Compression using Fusion of Hybrid Wavelet Transform and Vector Quantization

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ABSTRACT

This paper proposes novel lossy image compression technique using hybrid wavelet transform and vector quantization. First hybrid wavelet transform consisting of two different component transforms is generated and applied on color images. Discrete Kekre transform (DKT) and Discrete Cosine transform (DCT) play role of base and local transform respectively in hybrid wavelet transform. In transform domain 3.125% data is retained by making low energy coefficients zero and image is reconstructed. Vector quantization (VQ) algorithm is applied on these reconstructed images. In vector quantization only indices of code vectors are sent which gives more compression of hybrid wavelet transformed image. Three different vector quantization algorithms like Linde-Buzo-Gray (LBG), Kekre’s Proportionate Error (KPE) and Kekre’s Error Vector Rotation (KEVR) are applied on reconstructed images and their performance is compared. Error between original image and reconstructed image obtained after vector quantization is calculated and reconstructed image quality is observed for each VQ algorithm. In proposed method KPE algorithm shows better image quality than traditional LBG algorithm. Results of KPE are followed by KEVR algorithm. Combination of hybrid wavelet transform and VQ helps to achieve higher compression ratio up to 64 giving better quality of reconstructed image than obtained in DKT-DCT hybrid wavelet transform.

Keywords- Image Compression; Kekre Transform; KPE; KEVR; Vector Quantization.

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1. INTRODUCTION

Image compression is a technique that reduces redundancy in images and allows representing an image using less number of bits without degrading image quality to undesirable level. Objective of image compression is to reduce memory space required for storage so that more data can be stored in given amount of storage space [1]. It also reduces bandwidth required for transmission thus giving efficient transmission of data. Compression is broadly classified as lossless compression and lossy compression. In lossless image compression reconstructed image is exactly same as original image. Hence such type of compression is particularly used where image data is critical like in medical imaging. In lossy image compression there is difference in recovered image and original image. Though this difference is there, acceptable image quality can be obtained in lossy compression [2]. In literature many lossy image compression methods have been proposed. Transform based coding [3], wavelet transforms [4], hybrid wavelet transforms [5], artificial neural networks [6] and vector quantization [7] are widely used among them. Pixels in an image show certain level of correlation with neighboring pixels. Transforms map this correlated data into frequency domain as uncorrelated coefficients.
As low frequency coefficients in transform domain represent most of the information contents in the image, only those coefficients can be retained and high frequency coefficients can be discarded which results in compression. This paper proposes lossy image compression using hybrid wavelet transform and vector quantization [8]. Image is first transformed using hybrid wavelet transform [9,10]. Use of hybrid wavelet transform gives better compression ratio than wavelet transforms as it combines features of two different orthogonal transforms. Transformed image is reconstructed and VQ is then applied on this reconstructed image. Different VQ algorithms like KPE [11] and KEVR [12] are compared against traditional LBG [13] algorithm. Error measurement parameters like root mean square error (RMSE), mean absolute error (MAE) and average fractional change in pixel value (AFCPV) are used to compare performance of VQ algorithms.

Rest of the paper is organized as follows. Section II presents current state of art. Hybrid wavelet transforms and VQ algorithms are discussed in brief in section III. Proposed method is discussed in section IV. Performance of different VQ algorithms is evaluated in section V and section VI concludes the paper.

2. REVIEW OF LITERATURE

In literature many lossy image compression algorithms are proposed using different techniques like block truncation coding, transforms, wavelet transforms, vector quantization and their combinations. Kartik Sau et al. [14] have proposed lossy image compression of grayscale images using absolute moment block truncation coding and Clifford algebra. It gives good image quality with high PSNR values. Transformed vector quantization approach has been proposed by Robert Li et al. [15].

Image is transformed using DCT. Low energy coefficients are discarded and fast kohonen algorithm is used for vector quantization of transformed coefficients. Approximated image is obtained by applying inverse DCT at receiving end. S. Sathappan has proposed vector quantization based image compression [2] in which codebook is generated using LBG algorithm. Indices of vector quantization are compressed and residual codebook is generated by using Modified Fuzzy Possibilistic C-Means with Repulsion and Weighted Mahalanobis Distance. This residual codebook removes distortion in reconstructed image and improves the quality of reconstructed image. Debnath et al. have proposed image compression using combination of wavelet transform and VQ. It uses three level discrete wavelet transform resulting in ten different sub bands. Each sub band is then vector quantized and VQ indices are further Huffman encoded to increase compression ratio [16]. Compression using difference vector quantization has been proposed by jau JI shen and Ya Hsin Lo [17].

In their proposed technique each image is transformed into difference value’s matrix and VQ is applied on it. Clustering based hybrid DCT-VQ compression algorithm is proposed in [18] by Mahapatra and Jena. VQ is applied using K-means clustering method on DCT transformed image to speed up quantization process. It gives better compression than conventional VQ algorithms. Mahmood and Shyesteh [19] have proposed LBG VQ algorithm on DCT transformed image. Here image is divided into blocks and for each block DCT is applied. LBG algorithm is used to quantize transformed coefficients in each block. This method gives better results than conventional VQ algorithms. In [20] Kalra and Ghosh have proposed combination of wavelet based compression sensing and vector quantization. Wavelet transform is used to sparsify the input image while measurement vectors generated from the sparse vectors are transmitted using vector quantization.

3. HYBRID WAVELET TRANSFORM

As name suggests it is obtained by hybridization of two transforms. Two transforms used are called component transforms and they should be orthogonal. In this paper Discrete Kekre Transform (DKT) [21] and Discrete Cosine Transform (DCT) are used as component transforms to obtain DKT-DCT hybrid wavelet transform. Kekre transform matrix is generated using following equation:

\[
K_{xy} = \begin{cases} 
1 & x \leq y \\
-N+(x-1) & x = y+1 \\
0 & x > y+1 
\end{cases} 
\]

DKT transform matrix is given as

\[
K = \begin{bmatrix} 
1 & 1 & 1 & \ldots & 1 \\
-N+1 & 1 & 1 & \ldots & 1 \\
0 & . & . & \ldots & . \\
. & . & . & \ldots & . \\
0 & 0 & 0 & \ldots & 1 \\
0 & 0 & 0 & -N+(N-1) & 1 
\end{bmatrix} 
\]

Hybrid wavelet transform extracts traits of both component transforms used and gives better compression than individual component or its wavelet transform. Transform matrix is generated using Kekre’s wavelet generation method whose equation is given below.
It is simple and faster to generate because it involves Kronecker product in generation method. $A_p$ is base component of size pxp. $B_q$ is local component of size qxq. In DKT-DCT hybrid wavelet DKT acts as a base transform and DCT is used as local transform. $A_p \otimes B_q(1)$ gives ‘p’ number of rows showing global features of image. Identity matrix of size pxp is used for shifting rows of transform matrix. Kronecker product of Ip is taken with each row of matrix B except first row. It gives local properties of hybrid wavelet transform.

### 4. Vector Quantization

It is lossy data compression technique and has been used in variety of applications like biometrics [22,23], CBIR [24], image segmentation [25], pattern recognition etc. It maps k-dimensional vector space to finite set of code vectors called as codebook CB. This codebook contains N code vectors, i.e. $C_k = \{C_1, C_2, C_3, \ldots, C_N\}$ each of dimension k. Hence $C_k = \{c_{i1}, c_{i2}, \ldots, c_{ik}\}$. If only indices of these code vectors are transmitted it gives good compression. Hence good codebook design is essential to achieve compression with minimum distortion. Clustering algorithms are used to generate the codebook. Lesser size of codebook means more compression and hence distortion is also more. Large codebook gives less compression ratio with minimum distortion.

#### 4.1 Linde-Buzo-Gray Algorithm (LBG)[13]

It is like K-means clustering algorithm. It takes N trainee vectors as input and divides them into k clusters such that k<N. Vectors are grouped in a cluster using some similarity measure. Initially centroid of trainee vector is computed. This is initial code vector. Constant error is added to it and subtracted from it. It generates two vectors $v_1$ and $v_2$. Euclidean distance of all training vectors with $v_1$ and $v_2$ is computed. If the distance of training vector with $v_1$ is minimum then it is put in cluster 1 else it is placed in cluster 2. Again centroids of two newly formed clusters are computed minimum then it is put in cluster 1 else it is placed in cluster 2. Every time centroid is computed, it gives new codebook. Thus codebook size is doubled after every iteration. Figure 1 shows formation of 2 clusters using LBG in two dimensional case.
4.2 Kekre’s Proportionate Error Algorithm (KPE)[11]
Here to generate two vectors v1 & v2 proportionate error is added to the code vector. Magnitude of elements of the code vector decides the error ratio. Hereafter the procedure is same as that of LBG.

4.3 Kekre’s Error Vector Rotation Algorithm (KEVR)[12]
In this algorithm two vectors v1 & v2 are generated by adding error vector to the code vector. Euclidean distances of all the training vectors are computed with vectors v1 & v2 and two clusters are formed based on closest of v1 or v2. The code vectors of the two clusters are computed and then both clusters are split by adding and subtracting error vector rotated in k-dimensional space at different angle to both the code vector. This modus operandi is repeated for every cluster and every time to split the clusters error vector ei is added and subtracted from the code vector and two vectors v1 and v2 is generated. Error vector ei is the ith row of the error matrix of dimension k. The error vectors matrix E is given as:

\[
E = \begin{bmatrix}
  e_1 \\
  e_2 \\
  e_3 \\
  e_4 \\
  e_5 \\
  \vdots \\
  e_k
\end{bmatrix} = \begin{bmatrix}
  1 & 1 & 1 & 1 & \ldots & 1 & 1 & 1 \\
  1 & 1 & 1 & 1 & \ldots & 1 & 1 & -1 \\
  1 & 1 & 1 & 1 & \ldots & 1 & -1 & 1 \\
  1 & 1 & 1 & 1 & \ldots & 1 & -1 & -1 \\
  \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\
  1 & 1 & 1 & 1 & \ldots & -1 & 1 & 1
\end{bmatrix}
\]

5. Proposed Method
In this paper combined approach of hybrid wavelet transform [26] and VQ is proposed. Initially color image of size 256x256x3 is selected. Using DCT 16x16 and DCT 16x16, hybrid wavelet transform of size 256x256 is generated. Selected color image is transformed using this hybrid wavelet transform. Transform domain coefficients are then sorted in descending order of energy. In transform domain 2048 lowest energy coefficients are discarded and image is reconstructed. Iteratively 96.875% low energy coefficients are discarded and reconstructed images are obtained by applying inverse transform. Now vector quantization algorithm is applied on reconstructed images. Trainee vector is formed by considering R, G and B values of each pixel which gives vector size three. Codebook of size 16 and 32 are generated using three different VQ algorithms namely LBG [], KPE and KEVR. While transmission, only indices of these codebooks are sent which leads to further compression. Using these codebook indices, image can be reconstructed at the receiving end.

6. Experimental Results
Experiments are done on color images of different classes. Selected color images are shown in Figure 2. All images are of size 256x256x3. Three different VQ algorithms LBG, KPE and KEVR are applied on hybrid wavelet transformed image. Codebooks of size 16 and 32 are generated for each image using each of these algorithms. For comparative analysis different error parameters like RMSE, MAE and AFCPV are used.
Figure 3 plots graph of RMSE versus compression ratio for three different VQ algorithms. Codebook of size 16 is generated using each of these VQ algorithms. Graph shows error values are plotted up to compression ratio 192. KPE algorithm gives RMSE 19.76 giving acceptable quality of reconstructed image at such a high compression ratio. Up to compression ratio 24, error values in LBG are slightly higher than error values in KPE algorithm. This difference further increases gradually and becomes noticeable at compression ratio 64 onwards. KPE and KEVR show almost similar performance up to compression ratio 32. Further error in KEVR increases gradually and becomes distinctly greater than error in KPE at compression ratio 192. Still it is slightly less than error in LBG at all compression ratios.
MAE against compression ratio is plotted in Figure 4. Like RMSE, KPE and KEVR show almost similar MAE up to compression ratio 32. Difference in error further increases up to compression ratio 192. This error difference becomes noticeable between LBG and KPE also.

Figure 5 shows AFCP V at various compression ratios obtained using LBG, KPE and KEVR.

AFCPV shows clear distinction in values obtained in three different VQ algorithms from compression ratio 12. Difference between error in LBG and KPE as well as between KEVR and KPE is considerable and goes on increasing as compression ratio increases. In hybrid wavelet transform compression ratio is varied from 2 to 32. Images obtained at each of these compression ratios are vector quantized using VQ algorithms and codebook of size 32 is generated. It further increases compression ratio and it ranges from 9.6 to 153.6. Compression ratio increases after VQ is applied. RMSE is plotted against this increased compression ratio and shown in Figure 6. Up to compression ratio 21.94, almost similar error is given by all VQ algorithms. Onwards, KPE gives less error than LBG and KEVR. Difference between their errors is maximum at compression ratio 153.6.
Figure 6: Comparison of RMSE at various compression ratios using LBG, KPE and KEVR VQ algorithm, each generating Codebook of size 32

Figure 7 shows MAE against compression ratio with codebook size 32 in each VQ algorithm. Error pattern observed in MAE is similar to RMSE.

Figure 7: Comparison of MAE at various compression ratios using LBG, KPE and KEVR VQ algorithm, each generating Codebook of size 32

Figure 8 plots a graph of AFCPV versus compression ratio with codebook size 32 generated by VQ algorithms.

Figure 8: Comparison of AFCPV at various compression ratios using LBG, KPE and KEVR VQ algorithm, each generating Codebook of size 32
Difference in AFCPV values obtained in LBG and KPE is considerably high at lower compression ratios. Slowly this difference reduces up to compression ratio 21.94 and then again it increases at higher compression ratios. KPE and KEVR show almost equal AFCPV up to compression ratio 17.07. Gradually this difference increases with increase in compression ratio. Lowest AFCPV is given by KPE. Difference in AFCPV indicates the difference in reconstructed image quality. Figure 9 represents reconstructed ‘Lena’ image at compression ratio 64 using DKT-DCT hybrid wavelet transform as well as proposed combined approach with respective RMSE values. ‘CB’ indicates codebook size generated after applying VQ algorithm. Using each VQ algorithm codebooks of size 16 and 32 are generated. It has been observed that, image quality obtained by proposed framework is much better than image quality in hybrid wavelet transform. Blocky effect is prominent in hybrid wavelet transform but after application of VQ it is eliminated. Error decreases as codebook size is increased. KPE gives less error than LBG and KEVR.

<table>
<thead>
<tr>
<th>Original image</th>
<th>Hybrid Wavelet</th>
<th>LBG + Hybrid Wavelet</th>
<th>LBG + Hybrid Wavelet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid Wavelet</td>
<td>CB 16</td>
<td>CB 16</td>
<td>CB 32</td>
</tr>
<tr>
<td>RMSE →</td>
<td>13.82</td>
<td>12.82</td>
<td>10.92</td>
</tr>
<tr>
<td>KPE + Hybrid Wavelet</td>
<td>KPE + Hybrid Wavelet</td>
<td>KEVR + Hybrid Wavelet</td>
<td>KEVR + Hybrid Wavelet</td>
</tr>
<tr>
<td>CB 16</td>
<td>CB 32</td>
<td>CB 16</td>
<td>CB 32</td>
</tr>
<tr>
<td>MAE= 12.75</td>
<td>10.71</td>
<td>13.90</td>
<td>10.71</td>
</tr>
</tbody>
</table>

Figure 9: Reconstructed images obtained at compression ratio 64 using DKT-DCT hybrid wavelet transform and different VQ algorithms in combination with DKT-DCT Hybrid wavelet transform

<table>
<thead>
<tr>
<th>Reconstructed ‘Lena’ image using VQ+ Hybrid Wavelet at Compression Ratio 192, Codebook Size in VQ= 16</th>
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<tbody>
<tr>
<td>LBG+ Hybrid Wavelet</td>
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<tr>
<td>MAE= 12.98</td>
</tr>
<tr>
<td>Reconstructed ‘Lena’ image using VQ+ Hybrid Wavelet at Compression Ratio 153, Codebook Size in VQ= 32</td>
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<tr>
<td>LBG+ Hybrid Wavelet</td>
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<tr>
<td>MAE= 9.64</td>
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Figure 10: Reconstructed ‘Lena’ image at compression ratio 192 when codebook size = 16 in VQ algorithm and at compression ratio 153 when codebook size = 32 in VQ algorithm
5. CONCLUSION

Combination of hybrid wavelet transform and VQ is proposed in this paper. Reconstructed image in hybrid wavelet transform is further vector quantized by LBG, KPE and KEVR algorithms. Codebook of size 16 and 32 are generated using each VQ algorithm. It compresses the images further N times where this N depends on size of code book and dimension of trainee vector. Increase in codebook size decreases an error and hence gives better quality reconstructed image. Image quality obtained at compression ratio 32 by combination of hybrid wavelet and VQ is much better than image reconstructed in hybrid wavelet transform at same compression ratio. KPE vector quantization algorithm gives less error than LBG and KEVR when combined with DKT-DCT hybrid wavelet transform. Using proposed combined approach, compression ratio 64 can be obtained with good image quality. Image reconstructed at compression ratio 64 in hybrid wavelet transform is distorted and shows blocky effect which is not observed in proposed framework. Compression ratio up to 192 with acceptable image quality is obtained with codebook size 16 and compression ratio up to 153 can be obtained by codebook size 32. Image quality is still acceptable at such higher compression ratios with slight distortion.

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Dr. H. B. Kekre has received B.E. (Hons.) in Telecomm. Engg. from Jabalpur University in 1958, M.Tech (Industrial Electronics) from IIT Bombay in 1960, M.S.Engg. (Electrical Enng.) from University of Ottawa in 1965 and Ph.D. (System Identification) from IIT Bombay in 1970. He has worked Over 35 years as Faculty of Electrical Engineering and then HOD Computer Science and Engg. at IIT Bombay. After serving IIT for 35 years, he retired in 1995. After retirement from IIT, for 13 years he was working as a professor and head in the department of computer engineering and Vice principal at Thadomal Shahani Engg. College, Mumbai. Now he is senior professor at MPSTME, SVKM’s NMIMS University. He has guided 17 Ph.Ds., more than 100 M.E./M.Tech and several B.E. / B.Tech projects, while in IIT and TSEC. His areas of interest are Digital Signal processing, Image Processing and Computer Networking. He has more than 450 papers in National / International Journals and Conferences to his credit. He was Senior Member of IEEE. Presently He is Fellow of IETE, Life Member of ISTE and Senior Member of International Association of Computer Science and Information Technology (IACST). Recently fifteen students working under his guidance have received best paper awards. Currently eight research scholars working under his guidance have been awarded Ph. D. by NMIMS (Deemed to be University). At present seven research scholars are pursuing Ph.D. program under his guidance.

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