Two-level Vector Quantization Method for Codebook Generation using Kekre's Proportionate Error Algorithm

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Abstract

Vector Quantization is lossy data compression technique and has various applications. Key to Vector Quantization is good codebook. Once the codebook size is fixed then for any codebook generation algorithm the MSE reaches a value beyond which it cannot be reduced unless the codebook size is increased. In this paper we are proposing two-level codebook generation algorithm which reduces mean squared error (MSE) for the same codebook size. For demonstration we have used codebooks obtained from Keker's Proportionate error (KPE) algorithm. The proposed method is can be applied to any codebook generation algorithm.

Keywords: Vector Quantization, Codebook, Data Compression, Encoding.

1. INTRODUCTION

The increasing demand in various fields has made the digital image compression very vigorous in the area of research. Compression techniques reduce the amount of data needed to represent an image so that images can be economically transmitted and stored. Vector quantization (VQ) is one of the non lossless data compression techniques. VQ has been used in number of applications, like speech recognition and face detection [3], [5], pattern recognition [4], speech data compression [30], image segmentation [31-34], Content Based Image Retrieval (CBIR) [35], [36], Face recognition[40].

VQ is a mapping function which maps k-dimensional vector space to a finite set CB = $\{C_1, C_2, C_3, \ldots, C_N\}$. The set CB is called as codebook consisting of N number of codevectors and each codevector $C_i = \{c_{i1}, c_{i2}, c_{i3}, \ldots, c_{ik}\}$ is of dimension k. Good codebook design leads to less distortion in reconstructed image. Codebook can be designed in spatial domain by clustering algorithms [1], [2], [6], [7], [27-29], [37-39].

For encoding, image is fragmented into non overlapping blocks and each block is then converted to the training vector $X_i = (x_{i1}, x_{i2}, \ldots, x_{ik})$. The codebook is searched for the closest codevector Cmin by computing squared Euclidean distance as presented in equation (1) between vector X_i and all the codevectors of the codebook CB. This method is called as exhaustive search (ES).

$$d(X_i, C_{min}) = \min_{1\le j\le N}\{d(X_i, C_j)\} \text{ Where } d(X_i, C_j) = \sum_{p=1}^{k}(x_{ip} - c_{jp})^2 \quad (1)$$

Exhaustive Search (ES) method gives the optimal result at the end, but it intensely involves computational complexity. Observing equation (1) to obtain one nearest codevector for a training vector computations required are N Euclidean distance where N is the size of the codebook. So for M image training vectors, will require M*N number of Euclidean distances computations. It is obvious that if the codebook size is increased the distortion will decrease with increase in searching time.

Various encoding methods are given in literature: Partial Distortion search (PDS)[7], nearest neighbor search algorithm based on orthonormal transform (OTNNS) [8]. Partial Distortion Elimination (PDE) [9], triangular inequality elimination (TIE) [10], mean distance ordered partial codebook search (MPS) algorithm [11], fast codebook search algorithm based on the Cauchy-Schwarz inequality (CSI) [12], fast codebook search based on subvector technique (SVT) [13], the image encoding based on L2-norm pyramid of codewords [14] and the fast algorithms using the modified L2-norm pyramid (MLP) [15], fast codeword search algorithm based on MPS+TIE+PDE proposed by Yu-Chen, Bing-Hwang and Chih-Chiang (YBC) in 2008 [16], Kekre's fast search algorithms [17], [18], [19] and others [20], [21], [22], are classified as partial search methods. Some of the partial techniques use data structure to organize the codebook for example tree-based [23], [24] and projection based structure [25], [26]. All these algorithms lessen the computational cost needed for VQ encoding keeping the image quality close to Exhaustive search algorithm.

To generate codebook there are various algorithms. It is observed that for the same codebook size the distortion obtained from codebook generation algorithms varies. However the minimum error is not achieved. Once the codebook size is fixed then for all these algorithms the MSE reaches a value beyond which it cannot be reduced because the codevectors in the codebook have not reached their optimal position. Hence Two-level codebook generation algorithm which minimizes the distortion further is proposed. For demonstration codebooks obtained from Kekre's Proportionate Error (KPE) [29] algorithm is used and the results are compared with well known LBG codebook.. The method proposed is quite general and is applicable to any codebook generation algorithm.

2. KEKER'S PROPORTIIONATE ERROR ALGORITHM (KPE)

Let T= $\{X_1, X_2, \ldots\ldots, X_M\}$ be the training sequence consisting of M source vector. Assume that source vector is of length K, $X_m=\{x_{m,1}, x_{m,2}, \ldots\ldots x_{m,K}\}$ for m=1, 2, ………. , M. In this algorithm initial codevector is computed by taking the mean of all the training vectors X_i for i=1, 2, ..……., M. Thus initially the codebook contains only one codevector. Then two vectors from the codevector are computed by adding proportionate error instead of adding constant. From the codevector proportions between the members of vector is calculated.
Let k be the length of codevector,
C = $\{c_1, c_2, \ldots\ldots, c_k\}$ be the codevector, and
E = $\{e_1, e_2, \ldots\ldots, e_k\}$ be the error vector
$c_j = \min\{c_i / i= 1,2, \ldots. k\}$ where j is the index of the member of vector whose value is minimum among the vector members.
Then assign $e_j = 1$and if $c_i / c_j \le 10$ then assign $e_i = c_i / c_j$
else assign $e_i = 10$ for $i \ne j$ and i=1,2,………., k.

Two vectors v1 and v2 are formed by adding the error vector E to codevector C and by subtracting the error vector E from codevector C respectively. Euclidean distance between the all the training vectors Xi with v1 and with v2 are computed
i.e. d1=|| v1-X_i ||2 and d2=|| v2-X_i ||2 for i=1, 2, …..., M
if d1 < d2 then Xi is put in cluster1 else Xi is put in cluster2 and two clusters are created.

From each cluster codevector is computed by taking the mean of all the vectors in the cluster. Thus the codebook size is increased to two.
The above procedure is repeated for each of the codevector and that codebook size is increased to four. This procedure is repeated till the codebook size is increased to the size specified by the user or MSE is reduced to minimum permissible value.

3. TWO-LEVEL CODEBOOK GENERATION ALGORITHM

First the image is spitted in non-overlapping blocks of 2x2 pixels (each pixel consisting of R, G, and B color component). Hence we get vector of dimension 12. Codebooks of sizes 256, 512 and 1024 are obtained using following Two-level codebook generation algorithm.
Let F be the input image and N be the codebook size.

1. The x% (where x = 100, 75, 70, 69, 68, 67, 50) of size of codebook is generated using KPE algorithm.
2. Image $\hat{F}$ is reconstructed using codebook obtained in step 1.
3. Generate error image $E = F - \hat{F}$.
4. Construct codebook of size N-(N*x)/100 for an error image E using KPE.
5. Reconstruct error image $\hat{E}$ using codebook obtained from step 4.
6. Regenerate final image by adding $\hat{F}$ and $\hat{E}$.

The method is general and can be applied to any codebook generation algorithm. For illustration of this method KPE codebook generation algorithm is used and results are compared with well known LBG algorithm[2], [39].

4. RESULTS

The Two-level VQ algorithms are implemented on Intel processor 1.66 GHz, 1GB RAM machine to obtain results. We have tested these algorithms on seven images namely Flower, Ganesh, Scenary, Strawberry, Tajmahal and Tiger each of size 256X256 color images. The images selected correspond to different classes as shown in Figure 1.

Table I, II, III shows the performance comparison of MSE for different sharing between level 1 and level 2 using KPE codebooks of varying sizes 256, 512 and 1024 respectively.

Figure 1. shows the six color training images namely Ganesh, Strawberry, Scenary, Tajmahal and Tiger of size 256X256 on which this algorithm is tested.

Figure 2, 3 and 4. shows the plot of Average MSE for different sharing between level 1 and level 2 using LBG and KPE codebooks of sizes 256, 512 and 1024 respectively.

Figure 5. shows the results of Tajmahal image using Two-level technique.

Figure 1. Six color Training images of size 256x256

Images		**CB Size 256**						
	% of level 1	**100**	**75**	**70**	**69**	**68**	**67**	**50**
	CB Size for level 1	**256**	**192**	**179**	**176**	**174**	**171**	**128**
	CB size for level 2	**0**	**64**	**77**	**80**	**82**	**85**	**128**
Flower	**MSE after level 1**	314.99	217.90	218.89	219.05	219.06	219.20	219.39
	MSE after level 2	314.99	112.42	106.65	106.80	103.95	103.89	**89.93**
	PSNR	23.15	27.62	27.85	27.84	27.96	27.97	28.59
Ganesh	**MSE after level 1**	767.77	500.84	514.81	515.17	518.11	519.31	539.25
	MSE after level 2	767.77	392.40	388.61	379.74	373.24	360.28	**307.40**
	PSNR	19.28	22.19	22.24	22.34	22.41	22.56	23.25
Scenary	**MSE after level 1**	406.39	204.48	207.30	208.02	208.26	209.05	211.99
	MSE after level 2	406.39	132.90	135.62	134.33	134.57	135.10	**116.36**
	PSNR	22.04	26.90	26.81	26.85	26.84	26.82	27.47
Strawberry	**MSE after level 1**	338.06	239.81	242.08	242.40	242.61	243.42	247.22
	MSE after level 2	338.06	192.31	190.14	190.81	187.86	188.14	**168.14**
	PSNR	22.84	25.29	25.34	25.32	25.39	25.39	25.87
Tajmahal	**MSE after level 1**	364.59	266.81	270.00	270.59	270.60	271.15	280.39
	MSE after level 2	364.59	191.79	195.44	188.20	190.22	192.86	**158.67**
	PSNR	22.51	25.30	25.22	25.38	25.34	25.28	26.13
Tiger	**MSE after level 1**	463.80	374.79	387.73	388.62	389.62	390.93	401.15
	MSE after level 2	463.80	293.76	276.89	267.07	270.88	269.95	**245.79**
	PSNR	21.47	23.45	23.71	23.86	23.80	23.82	24.23
Average	**MSE after level 1**	442.60	300.77	306.80	307.31	308.04	308.84	316.57
	MSE after level 2	442.60	219.26	215.56	211.16	210.12	208.37	**181.05**
	PSNR	21.88	25.13	25.20	25.27	25.29	25.31	25.92
Percentage MSE Reduction			50.46	51.30	52.29	52.53	52.92	59.09

TABLE 1. Comparison of MSE for different sharing between level 1 and level 2 using KPE codebook of size 256

Images		CB Size 512						
	% of level 1	**100**	**75**	**70**	**69**	**68**	**67**	**50**
	CB Size for level 1	**512**	**384**	**358**	**353**	**348**	**343**	**256**
	CB size for level 2	**0**	**128**	**154**	**159**	**164**	**169**	**256**
Flower	**MSE after level 1**	249.18	149.72	151.50	152.16	152.31	152.44	152.81
	MSE after level 2	249.18	85.23	84.94	79.83	78.83	77.78	**56.32**
	PSNR	24.17	28.82	28.84	29.11	29.16	29.22	30.62
Ganesh	**MSE after level 1**	654.09	402.08	418.00	420.02	421.03	423.28	440.35
	MSE after level 2	654.09	272.96	256.55	260.02	256.35	254.12	**204.44**
	PSNR	19.97	23.77	24.04	23.98	24.04	24.08	25.03
Scenary	**MSE after level 1**	296.83	156.28	160.23	160.49	161.32	161.99	165.37
	MSE after level 2	296.83	102.56	100.29	99.55	101.65	96.54	**73.12**
	PSNR	23.41	28.02	28.12	28.15	28.06	28.28	29.49
Strawberry	**MSE after level 1**	277.28	197.55	199.55	200.01	200.53	200.76	203.34
	MSE after level 2	277.28	125.42	123.32	121.46	120.53	118.86	**87.12**
	PSNR	23.70	27.15	27.22	27.29	27.32	27.38	28.73
Tajmahal	**MSE after level 1**	279.01	222.44	226.39	227.13	227.74	229.23	233.75
	MSE after level 2	279.01	116.71	110.26	113.15	110.72	118.67	**77.71**
	PSNR	23.67	27.46	27.71	27.59	27.69	27.39	29.23
Tiger	**MSE after level 1**	432.18	285.36	295.17	297.56	298.57	300.36	313.92
	MSE after level 2	432.18	168.46	175.61	173.58	170.13	174.37	**131.46**
	PSNR	21.77	25.87	25.69	25.74	25.82	25.72	26.94
Average	**MSE after level 1**	364.76	235.57	241.81	242.90	243.58	244.68	251.59
	MSE after level 2	364.76	145.22	141.83	141.27	139.70	140.06	**105.03**
	PSNR	22.78	26.85	26.94	26.98	27.02	27.01	28.34
Percentage MSE Reduction			60.19	61.12	61.27	61.70	61.60	71.21

TABLE 2. Comparison of MSE for different sharing between level 1 and level 2 using KPE codebook of size 256

Images		CB Size 1024						
	% of level 1	**100**	**75**	**70**	**69**	**68**	**67**	**50**
	CB Size for level 1	**1024**	**768**	**716**	**706**	**696**	**686**	**512**
	CB size for level 2	**0**	**256**	**308**	**318**	**328**	**338**	**512**
Flower	**MSE after level 1**	167.20	98.92	101.35	101.63	101.74	102.01	102.80
	MSE after level 2	167.20	47.03	47.94	47.95	47.29	46.30	**33.35**
	PSNR	25.90	31.41	31.32	31.32	31.38	31.47	32.90
Ganesh	**MSE after level 1**	544.79	296.69	307.67	309.55	310.71	312.00	322.13
	MSE after level 2	544.79	160.06	164.04	163.50	161.24	160.06	**125.42**
	PSNR	20.77	26.09	25.98	26.00	26.06	26.09	27.15
Scenary	**MSE after level 1**	189.24	106.26	107.78	108.30	108.52	108.84	111.21
	MSE after level 2	189.24	45.91	48.60	49.58	49.28	48.48	**34.36**
	PSNR	25.36	31.51	31.26	31.18	31.20	31.27	32.77
Strawberry	**MSE after level 1**	233.57	157.25	158.90	159.09	159.56	160.10	162.81
	MSE after level 2	233.57	67.74	67.87	67.62	68.29	67.42	**49.90**
	PSNR	24.45	29.82	29.81	29.83	29.79	29.84	31.15
Tajmahal	**MSE after level 1**	230.30	169.30	173.25	173.64	174.41	174.02	176.35
	MSE after level 2	230.30	65.48	64.15	64.96	66.43	65.17	**46.34**
	PSNR	24.51	29.97	30.06	30.00	29.91	29.99	31.47
Tiger	**MSE after level 1**	345.72	193.81	198.90	199.54	201.05	201.86	212.35
	MSE after level 2	345.72	92.48	91.33	91.04	90.95	90.06	**68.50**

	PSNR	22.74	28.47	28.52	28.54	28.54	28.59	29.77
Average	MSE after level 1	285.14	170.37	174.64	175.29	176.00	176.47	181.28
	MSE after level 2	285.14	79.78	80.66	80.78	80.58	79.58	**59.65**
	PSNR	23.96	29.55	29.49	29.48	29.48	29.54	30.87
Percentage MSE Reduction			72.02	71.71	71.67	71.74	72.09	79.08

TABLE 3. Comparison of MSE for different sharing between level 1 and level 2 using KPE codebook of size 256

Note: The highlighted figures in all these tables are for minimum value of MSE. It is observed that most of them are close to 50% allocation of codebook to level 1. This indicates that codebook be divided in the ratio 1:1 between level 1 and level 2. Further it is observed that MSE reduces by 59%, 71% and 79% for the codebook size 256, 512 and 1024 respectively.

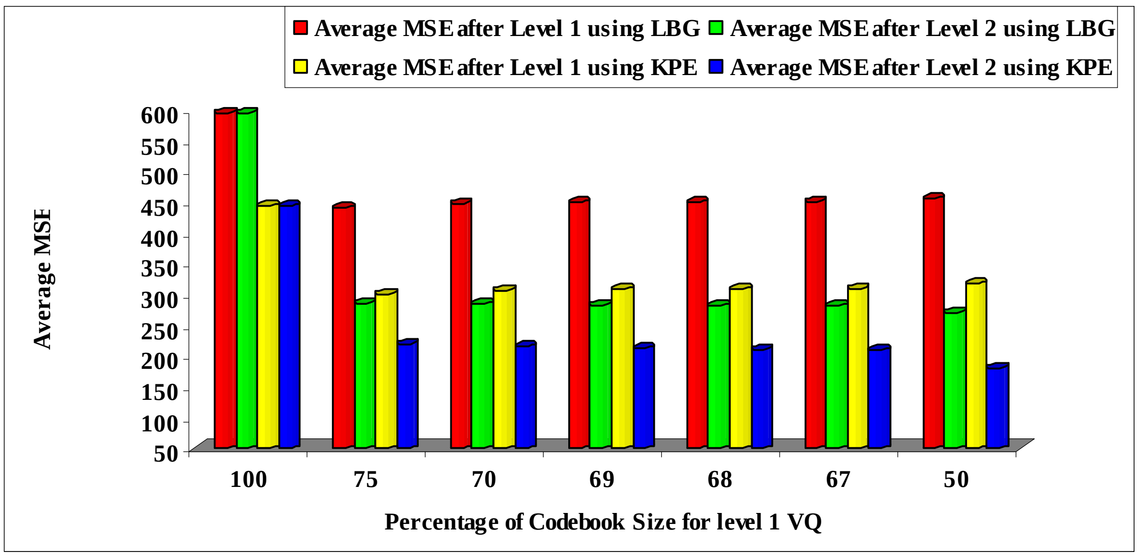

Figure 2. Plot of Level 1and level 2 average MSE Vs percentage of codebook size for level 1 VQ using LBG and KPE for codebook size 256.

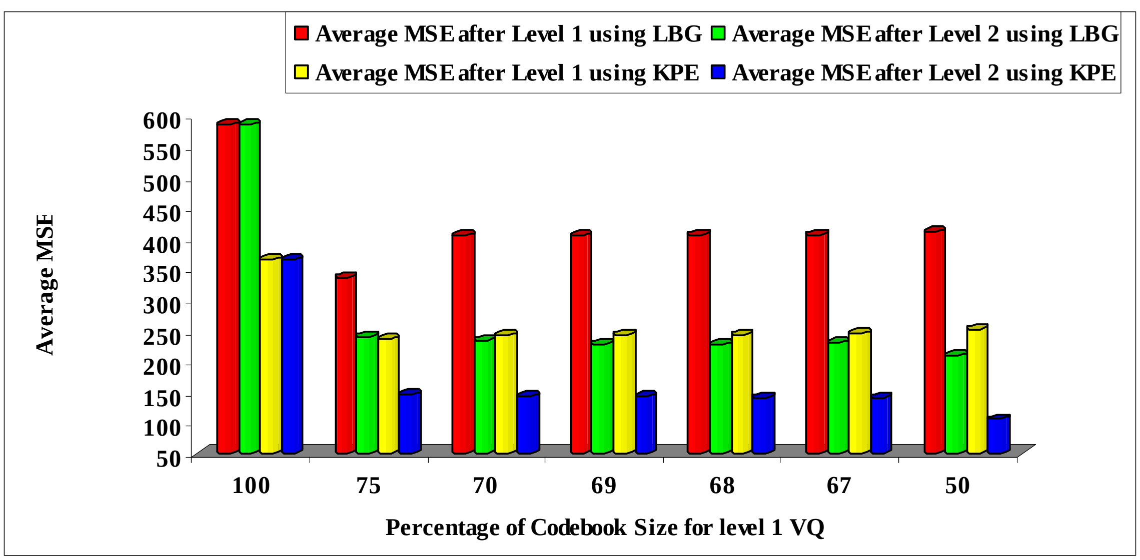

Figure 3. Plot of Level 1and level 2 average MSE Vs percentage of codebook size for level 1 VQ using LBG and KPE for codebook size 512.

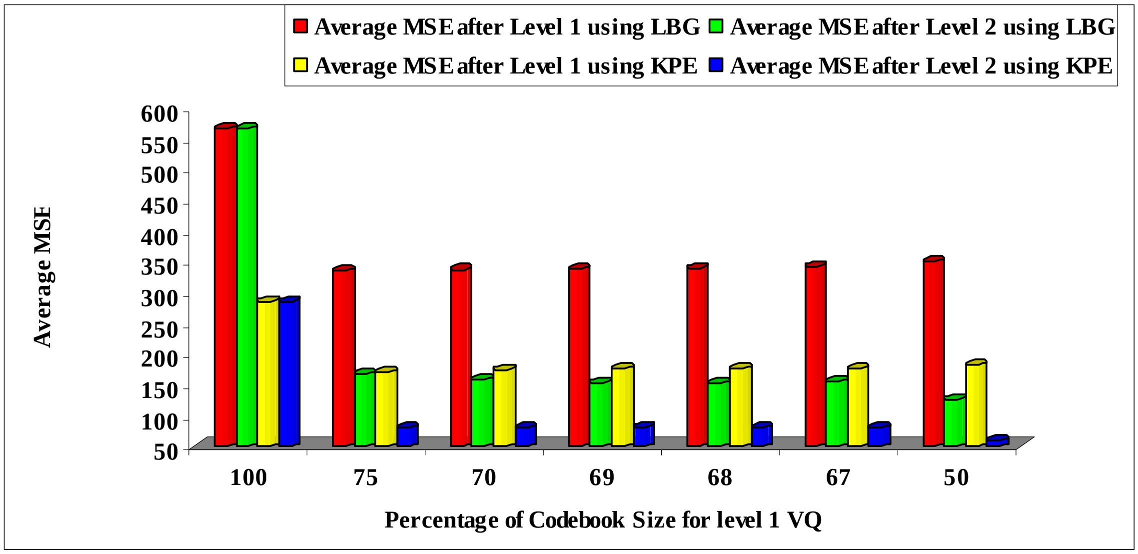

Figure 4. Plot of Level 1and level 2 average MSE Vs percentage of codebook size for level 1 VQ using LBG and KPE for codebook size 1024.

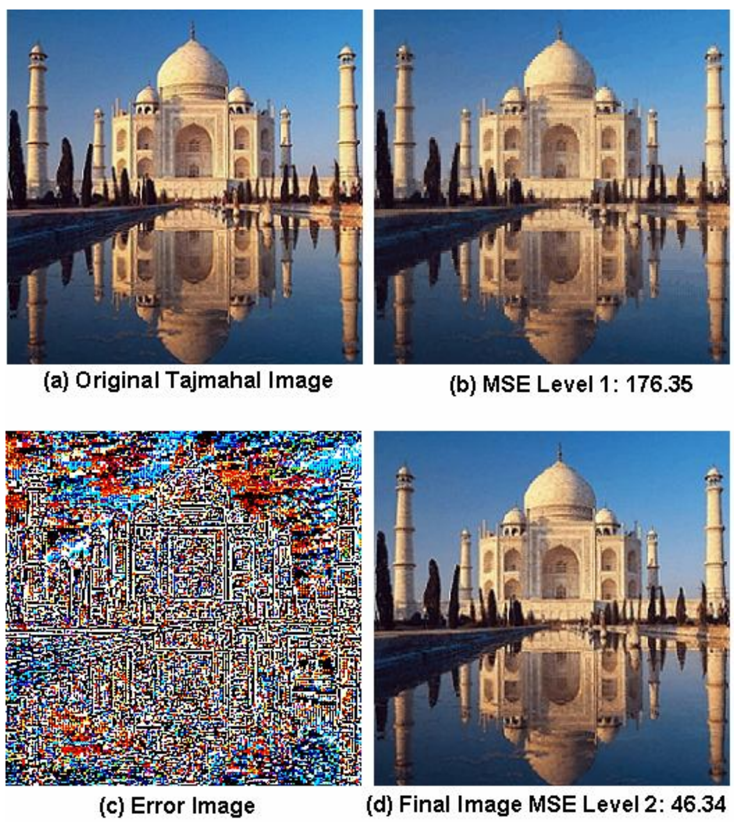

Figure 5. Tajmahal image reconstructed after two-level VQ and error images after level 1 and level 2, image size 256x256 codebook size 512 for level 1 and 512 for level 2.

5. CONCLUSIONS

Paper presents a novel error minimization technique using two-level VQ. It is observed that once we fix the codebook size and then we use any VQ algorithm the MSE obtained for that size cannot be reduced further unless the codebook size is increased. Here in this paper we present a novel idea of splitting the codebook in two levels in the ratio L1:L2. Any codebook algorithm can be used for level 1 and the error image is obtained. On this error image same VQ algorithm is used in level 2. It is observed that this method drastically reduces MSE as compared to allocation of entire codebook to level 1. Minimum MSE obtained by this algorithm is based on ratio L1:L2 and is image dependent. However size allocation in the ratio of 1:1 for level 1 and level 2 on the average gives the best results reducing MSE by 79 percent for the codebook size 1024. Further it is observed that MSE reduction obtained using KPE codebook with respect to LBG is 33% to 53% for the codebook size 256 to 1024 respectively.

6. REFERENCES

1. R. M. Gray, "Vector quantization", IEEE ASSP Mag., pp. 4-29, Apr. 1984.
2. Y. Linde, A. Buzo, and R. M. Gray, "An algorithm for vector quantizer design," IEEE Trans.Commun., vol. COM-28, no. 1, pp. 84-95, 1980.
3. Chin-Chen Chang, Wen-Chuan Wu, "Fast Planar-Oriented Ripple Search Algorithm for Hyperspace VQ Codebook", IEEE Transaction on image processing, vol 16, no. 6, June 2007.
4. Ahmed A. Abdelwahab, Nora S. Muharram, "A Fast Codebook Design Algorithm Based on a Fuzzy Clustering Methodology", International Journal of Image and Graphics, vol. 7, no. 2 pp. 291-302, 2007.
5. C. Garcia and G. Tziritas, "Face detection using quantized skin color regions merging and wavelet packet analysis," IEEE Trans. Multimedia, vol. 1, no. 3, pp. 264–277, Sep. 1999.
6. A.Gersho, R.M. Gray.: 'Vector Quantization and Signal Compressio', Kluwer Academic Publishers, Boston, MA, 1991.
7. C. D. Bei and R. M. Gray.: 'An improvement of the minimum distortion encoding algorithm for vector quantization', IEEE Trans. Commun.,vol. 33, No. 10, pp. 1132–1133, Oct. 1985.
8. Z. Li, and Z.- M. Lu. : 'Fast codevector search scheme for 3D mesh model vector quantization', Electron. Lett., vol. 44, No. 2, pp. 104-105, Jan 2008.
9. C. Bei, R. M. Gray, ''An improvement of the minimum distortion encoding algorithm for vector quantization'', IEEE Trans. Commun., Vol. 33, no. 10, pp. 1132–1133, Oct 1985.
10. S. H. Huang, S. H. Chen, ''Fast encoding algorithm for VQ-based image coding'', Electron. Lett. Vol. 26, No. 19, pp. 1618–1619, 1990.
11. S. W. Ra, J. K. Kim, ''A fast mean-distance-ordered partial codebook search algorithm for image vector quantization'', IEEE Trans. Circuits-II, vol. 40, No. 9, pp. 576–579, 1993.
12. K .S. Wu, J.C. Lin, ''Fast VQ encoding by an efficient kick-out condition'', IEEE Trans. Circ. Syst. Vid., vol.10, No. 1, pp. 59–62, 2000.
13. J .S. Pan, Z.M. Lu, S.H. Sun, ''An efficient encoding algorithm for vector quantization based on subvector technique'', IEEE Trans. Image Process. Vol 12, No.3, pp. 265–270, 2003.
14. B. C. Song, J.B. Ra, ''A fast algorithm for vector quantization using L2-norm pyramid of codewords'', IEEE Trans. Image Process. Vol. 4, No.12, pp. 325–327, 2002.
15. Z. Pan, K. Kotani, T. Ohmi, ''Fast encoding method for vector quantization using modified L2-norm pyramid'', IEEE Signal Process. Lett. Vol. 12, issue 9, pp. 609–612, 2005.
16. Y. Chen, B. Hwang, C. Chiang, "Fast VQ codebook search algorithm for grayscale image coding", Image and Vision Compu., vol. 26, No. 5, pp. 657-666, May 2008.
17. H. B. Kekre, Tanuja K. Sarode, "Centroid Based Fast Search Algorithm for Vector Quantization", International Journal of Imaging (IJI), Vol 1, No. A08, pp. 73-83, Autumn 2008, available: http://www.ceser.res.in/iji.html
18. H. B. Kekre, Tanuja K. Sarode, "Fast Codevector Search Algorithm for 3-D Vector Quantized Codebook", WASET International Journal of cal Computer Information Science and Engineering (IJCISE), Volume 2, No. 4, pp. 235-239, Fall 2008. available: http://www.waset.org/ijcise.
19. H. B. Kekre, Tanuja K. Sarode,"Fast Codebook Search Algorithm for Vector Quantization using Sorting Technique", ACM International Conference on Advances in Computing,

Communication and Control (ICAC3-2009), 23-24 Jan 2009, Fr. Conceicao Rodrigous College of Engg., Mumbai. Available on online ACM portal.

20. C. C. Chang and I. C. Lin, "Fast search algorithm for vector quantization without extra look-up table using declustered subcodebooks," IEE Proc. Vis., Image, Signal Process., vol. 152, No. 5, pp. 513–519, Oct.2005.
21. C. M. Huang, Q. Bi, G. S. Stiles, and R. W. Harris, "Fast full-search equivalent encoding algorithms for image compression using vector quantization," IEEE Trans. Image Process., vol. 1, No. 3, pp. 413–416, Jul. 1992.
22. Y. C. Hu and C. C. Chang, "An effective codebook search algorithm for vector quantization", Imag. Sci. J., vol. 51, No. 4, pp. 221–234, Dec. 2003.
23. R. M. Gray and Y. Linde, "Vector quantization and predictive quantizers for gauss-markov sources," IEEE Trans. Commun., vol. 30, No. 2, pp. 381–389, Feb. 1982.
24. S. J. Wang and C. H. Yang, "Hierarchy-oriented searching algorithms using alternative duplicate codewords for vector quantization mechanism," Appl. Math. Comput., vol. 162, No. 234, pp. 559–576, Mar. 2005.
25. S. C. Tai, C. C. Lai, and Y. C. Lin, "Two fast nearest neighbor searching algorithms for image vector quantization," IEEE Trans. Commun., vol. 44, No. 12, pp. 1623–1628, Dec. 1996.
26. C. C. Chang, D. C. Lin, and T. S. Chen, "An improved VQ codebook search algorithm using principal component analysis," J. Vis. Commun. Image Represent., vol. 8, No. 1, pp. 27–37, Mar. 1997.
27. H. B. Kekre, Tanuja K. Sarode, "New Fast Improved Codebook Generation Algorithm for Color Images using Vector Quantization," International Journal of Engineering and Technology, vol.1, No.1, pp. 67-77, September 2008.
28. H. B. Kekre, Tanuja K. Sarode, "Fast Codebook Generation Algorithm for Color Images using Vector Quantization," International Journal of Computer Science and Information Technology, Vol. 1, No. 1, pp: 7-12, Jan 2009.
29. H. B. Kekre, Tanuja K. Sarode, "An Efficient Fast Algorithm to Generate Codebook for Vector Quantization," First International Conference on Emerging Trends in Engineering and Technology, ICETET-2008, held at Raisoni College of Engineering, Nagpur, India, 16-18 July 2008, Avaliable at online IEEE Xplore.
30. H. B. Kekre, Tanuja K. Sarode, "Speech Data Compression using Vector Quantization", WASET International Journal of Computer and Information Science and Engineering (IJCISE), vol. 2, No. 4, 251-254, Fall 2008. available: http://www.waset.org/ijcise
31. H. B. Kekre, Tanuja K. Sarode, Bhakti Raul, "Color Image Segmentation using Kekre's Algorithm for Vector Quantization", International Journal of Computer Science (IJCS), Vol. 3, No. 4, pp. 287-292, Fall 2008. available: http://www.waset.org/ijcs.
32. H. B. Kekre, Tanuja K. Sarode, Bhakti Raul, "Color Image Segmentation using Vector Quantizationt", Journal of Advances in Engineering Science, Section C, Number 3, 2008.
33. H. B. Kekre, Tanuja K. Sarode, Bhakti Raul, "Color Image Segmentation using Vector Quantization Techniques Based on Energy Ordering Concept" International Journal of Computing Science and Communication Technologies (IJCSCT) Volume 1, Issue 2, January 2009.
34. H. B. Kekre, Tanuja K. Sarode, Bhakti Raul, "Color Image Segmentation using Kekre's Fast Codebook Generation Algorithm Based on Energy Ordering Concept", ACM International Conference on Advances in Computing, Communication and Control (ICAC3-2009), 23-24 Jan 2009, Fr. Conceicao Rodrigous College of Engg., Mumbai. Available on online ACM portal.
35. H. B. Kekre, Ms. Tanuja K. Sarode, Sudeep D. Thepade, "Image Retrieval using Color-Texture Features from DCT on VQ Codevectors obtained by Kekre's Fast Codebook Generation", ICGST-International Journal on Graphics, Vision and Image Processing (GVIP), Volume 9, Issue 5, pp.: 1-8, September 2009. Available online at http://www.icgst.com/gvip/Volume9/Issue5/P1150921752.html.
36. H.B.Kekre, Tanuja K. Sarode, Sudeep D. Thepade, "Color-Texture Feature based Image Retrieval using DCT applied on Kekre's Median Codebook", International Journal on Imaging (IJI), Available online at www.ceser.res.in/iji.html.

37. H. B. Kekre, Tanuja K. Sarode, "Vector Quantized Codebook Optimization using K-Means", International Journal on Computer Science and Engineering (IJCSE) Vol.1, No. 3, 2009, pp.: 283-290, Available online at: http://journals.indexcopernicus.com/abstracted.php?level=4&id_issue=839392.
38. H. B. Kekre, Tanuja K. Sarode, "Multilevel Vector Quantization Method for Codebook Generation", International Journal of Engineering Research and Industrial Applications (IJERIA), vol. 2, no. V, 2009, ISSN 0974-1518, pp.: 217-231. Available online at. http://www.ascent-journals.com/ijeria_contents_Vol2No5.htm.
39. H. B. Kekre, Tanuja K. Sarode, "Bi-level Vector Quantization Method for Codebook Generation", Second International Conference on Emerging Trends in Engineering and Technlogy, at G. H. Raisoni College of Engineering, Nagpur on 16-18 December 2009 pp.:866-872, this paper is available on IEEE Xplore.
40. H. B. Kekre, Kamal Shah, Tanuja K. Sarode, Sudeep D. Thepade, "Performance Comparison of Vector Quantization Technique – KFCG with LBG, Existing Transforms and PCA for Face Recognition", International Journal of Information Retrieval (IJIR), Vol. 02, Issue 1, pp.: 64-71, 2009.