Vector Quantized Codebook Optimization using K-Means

Dr. H.B. Kekre, Ms. Tanuja K. Sarode

Abstract:- *In this paper we are proposing K-means algorithm for optimization of codebook. In general K-means is an optimization algorithm but this algorithm takes very long time to converge. We are using existing codebook so that the convergence time for K-means is reduced considerably. For demonstration we have used codebooks obtained from Linde Buzo and Gray (LBG) and Kekre's Fast Codebook Generation (KFCG) algorithms. It is observed that the optimal error obtained from both LBG and KFCG is almost same indicating that there is a unique minima. From the results it is obvious that KFCG codebook takes less number of iterations as compared to LBG codebook. This indicates that KFCG codebook is close to the optimum. This is also indicated by less Mean Squared Error (MSE) for it.*

Key Words:- *Vector Quantization (VQ), Codebook, Codebook Optimization, Data Compression, Encoding.*

I. 1. INTRODUCTION

Images are used for a communication from ancient age and because of the rapid technological growth and the usage of the internet today we are able to store and transmit digital data/image today. Also the transmission of multimedia applications over the web is increasing day by day. The multimedia applications consist of mainly speech, images, and videos. These applications requires large amount of data resulting in consumption of huge bandwidth and storage resources. Vector quantization (VQ) [1]-[3] is an efficient technique for data compression and has been successfully used in various applications involving VQ-based encoding and VQ-based recognition. The response time is very important factor for real time application [1]. Many type of VQ, such as classified VQ [9], [10], address VQ[9], [11], finite state VQ[9], [12], side match VQ[9], [13], mean-removed classified VQ[9], [14], and predictive classified VQ[9], [15], have been used for various purposes. VQ has been applied to some other applications, such as index compression [9], [16], and inverse half toning [9], [17], [18]. VQ has been very popular in a variety of research fields such as speech recognition and face detection [5], [19], pattern recognition [22], segmentation [23],[46-48], CBIR [24], [25]. VQ is also used in real time applications such as real time video-based event detection [5], [20] and anomaly intrusion detection systems [5], [21].

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VQ can be defined as a mapping function that maps k-dimensional vector space to a finite set $\mathbf{CB = \{C_1, C_2, C_3, \ldots\ldots, C_N\}}$. The set CB is called codebook consisting of N number of codevectors and each codevector $C_i = \{c_{i1}, c_{i2}, c_{i3}, \ldots\ldots, c_{ik}\}$ is of dimension k. The key to VQ is the good codebook. Codebook can be generated in spatial domain by clustering algorithms [3], [4], [26-29], [32] or in transform domain [6]-[8]. The method most commonly used to generate codebook is the Linde-Buzo-Gray (LBG) algorithm [3], [4] which is also called as Generalized Lloyd Algorithm (GLA).

In Encoding phase image is divided into non overlapping blocks and each block then converted to the training vector $\mathbf{X_i = (x_{i1}, x_{i2}, \ldots\ldots, x_{ik})}$. The codebook is then searched for the nearest codevector C_{min} by computing squared Euclidean distance as presented in equation (1) with vector $\mathbf{X_i}$ with all the codevectors of the codebook **CB.** This method is called exhaustive search (ES).

$$d(X_i, C_{\min}) = \min_{1\le j\le N}\{d(X_i, C_j)\} \text{ Where}$$

$$d(X_i, C_j) = \sum_{p=1}^{k}(x_{ip} - c_{jp})^2 \qquad (1)$$

Although the Exhaustive Search (ES) method gives the optimal result at the end, it involves heavy computational complexity. If we observe the above equation (1) to obtain one nearest codevector for a training vector requires N Euclidean distance computation 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 to reduce the distortion the search time will also increase.

In order to reduce the search time there are various search algorithms available in literature [30-31],[33-45]. All these are partial search algorithms reduces the computational cost needed for VQ encoding keeping the image quality close to Exhaustive search algorithm

Once the codebook size is fixed then for all these algorithms the MSE reaches a value beyond which it cannot be reduced. Although the codevectors in the codebook have not reached their optimal position. K-means [32] is an algorithm giving the optimal solution, it depends on the random initial selection of the codevectors. This initial selection is usually far off from the optimal solution. Hence it takes extremely huge time to converge. There is very low probability that the initial solution is close to the optimal solution. In this paper we are proposing K-means algorithm for optimization of codebook which already exists. For demonstration we have used codebooks obtained from LBG [3], [4] and KFCG [27] algorithms.

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II. CODEBOOK GENERATION ALGORITHMS

In this section we discuss VQ codebook generation algorithms LBG, KFCG and K-Means.

A. LBG Algorithm [3], [4]

In this algorithm centroid is computed as the first codevector for the training set. In Fig. 1 two vectors v_1 & v_2 are generated by adding constant error to the codevector. Euclidean distances of all the training vectors are computed with vectors v_1 and v_2 thus two clusters are formed based on nearest of v_1 or v_2. This procedure is repeated for every cluster. The drawback of this algorithm is that the cluster elongation is $+135^o$ to horizontal axis in two dimensional cases. This results in inefficient clustering.

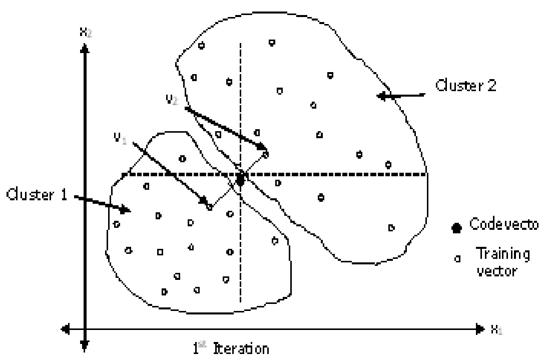

Fig.1. LBG for 2 dimensional case

B. Kekre's Fast Ccodebook Generation algorithm (KFCG) [14], [27]

In reference [27] we have proposed this algorithm for image data compression. This algorithm reduces code book generation time. Initially we have one cluster with the entire training vectors and the codevector C_1 which is centroid. In the first iteration of the algorithm, the clusters are formed by comparing first member of training vector with first member of code vector C_1. The vector X_i is grouped into the cluster 1 if $x_{i1} < c_{11}$ otherwise vector X_i is grouped into cluster 2. In second iteration, the cluster 1 is split into two by comparing second member x_{i2} of vector X_i belonging to cluster 1 with that of the member c_{12} of the codevector C_1. Cluster 2 is split into two by comparing the member x_{i2} of vector X_i belonging to cluster 2 with that of the member c_{22} of the codevector C_2.

This procedure is repeated till the codebook size is reached to the size specified by user. It is observed that this algorithm gives minimum error and requires least time to generate codebook as compared to other algorithms [14], [49], [51].

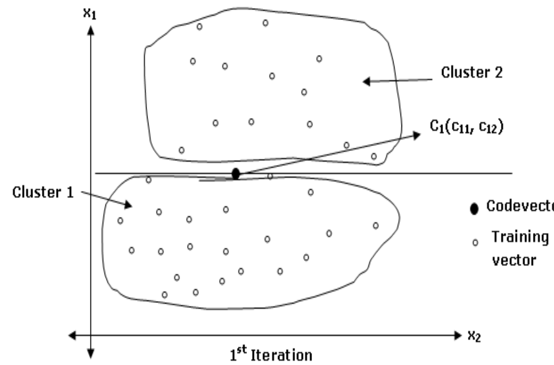

Fig.2a.

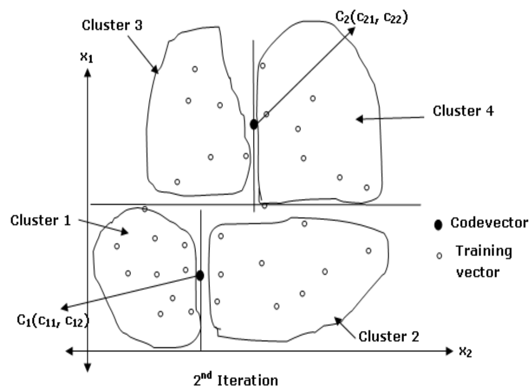

Fig.2b.

Fig. 2 KFCG algorithm for 2 dimensional case

C. K-Means Algorithms [32]

Select k random vectors from the training set and call it as codevectors. Find the squared Euclidean distance of all the training vectors with the selected k vectors and k clusters are formed. A training vectors X_j is put in i^{th} cluster if the squared Euclidean distance of the X_j with i^{th} codevector is minimum. In case the squared Euclidean distance of X_j with codevectors happens to be minimum for more than one codevector then X_j is put in any one of them. Compute centroid for each cluster. Centroids of each of cluster form set of new codevectors as an input to K-Means algorithm for the next iterations. Compute MSE for each of k clusters. Compute net MSE.

Repeat the above process till the net MSE converges. This algorithm takes very long time to converge and to obtain minimum net MSE if we start from random k vectors selection. Instead of this random selection we are giving codebook generated from LBG and KFCG algorithms. It is observed that this algorithm converges faster by reducing the convergence time by factor of more than three.

III. PROPOSED METHOD

Following are the steps for proposed method

1. Obtain codebook containing k codevectors using LBG or KFCG or any other codebook generation algorithm.
2. Give the above codebook as an input to K-Means algorithm (i.e. Instead of this random selection we are giving codebook generated from LBG and KFCG algorithms).

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3. Find the squared Euclidean distance of all the training vectors with the k codevectors and k clusters are formed. A training vectors X_j is put in i^{th} cluster if the squared Euclidean distance of the X_j with i^{th} codevector is minimum. In case the squared Euclidean distance of X_j with codevectors happens to be minimum for more than one codevector then X_j is put in any one of them.
4. Compute centroid for each cluster.
5. Compute MSE for each of k clusters and net MSE.
6. Replace initial codevectors by the centroids of each cluster respectively.
7. Repeat the steps 3 to 5 till the two successive net MSE values are same.

IV. RESULTS

The algorithms are implemented on Intel processor 1.66 GHz, 1GB RAM machine to obtain results. We have tested these algorithms on six color images Madhuri, Bridge, Bird, Houseboat, Peppers and Viharlake of size 256x256x3.

Table 1, 2, 3 show the comparison of minimized error vs number of iteration required for optimization of LBG and KFCG codebook of size 256, 512 and 1024 using K-means on color images respectively.

Fig. 3. shows the Variation of MSE vs number of iteration for Viharlake images for different codebook sizes 256, 512 and 1024.

Fig. 4 shows six Training Images of size 256x256x3 covering different classes.

Fig. 5 shows sample Bird images showing original, Initial and Final Images for LBG and KFCG codebooks of size 1024 with MSE.

Table 1 Comparison of minimized error vs number of iteration required for optimization of LBG and KFCG codebook of size 256 using K-means.

CB Size 256

Parameters	Madhuri		Bridge		Bird		Houseboat		Peppers		Viharlake	
	LBG	KFCG	LBG	KFCG	LBG	KFCG	LBG	KFCG	LBG	KFCG	LBG	KFCG
Initial MSE	213.60	98.64	358.39	111.70	247.09	81.76	421.73	168.83	308.21	117.36	133.40	75.33
Minimized MSE	71.45	67.42	83.98	80.85	58.65	53.45	112.58	103.58	81.20	79.20	50.58	51.07
No. of Iterations	89	42	66	52	37	40	83	49	43	38	54	63

Table 2 Comparison of minimized error vs number of iteration required for optimization of LBG and KFCG codebook of size 512 using K-means.

CB Size 512

Parameters	Madhuri		Bridge		Bird		Houseboat		Peppers		Viharlake	
	LBG	KFCG	LBG	KFCG	LBG	KFCG	LBG	KFCG	LBG	KFCG	LBG	KFCG
Initial MSE	191.77	77.34	285.72	87.65	213.66	63.23	357.46	127.68	257.92	92.05	115.52	61.11
Minimized MSE	54.87	49.41	66.50	61.55	47.33	39.43	86.33	76.37	63.66	58.70	37.58	37.81
No. of Iterations	41	37	57	32	42	21	66	37	60	37	38	27

Table 3 Comparison of minimized error vs number of iteration required for optimization of LBG and KFCG codebook of size 1024 using K-means.

CB Size 1024

Parameters	Madhuri		Bridge		Bird		Houseboat		Peppers		Viharlake	
	LBG	KFCG	LBG	KFCG	LBG	KFCG	LBG	KFCG	LBG	KFCG	LBG	KFCG
Initial MSE	155.52	50.37	207.47	61.41	165.90	43.22	284.61	81.00	208.96	66.69	92.31	39.59
Minimized MSE	43.71	34.23	54.19	43.84	39.07	27.64	67.01	53.73	52.83	43.54	28.68	26.86
No. of Iterations	35	25	47	20	54	20	35	22	62	29	31	20

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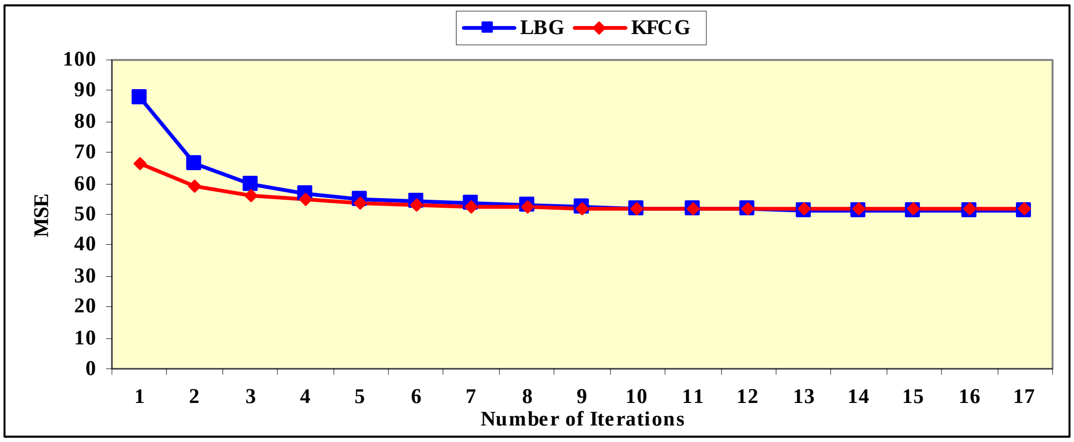
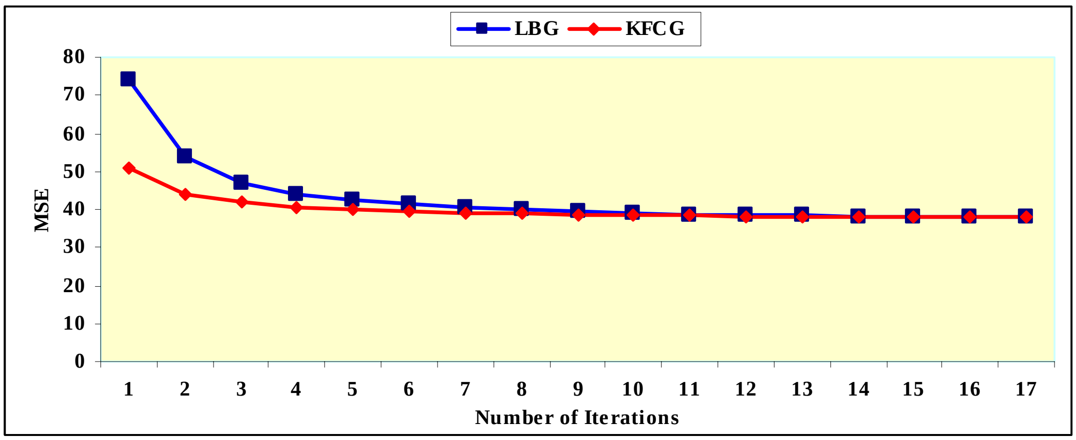
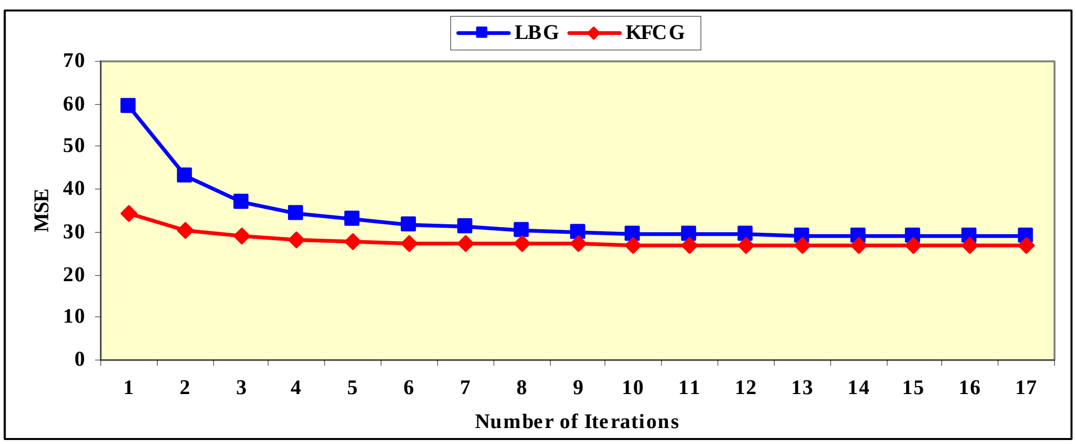


a. Variation of MSE vs number of iteration for Viharlake images for different codebook size 256.



b. Variation of MSE vs number of iteration for Viharlake images for different codebook size 512.



c. Variation of MSE vs number of iteration for Viharlake images for different codebook size 1024.

Fig. 3. Variation of MSE vs number of iteration for Viharlake images for different codebook sizes 256, 512 and 1024.

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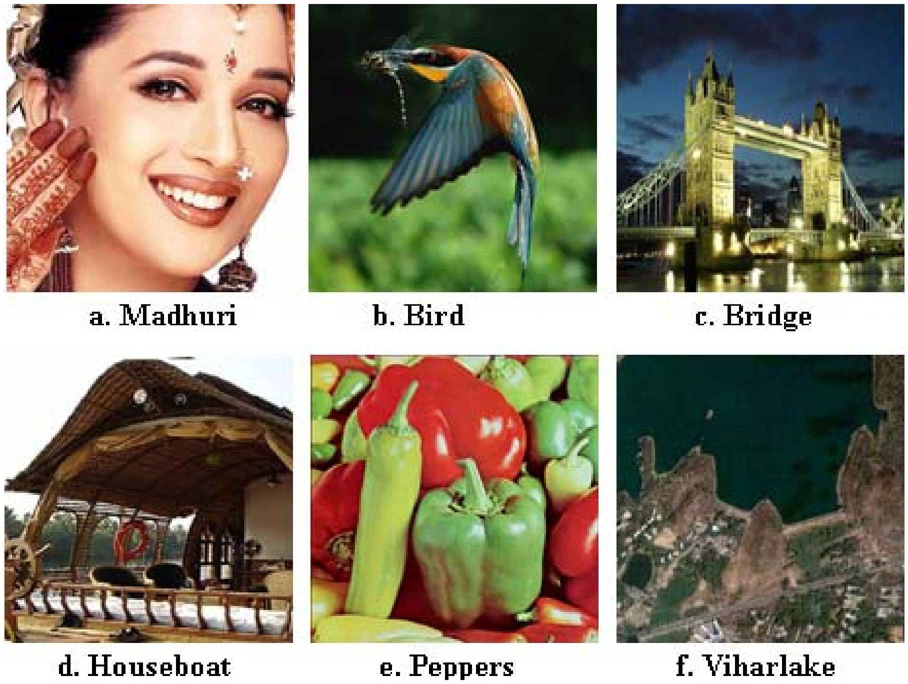

Fig. 4. Six Training Images of size 256x256x3 covering different classes.

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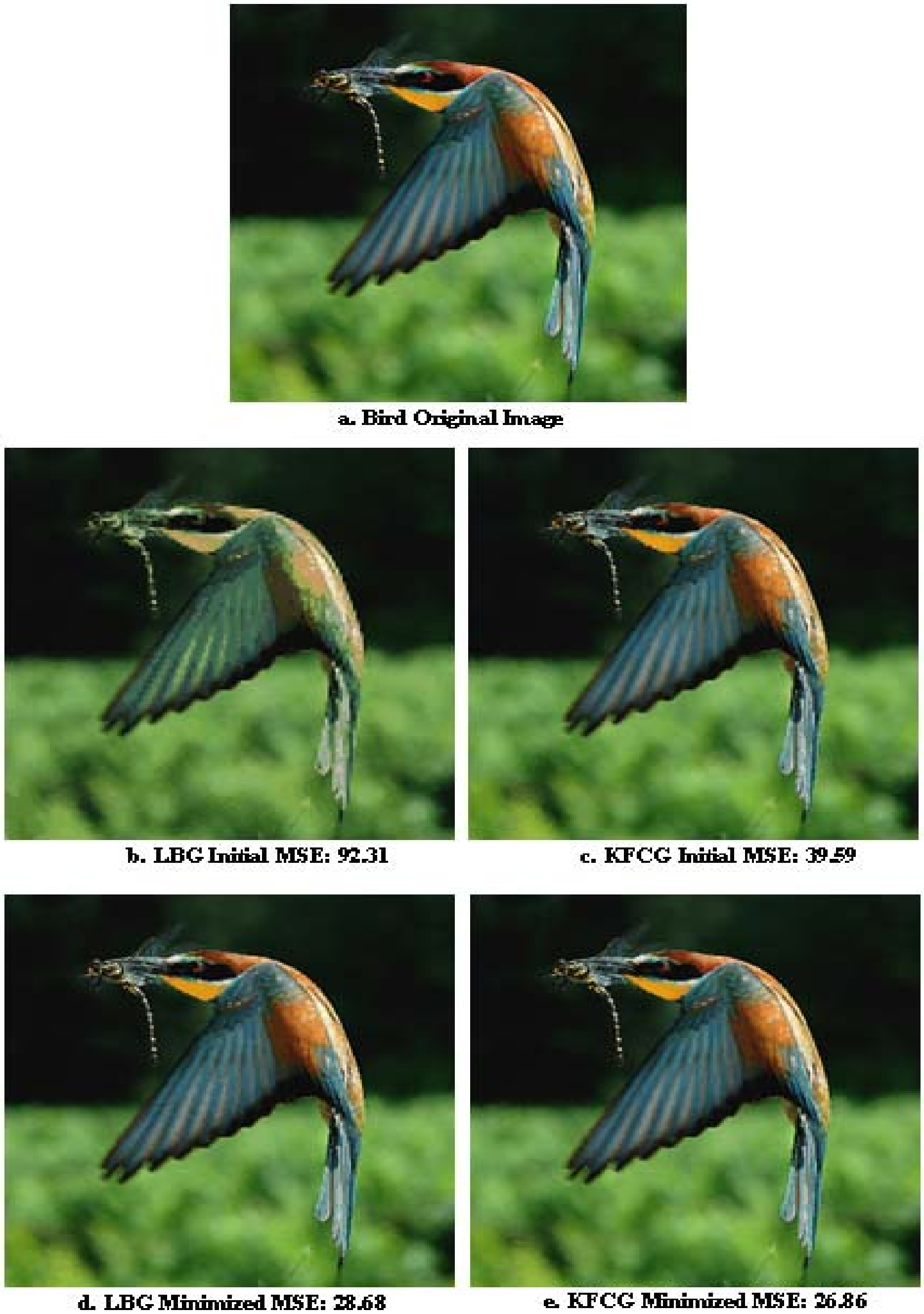

Fig. 5 Sample Bird images showing original, Initial and Final Images for LBG and KFCG codebooks of size with MSE 1024.

5. CONCLUSION

K-means algorithm is an optimization algorithm. It reaches optimal value if there is only one minima. The time taken for the optimal solution depends upon the initial starting point. If there is no apriory knowledge of the optimal point one has to start by randomly choosing the initial values. Hence it takes extremely large time for convergence as the initial value is invariably too far off from optimal solution. In this paper we are proposing K-means algorithm for optimization of codebook which already exist so that the convergence time is reduced considerably. For demonstration we have used codebooks obtained from LBG and KFCG algorithms. It is observed that the minimum error obtained from both LBG and KFCG codebooks is almost same indicating that there is a unique minima. From the results it is obvious that KFCG codebook takes lesser number of iteration in most cases as compared to LBG codebook. This indicates that KFCG codebook is closer to the optimum. This is also confirmed by lesser MSE value for it.

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