Comparison of Hybrid Vector Quantizers for Narrow band Speech Signals

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***Abstract*: Vector quantization techniques play a dominant role in compression of speech signals. There exists a variety of vector quantization techniques. This paper deals with enhancing the performance of the existing vector quantization techniques using hybrid methods. The vector quantization techniques that exist are the split vector quantization(SVQ), multi stage vector quantization(MSVQ), split- multi stage vector quantization(S-MSVQ),switched split vector quantization(SSVQ), switched multistage vector quantization(SWMSVQ), and multi switched split vector quantization(MSSVQ). The process of vector quantization for all techniques involves the generation of codebooks. The codebooks are generated using LBG algorithm. The spectral distortion performance, computational complexity, and memory requirements of split vector quantization (SVQ), multi stage vector quantization(MSVQ) and switched split vector quantization (SSVQ),split-multi stage vector quantization(S-MSVQ), switched multistage vector quantization(SWMSVQ), and multi switched split vector quantization(MSSVQ) techniques are compared.**

Keywords -Linear predictive coding, Multi stage vector quantization (MSVQ), split vector quantization (SVQ)

I.INTRODUCTION

Quantization is a process of mapping an infinite set of scalar or vector quantities by a finite set of scalar or vector quantities. Two types of quantization techniques exist. They are scalar quantization and vector quantization. “Scalar quantization deals with the quantization of samples on a sample by sample basis”, while “vector quantization deals with quantizing the samples in groups called vectors”. Vector quantization increases the optimality of a quantizer. In speech coding [], quantization is required to reduce the number of bits used to represent a sample of speech signal. When less number of bits is used to represent a sample the bit-rate, complexity and memory requirement gets reduced. Quantization results in the loss in the quality of a speech signal, which is undesirable. So a compromise must be made between the reduction in bit-rate and the quality of speech signal. An example of two dimensional vector quantizer is shown in Fig.1

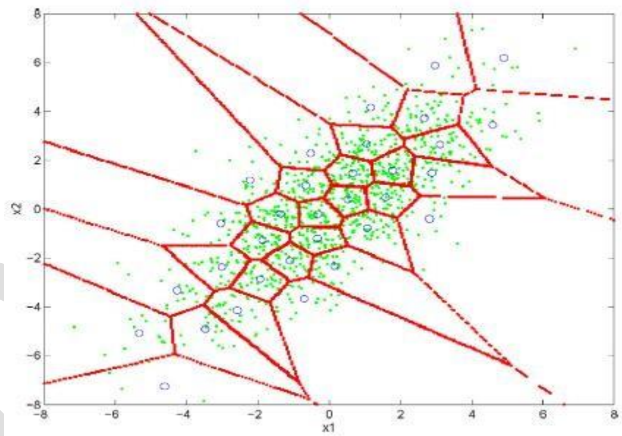


Fig.1 Two dimentional Vector Quantizer.

Vector quantization technique has become a great tool with the development of non variational design algorithms like the Linde, Buzo, Gray (LBG) algorithm. On the other hand besides spectral distortion the vector quantizer is having its own limitations like the computational complexity and memory requirements required for the searching and storing of the codebooks. For applications requiring higher bit-rates the computational complexity and memory requirements increases exponentially. The block diagram of a vector quantizer is shown in below figure. The block diagram consists of three blocks, input vector buffer, vector quantizer, codebook with codewords.Input vector and codewords are applied to the vector quantizer and develops index i and it will useful in further recognition process.

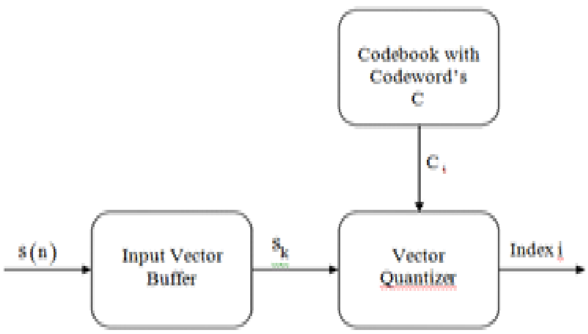


Fig: Block diagram of Vector Quantizer

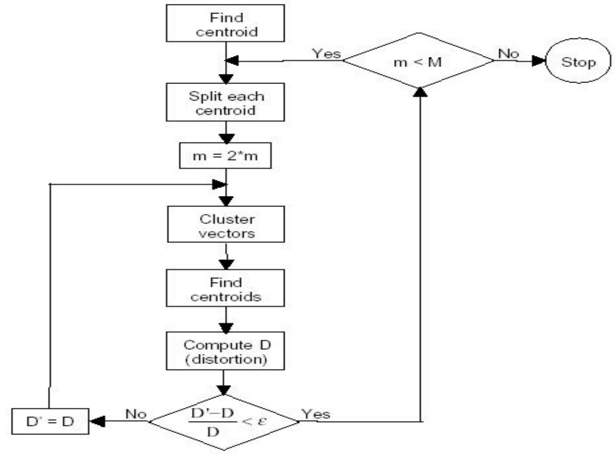


Fig.2 Flow diagram of the LBG algorithm.

Vector quantization use a set of reference vectors derived from a data set named training set. Using the codebook, each vector element of the input data is represented by one codeword. An accepted classification scheme subdivides this clustering or vector quantization techniques in two main groups- hard (net) or soft (fuzzy). The difference between these two groups is the degree of membership of each vector to a cluster. In the hard scheme vector quantization, each vector belongs to only one cluster, with the membership degree equal to unity. In soft scheme vector quantization, each vector can belong to several different clusters, with different degree of membership.

II.CODEBOOK DESIGN

The codebooks are designed using an iterative algorithm called Linde, Buzo and Gray (LBG) algorithm. The input to the LBG algorithm is a training sequence. The training sequence is the concatenation of a set LSF vectors obtained from people of different groups and of different ages. The speech signals used to obtain training sequence must be free of background noise. The codebook generation using LBG algorithm requires the generation of an initial codebook, which is the centroid or mean obtained from the training sequence. The centroid obtained is then split into two centroids or codewords using the splitting method.It will shown in the below figure 2.

III.SPECTRAL DISTORTION

The quality of the speech signal is an important parameter in speech coders and is measured in terms of spectral distortion measured in decibels (dB). The spectral distortion is measured between the LPC power spectra of the quantized and unquantized speech signals[7]. The spectral distortion is measured frame wise and the average or mean of the spectral distortion calculated over all frames is taken as the final value of the spectral distortion. the spectral distortion is given by equation:

$$SD= \sqrt{\frac{1}{(f2-f1)}\int_{f1}^{f2}[10\log\log_{10} si(f) - 10\log_{10}\widehat{si(f)}]2} \quad \text{in db.}$$

The average or mean of the spectral distortion SD is given by equation:

$$SD= \frac{1}{N}\sum_{i=i}^{N} SDi$$

IV. VECTOR QUANTIZATION TECHNIQUES

1.Split vector quantizer: In Split Vector Quantization the training sequence used for codebook generation is split into vectors of smaller dimension. And each split of the training sequence is used to generate separate sub codebooks[13], there by independent vector quantizers exist and the bits must be allocated to each of them. As a result less number of bits is available at each quantizer, the computational complexity and memory requirements gets reduced as they depend on the number of bits allocated to the quantizer and on the dimension of the vector to be quantized.

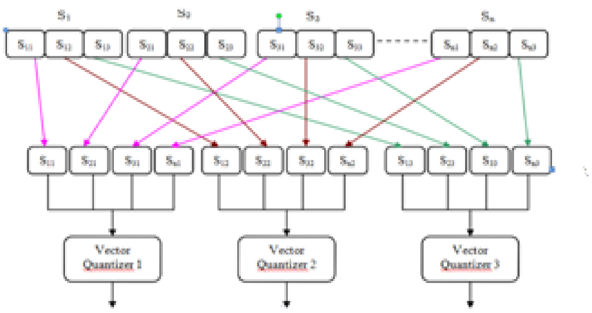


Fig.3 Block diagram of three part Split Vector Quantizer

2.Multi stage vector quantizer:

Multistage Vector Quantizer is a cascaded connection of several vector quantizers, where the output of one stage is given as an input to the next stage and the bits used for quantization are divided among the stages connected in cascade[12].

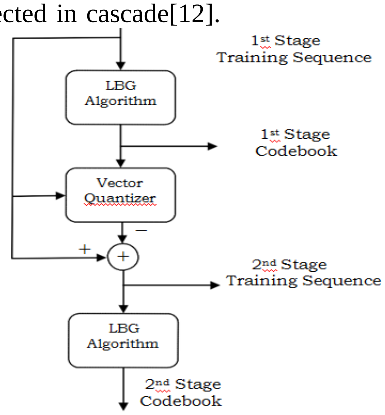


Fig.4Generation of codebooks at different stages of Multistage vector quantizer.

3.Split-Multistage vector quantizer:

The block diagram of a Split-Multistage Vector Quantizer with three parts and three stages is shown in Fig 5. The block diagram is similar to three stage Multistage Vector Quantizer except for the splits at each stage. In Split-Multistage Vector Quantizer each split is treated as a separate vector quantizer and the vectors at each split are quantized independently. The quantization mechanism involved in Split-Multistage Vector Quantizer is similar to the quantization process involved in Multistage Vector Quantizer, except that in Split-Multistage Vector Quantizer at each stage thesub-vectors are quantized independently.

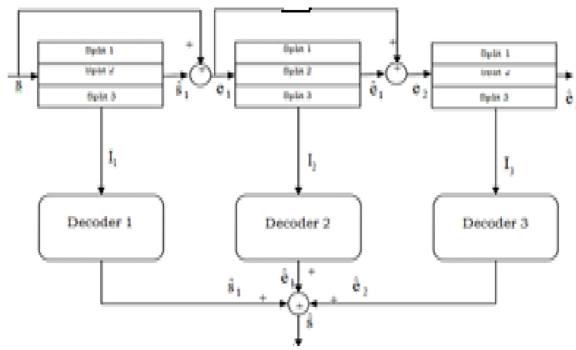


Fig.5 Switched Split Vector Quantization

4.Switched split vector quantizer:

Switched Split Vector Quantization (SSVQ) is one of the latest vector quantization techniques and is developed to improve the performance of Split Vector Quantization technique. Switched Split Vector Quantization technique is a hybrid of Switch Vector Quantization and Split Vector Quantization techniques and is used to exploit the linear and non linear dependencies that exist between the splits of a Split Vector Quantizer. In Switched Split Vector Quantizer initially the Switch Vector Quantizer partitions the entire vector space into voronoi regions and exploits the dependencies that exist across all dimensions of the vector space. Then the Split Vector Quantizer is:

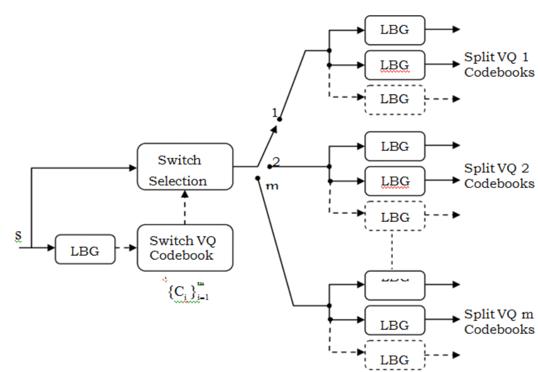
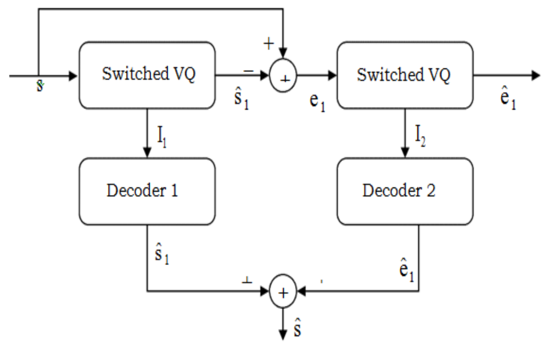


Fig.6Switched multistage vector quantization.

5. Switched Multistage Vector Quantizer:

Switched Multistage Vector Quantization (SWMSVQ) technique is the hybrid vector quantization technique which is used to improve the performance of a Multistage Vector Quantization technique. Switched Multistage Vector Quantization technique[11] is a hybrid of Switch

Vector Quantization and Multistage Vector Quantization techniques.



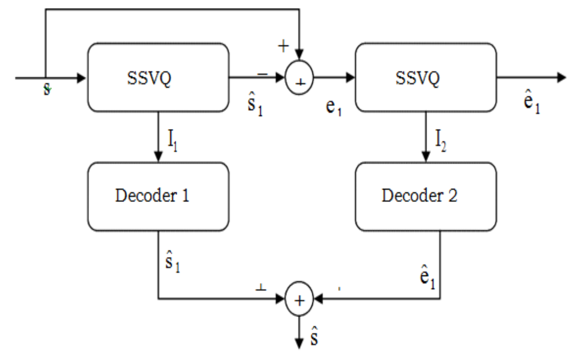
(I_i denotes the index of i^{th} quantizer)

Fig.7 Block Diagram of Switched Multistage Vector Quantizer

6. Multi Switched Split Vector Quantizer:

Multi Switched Split Vector Quantization (MSSVQ) technique is the technique. It is an efficient hybrid vector quantization technique which exhibits better performance compared to other hybrid vector quantization techniques. Multi Switched Split Vector Quantization technique is a hybrid of Multistage Vector Quantization, Switch Vector Quantization and Split Vector Quantization techniques. Multi Switched Split Vector Quantization technique can be implemented in two ways[10]. They are hard decision and soft decision schemes. The concept of hard decision and soft decision schemes is similar to the concept discussed in Switched Split Vector Quantization technique [4]. The required codebooks are generated as in the case of Split-Multistage Vector Quantization technique. Each stage of Multi Switched Split Vector Quantizer uses a Switched Split Vector Quantizer in either the soft or hard decision schemes.

The block diagram of a P x m x sp MSSVQ is shown below in Fig 8, where ‘P’ corresponds to the number of stages, ‘m’ corresponds to the number of switches and ‘sp’ represents the number of splits [89-90]. In Multi Switched Split Vector Quantizer each input vector ‘s’ to be quantized is passed through the first stage of Switched Split Vector Quantizer to obtain the quantized version of the input vector $\hat{s}_1$. The error resulting at the first stage of quantization is given as an input to the Switched Split Vector Quantizer of the second stage to obtain the quantized version of the error vector$\hat{e}_1$.



(I_i denotes the index of i^{th} quantizer)

Fig.8 MULTI SWITCHED SPLIT VECTOR QUANTIZER

V. RESULTS

To calculate complexity and memory requirements the following formulae are to be used.

$$\text{Complexity}_{\text{MSVQ}} = \sum_{j=1}^{P}\left(4n2^{b_j} - 1\right)$$

$$\text{Complexity}_{\text{MSSVQ HARD}} = P\left(4n2^{b_m} - 1\right) + \sum_{j=1}^{P}\sum_{i=1}^{sp}\left(4n_i 2^{b_{ji}} - 1\right)$$

$$\text{Complexity}_{\text{SSVQ HARD}} = \left(4n2^{b_m} - 1\right) + \sum_{i=1}^{sp}\left(4n_i 2^{b_i} - 1\right)$$

$$\text{Memory}_{\text{MSVQ}} = \sum_{j=1}^{P} n2^{b_j}$$

$$\text{Memory}_{\text{SSVQ HARD}} = n2^{b_m} + 2^{b_m}\sum_{i=1}^{sp} n_i 2^{b_i}$$

$$\text{Memory}_{\text{MSSVQ HARD}} = Pn2^{b_m} + 2^{b_m}\sum_{j=1}^{P}\sum_{i=1}^{sp} n_i 2^{b_{ji}}$$

Table I Computational complexities of various vector quantization techniques at different bit-rates.

Bits/frame	Svq	Msvq	S-msvq	Ssvq	Swmsvq	mssvq
24	10.23	30.71	0.80	8.7	15.5	0.9
23	8.7	25.59	0.75	7.2	13.03	0.8
22	7.1	20.47	0.71	5.1	10.47	0.77
21	5.11	15.35	0.66	4.4	7.9	0.70

Table II spectral distortion of various vector quantization techniques at different bit-rates.

Bits/frame	Svq	Msvq	S-msvq	Ssvq	Swmsvq	mssvq
24	.29	0.12	.17	.15	.12	.03
23	.32	.12	.17	.17	.12	.03
22	.33	.13	.18	.17	.13	.03
21	.33	.14	.18	.18	.13	.13

Table III Memory requirements of various vector quantization techniques.

Bits/frame	svq	msvq	smsvq	ssvq	swmsvq	mssvq
24	2560	7680	204	4372	3900	396
23	2176	6400	192	3604	3260	364
22	1792	5120	180	2580	2620	332
21	1280	3840	168	2196	1980	300

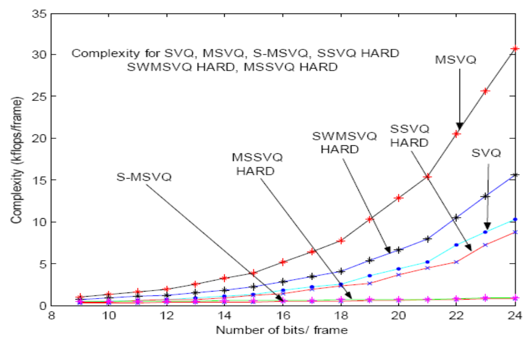


Fig.9 Complexity for SVQ,MSVQ,

S-MSVQ,SSVQ,SWMSVQ,MSSVQ.

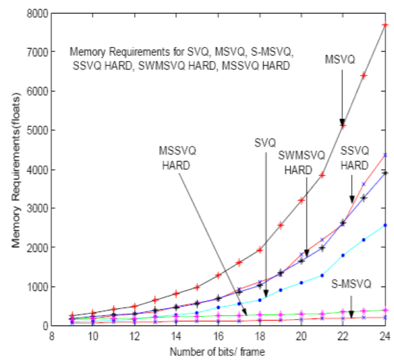


Fig.10 Memory requirements for SVQ,MSVQ,

S-MSVQ,SSVQ,SWMSVQ,MSSVQ

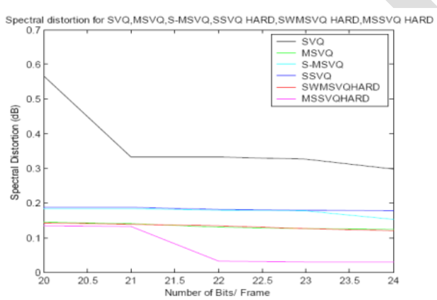


Fig.11 Spectral distortion for SVQ,MSVQ,

S-MSVQ,SSVQ,SWMSVQ,MSSVQ

CONCLUSION

MSSVQ provides better trade-off between bit rate and spectral distortion performance, computational complexity, and memory requirements, when compared to all the product code vector quantization techniques like SVQ, MSVQ,S-MSVQ, SSVQ,SWMSVQ.So MSSVQ is proved to be better. The decrease in the computational complexity is due to the less availability of bits at each stage of quantization as the number of stages increases. I t can be observed that for SSVQ the memory required is high when compared to SVQ. This has been overcome by MSSVQ where the memory required is less when compared to SVQ, MSVQ and SSVQ. So after comparison of all the above product code vector quantization techniques MSSVQ is proved to be better technique. By using Matlab we can get all the results with the help of suitable mathematical analysis.

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