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Codebook Optimization Using ACO Algorithm

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Abstract — The ACO algorithm, inspired by ant behavior, is used to optimize codebooks in speech processing. This study focuses on compressing speech signals efficiently to reduce bandwidth usage. Vector Quantization, a block coding technique, is employed, utilizing codebooks generated by the Linde-Buzo-Gray (LBG) algorithm. The ACO algorithm is proposed as an optimization method for these codebooks, aiming to minimize spectral distortion. Results show that ACO-optimized codebooks reduce spectral distortion.

Keywords— *Vector quantization, Speech compression, Linde-Buzo-Gray, ACO.*

I. INTRODUCTION

Speech compression is a critical aspect of modern communication systems, enabling efficient transmission and storage of speech signals. Traditional compression methods often involve complex algorithms that can be computationally intensive. Ant Colony Optimization (ACO) offers a novel approach to optimize the compression process, leveraging the principles of swarm intelligence inspired by the foraging behavior of ants.
Ant Colony Optimization (ACO) is a metaheuristic optimization algorithm that simulates the behavior of ant colonies to find optimal solutions to complex problems. In the context of speech compression, ACO can be applied to optimize the codebook used in vector quantization. Vector quantization involves partitioning the speech signal into segments and representing each segment by a codeword from a codebook. The quality of the compression depends on the design of the codebook, which ideally should contain codewords that closely match the segments of the speech signal.

In this paper, we propose a novel approach to speech compression using ACO to optimize the codebook for vector quantization. We demonstrate the effectiveness of our approach through experimental results showing improved spectral distortion and speech quality compared to traditional methods. Our work contributes to the field of speech compression by providing a new perspective on optimizing codebooks for efficient speech signal representation.

II. VECTOR QUANTIZATION

Vector quantization is an example of lossy compression method used in signal processing to reduce the number of bits needed for representing a signal by means of dividing it into small non-overlapping vectors and encoding each vector using a codebook. This codebook is made up of some code vectors where invention is to identify the most suitable code vector in the codebook that can represent every vector from the signal. The objective of this process is to minimize distortion between original and reconstructed signals obtained from decoding a book of codes. Linde-Buzo-Gray (LBG) algorithm usually generates such a book, since it partitions training data into clusters effectively. In general, vector quantization remains one of the best ways for reducing data rates at acceptable quality levels concerning signals.

In vector quantization, a real-valued N-dimensional input vector is compared with the real-valued dimensional codewords of a codebook. This process, illustrated in the block diagram of a vector quantizer (Figure 1), aims to find the codeword that best matches the input vector, minimizing distortion. The codebook's low-bit-rate codewords are then used to represent the high-bit-rate input vectors.

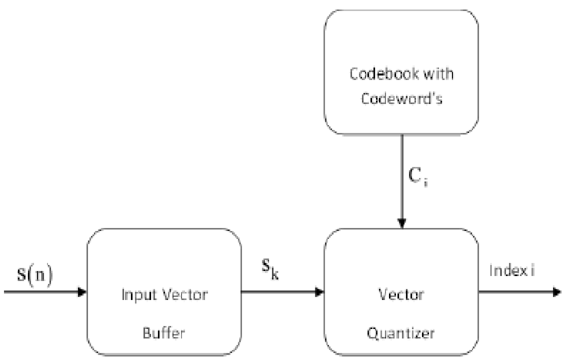

Figure-1. Block diagram of Vector Quantization

III. ACO ALGORITHM

The Ant Colony Optimization (ACO) algorithm, proposed by Marco Dorigo in 1992, mimics the foraging behavior of ants to solve combinatorial optimization problems. Inspired by stigmergy, where ants communicate indirectly by leaving pheromone trails, ACO uses artificial ants to find optimal solutions. Initially, ants explore paths randomly, leaving pheromones. Shorter paths accumulate more pheromones, attracting more ants. This process iterates, converging towards the shortest path. Modern ACO algorithms enhance this by adding artificial elements to simulate natural ant behavior. In Ant Colony Optimization Pheromone trails represent the quality of solution which is codebook in this case.

Steps to implement the Ant Colony Optimization Algorithm are:

Step 1: Initialize parameters, Initialize random codebook population like the input LBG Codebook. Each ant represent one codebook.

Step 2: Calculate the fitness of all ants/Initial codebooks using the fitness equation given below.

$$\text{Fitness}(C) = \sum_{j=1}^{N_c} \sum_{i=1}^{N_b} u_{ij} \times \left\| X_i - C_j \right\|^2$$

Where X_i is the ith input vector and C_j is the jth codeword of size N_b.

Where N_c is the codebook size.

Step 3: An ant will update the random generated codebooks using local and global update rule which is given by the equation below.

$$T(i,k) = (1-\rho) \times T(i,k) + \rho \times \Delta T(i,k)$$

Where $T(i,k)$ is the ith codebook in kth iteration.

Where $\Delta T(i,k)$ is the distance between random codebook i and input codebook C.

Step 4: After all ants change their values in local updating best ant changes their values using global updating rule which is given by the equation below.

$$T(i,k) = (1-\alpha) \times T(i,k) + \alpha \times \Delta T(i,k)$$

Step 5: Repeat step 2 to 4 until predefined number of iterations.

IV. SPECTRAL DISTORTION

When it comes to speech coding, ensuring high quality of the speech signal is extremely important. One way to assess this quality is through spectral distortion, which is usually measured in decibels (dB). To achieve transparency in coding, so that any quantization is not noticeable to the listener, the average spectral distortion should be kept below 1 dB. This distortion is determined by comparing the LPC power spectra of the quantized and original speech signals frame by frame. The overall spectral distortion value is then calculated by averaging the distortions across all frames.

$$SD_i = \sqrt{\frac{1}{(f_2-f_1)}\int_{f_1}^{f_2}[10\log_{10} s_i(f) - 10\log_{10} \hat{s}_i(f)]df(db)}$$

Where $S_i(f)$ and $\hat{}S_i(f)$ the LPC power spectra of the unquantized and quantized ith frame respectively.

The frequency "f" is expressed in Hz, while "f1" indicates the frequency range. For narrowband speech coding, the frequency range in use is 0 to 4000 Hz. The average or mean of the spectral distortion SD is given by equation

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

The conditions for transparent speech coding are:
1. Average spectral distortion (SD) ≤ 1dB.
2. No outlier frames with distortion > 4dB.
3. Percentage of frames with 2-4dB distortion < 2%.

V. RESULTS

Transparent speech coding requires that the average spectral distortion (SD) remains below 1dB, with no outlier frames showing a distortion exceeding 4dB. Additionally, the percentage of frames with distortions between 2 and 4dB should be less than 2%.

Bits / frame	SD (dB)	Percentage of outliers	
		2-4 dB	>4dB
24(8+8+8)	1.411	0.22	0.03
23(7+8+8)	1.900	0.23	0.03
22(7+7+8)	1.907	0.24	0.03
21(7+7+7)	1.915	0.27	0.10
20(6+7+7)	2.481	0.28	0.10

Table-1. Spectral distortion of LBG Vector quantization

Bits / frame	SD (dB)	Percentage of outliers	
		2-4 dB	>4dB
24(8+8+8)	1.360	0.22	0.0181
23(7+8+8)	1.880	0.30	0.102
22(7+7+8)	1.890	0.27	0.108
21(7+7+7)	1.894	0.26	0.108
20(6+7+7)	2.41	0.265	0.192

Table-2. Spectral distortion of ACO Vector quantization

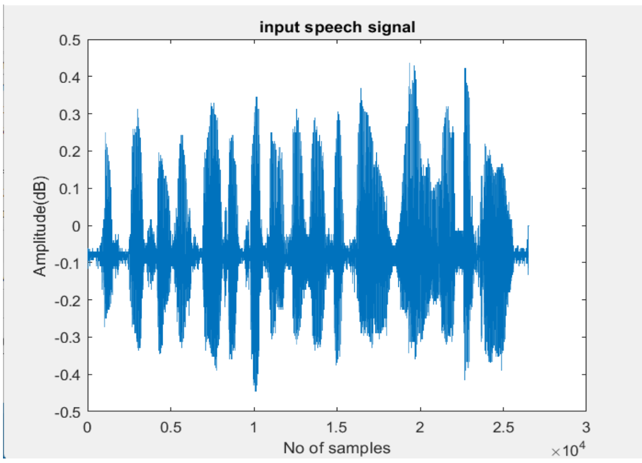

Figure-2(a). Input Speech Signal

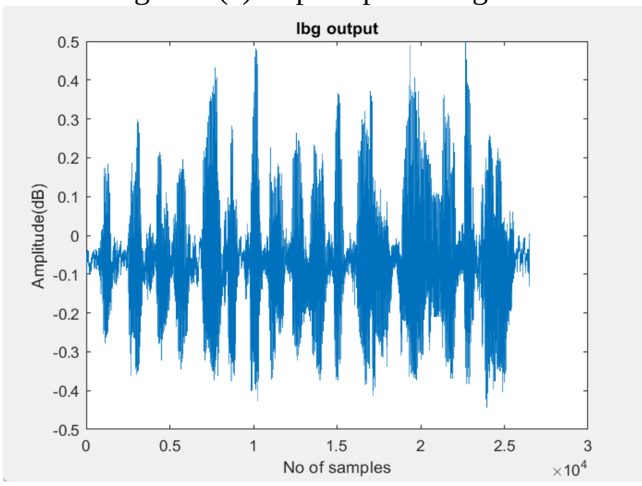

Figure-2(b). LBG Speech Signal (8-bit)

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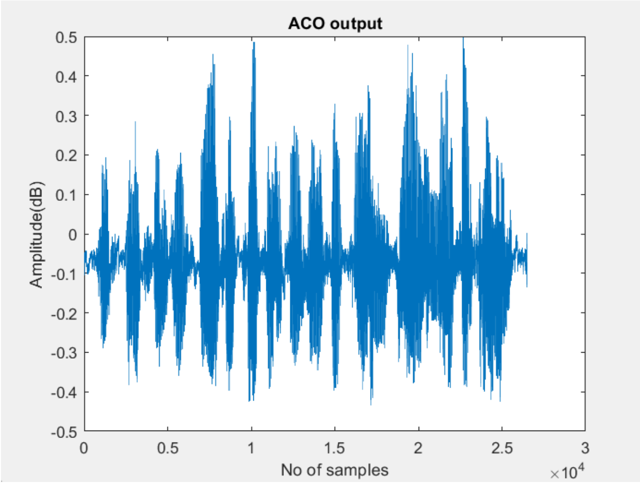

Figure-2(c). ACO Speech Signal (8-bit)

VI. CONCLUSION

In conclusion, the ACO algorithm offers a promising approach to optimizing codebooks for speech signal compression, effectively reducing spectral distortion. By leveraging ant-inspired behavior, ACO enhances the efficiency of codebook generation, complementing the existing LBG algorithm. The study highlights the potential of ACO in improving speech processing and bandwidth utilization in communication system.

VII. REFERENCES

[1] Chiranjeevi, K., Jena, U.R. and Harikam, A. (2016) 'Vector quantisation using hybrid teaching learning and pattern search optimisation for image compression', *Int. J. Computational Systems Engineering*, Vol. 2, No. 4, pp.209–221.

[2] Chun-Wei Tsai, Shih-Pang Tseng, Chu-Sing Yang, Ming-Chao Chiang, 'A fast ant colony optimization for codebook generation'.

[3] Li Xia, Luo Xuehui and Zhang Jihong, 'Codebook design with hybridization of ant colony with improved LBG algorithm'.

[4] Enqing Dong, HongMei Hu, 'A New Codebook Design Scheme Based on Ant Colony Clustering'.

[5] SK.Abdul Samadh, S. Manvitha, SK.Nazeem Pasha, S.Naveen, 'Codebook Generation for Speech Compression Using LBG Algorithm.

[6] Xia Li, Xing Yu and Xuehui Luo, 'Parallel Implementation of Ant Colony Optimization for VectorQuantization Codebook Design'.

[7] K.-L. Du and M.N.S. Swamy, Search and Optimization by Metaheuristics.

[8] Ping Duan, Yong AI, 'Research on an Improved Ant Colony Optimization Algorithm and its Application'.

[9] Fatiha Merazka, 'VQ Codebook Design using Hybrid Ant Colony Algorithm for Speech Line Spectral Frequencies'