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Speech Compression Using FireFly-LBG Algorithm

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Abstract — Firefly algorithm is used for codebook generation, the codebook generation is used in vector quantization for compression of speech signal. The codebook is generated using Linde Buzo Gray for VQ of speech signals. Using firefly optimization algorithm the optimization is done on the codebook mainly to reduce spectral distortion that is obtained in the output of speech signal after compression. The performance measure of optimization algorithm is done by means of time complexity, spectral distortion, computational complexity and memory requirements. The performance of VQ is compared with and without optimization.

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

I. Introduction

Speech processing is the study of speech signals and the processing methods of signals. Speech signal transmission requires a large amount of bandwidth which is really expensive. So, in order to overcome this problem, we use quantization to compress the speech signal before transmission which results in the usage of less bandwidth. The major important technique for signal compression is Vector Quantization (VQ), which is to be optimized. Vector Quantization (VQ) is one of the block coding techniques that quantizes blocks of data instead of a single sample. VQ exploits relations existing between neighboring signal samples by quantizing them together, the goal of VQ code- book generation is to find an optimal code book that yields the lowest possible distortion when compared with all other code books of the same size. VQ performance is directly proportional to the code-book size and the vector size.

Firefly algorithm is used for codebook generation the codebook generation is used in vector quantization for compression of speech signal there are different methods for codebook generation like LBG (Linde-Buzo-Gray), BAT algorithm Honey Bee Mating algorithm, Hybrid Cuckoo search, PSO. Linde—Buzo—Gray (LBG), a traditional method of Vector Quantization (VQ) generates a local optimal codebook which results in lower PSNR value.

In this paper, the codebook is generated using Linde Buzo Gray for VQ of speech signals. Using firefly optimization algorithm the optimization is done on the codebook mainly to reduce spectral distortion that is obtained in the output of speech signal after compression. The performance measure of optimization algorithm is done by means of time complexity, spectral distortion, computational complexity and memory requirements. The performance of VQ is compared with and without optimization.

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.

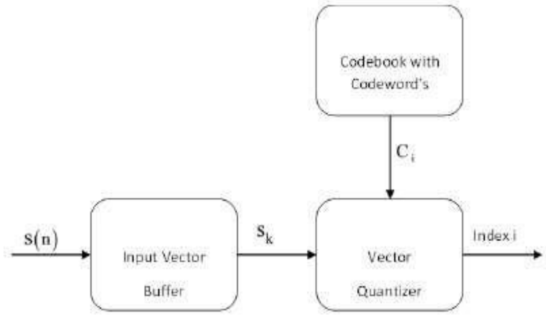

Figure-1. Block diagram of Vector Quantization

III. FIREFLY ALGORITHM

In the firefly algorithm, a meta heuristic optimization method developed by Xin-She Yang, the movement and interaction of the agents within the algorithm are inspired by the bioluminescent communication of fireflies. The foundational principles of this algorithm are articulated through three idealized rules that abstract the natural behavior of fireflies into a computational framework:

(1) Fireflies in the model are considered to be gender-neutral, enabling attraction between any two fireflies irrespective of sex.
(2) The attractiveness of a firefly is directly correlated with its luminosity; therefore, a firefly exhibiting lesser brightness will gravitate towards a more luminous counterpart.

If there is no brighter one than a particular firefly, it will move randomly. As firefly attractiveness one should select any monotonically decreasing function of the distance, j = d(x_i, x_j) to the chosen jth firefly, e.g. the exponential function r_i, j=$\|X_i$-$X_j\|$.

Fitness Function for firefly algorithm:

$$Fitness(C) = \frac{1}{D(C)} = \frac{N_b}{\sum_{j=1}^{N_c}\sum_{i=1}^{N_b}\mu_{ij}\cdot\left\|x_i - c_j\right\|^2}$$

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.
Where N_b is the codeword size.

IV. STEPS TO IMPLEMENT FIREFLY ALGORITHM

Step:1 Involves initializing the LBG algorithm by setting the codebook to one of the initial solutions, followed by the random generation of a set of initial trivial solutions, denoted as X_i, i=1,2, ……, m−1. Each solution represents a codebook with N_c codewords. Additionally, this step provides the parameters α, β_0, the maximum cycle number L and γ. Let L=0 denote the initialization stage.

Step:2 Involves selecting the best solution from all the solutions and defining it as the maximum X_i, i.e., the solution with the highest fitness. This best solution is then randomly moved to a different position.

$$i_{max} = \arg max_i \text{ Fitness}(X_i)$$
$$X_{imax} = \arg max_i \text{ Fitness}(X_i)$$

Step:3 In Step 3, each solution Xj calculates its fitness value analogous to the brightness of a firefly.Subsequently, for each solution Xj,this step identifies another solution Xi with greater brightness and moves towards it according to the following equations.

$$r_{i,j} = ||X_i - X_j|| = k=1N_c\ l=1L(X_i, k_l - X_j, k_l)\text{^}2 \quad \beta = \beta_{0e} - \gamma_{i,j}$$
$$X_j, k_l = (1-\beta)X_i, k_l + \beta X_j, k_l + v_j, k_l$$

Where the v_j, k_l=V(0,1) is a randomly number

Step:4 The best solution, denoted as max_i, the following equation.

$$X_{imax}, k_l = X_{imax}, k_l + v_{imax} k_l$$

where v_j, k_l=V(0,1) is a randomly number

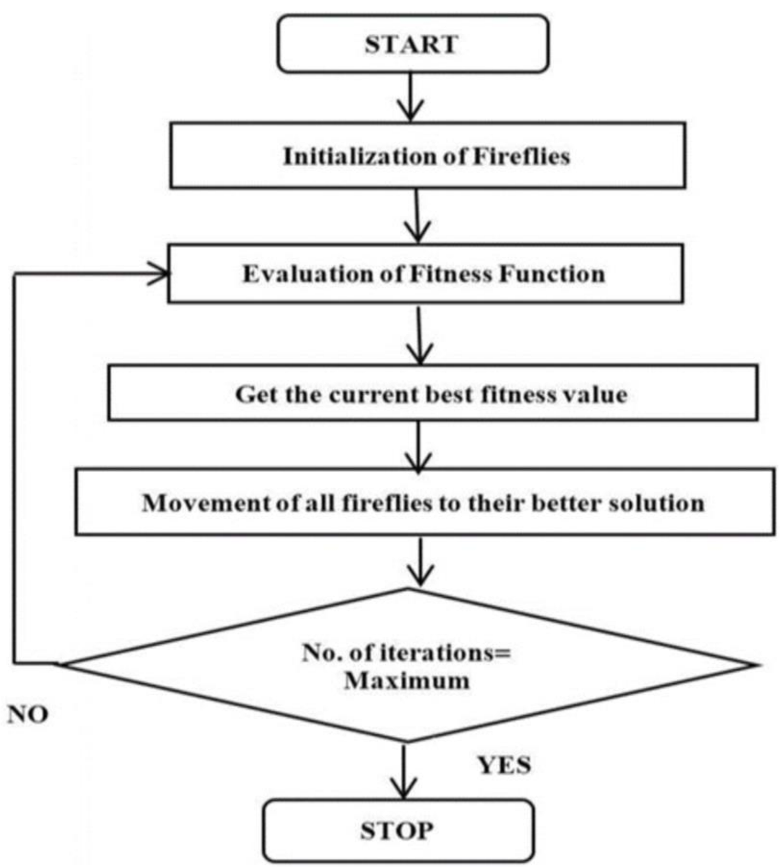

Figure-2. Flowchart to implement the FireFly Algorithm

Step:5 It involves checking the termination criterion of the algorithm, if the current cycle number will randomly change its position.

V. SPECTRAL DISTORTION MEASURE

For a speech coding system to achieve transparency where the effects of quantization are imperceptible to the listener the average spectral distortion must be maintained below 1 dB. This measurement involves a frame-by-frame comparison of the Linear Predictive Coding (LPC) power spectra of the original and quantized speech signals. 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%.

VI. 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)	1.356	0.16	0.0126
23(7+8+8)	1.700	0.206	0.05
22(7+7+8)	1.812	0.24	0.06
21(7+7+7)	1.850	0.21	0.08
20(6+7+7)	2.450	0.265	0.19

Table-2. Spectral Distortion of Fire-Fly Vector quantization

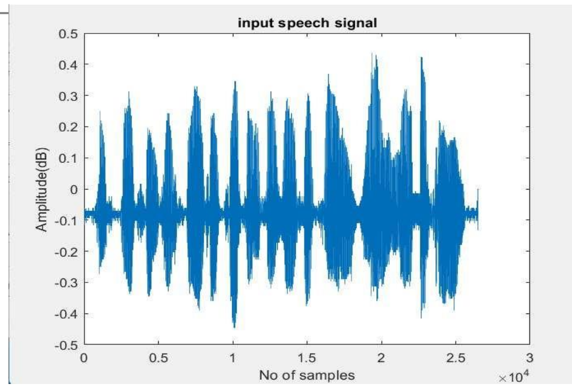

Figure-3(a). Input Speech Signal

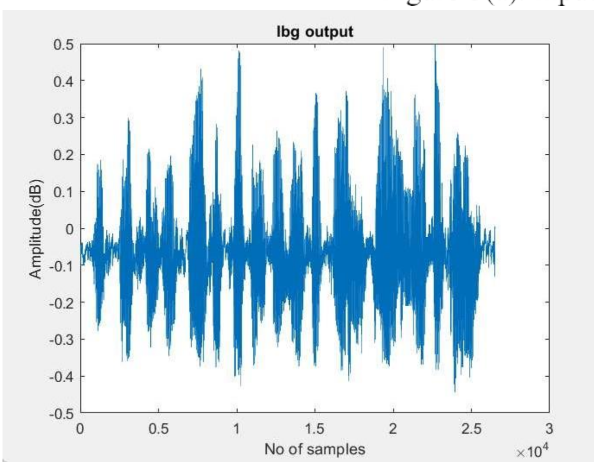

Figure-3(b). LBG Speech Signal (8-bit)

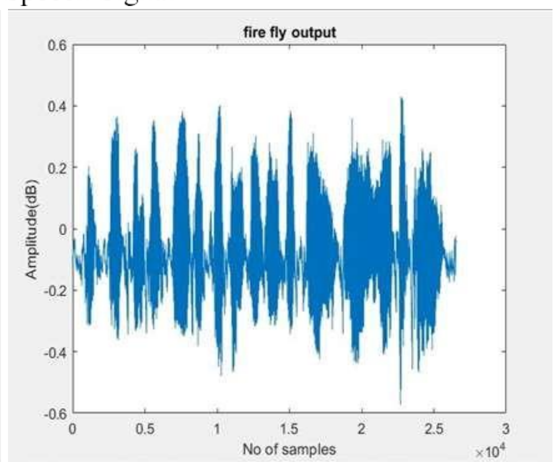

Figure-3(c). Firefly Speech Signal (8-bit)

VII . CONCLUSION

In conclusion, the Firefly algorithm presents a promising approach to optimizing codebooks for speech signal compression, leading to a significant reduction in spectral distortion. By harnessing firefly-inspired behavior, this algorithm enhances the efficiency of codebook generation, offering a valuable complement to the established LBG algorithm. The study underscores the potential of the Firefly algorithm in advancing speech processing techniques and optimizing bandwidth utilization within communication systems.

VIII . REFERENCES

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- M. Laxmi Prasanna Rani1Gottapu Sasibhushana Rao2B. Prabhakara Rao3"An efficient codebook generation using firefly algorithm for optimum "© Springer-Verlag GmbH Germany, part of Springer Nature 2020