Speech signal with Enhanced Multi – Pulse excitation codevector with minimized Mean Square Error

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Abstract—*Paper address concept of speech signal with enhanced multi-pulse excitation codevector with minimized mean square error.In a present, G.729 speech codec have used "Focused Search Method" for finding excitation pulse frame which contain four pulse. We have to add more pulse in excitation structure frame of speech codec G.729 by using proposed "Global Pulse Replacement Approach". By doing this, SNR, MSR, RMSR will be increased.*

Keywords—G.729 Speech Codec, Codebook,Focused search method, Global Pulse Replacement

I. Introduction

Current world communication has been digitized. There is a request of efficient and consistent real-time communication services. Speech coding technique has made this conceivable. It is an application of data compression. It is a procedure by which a digitized speech can be represented in as few bits as possible and at the same time maintaining an acceptable speech quality [1]. Some of the significant applications of speech coding technique are Voice over Internet Protocols (VoIP) and mobile telephony. VoIP enables the transmission of voice through data networks by making use of Internet Protocols (IP) [5].

The most commonly used speech coding technique is Code Excited Linear Prediction (CELP) coding [2]. CELP is a speech algorithm that provides excellent quality of speech at low bit rates and this is based on the source-filter model of speech production. But there is a major disadvantage to CELP that it consumes a lot of memory to physically store the entire stochastic codebook. Algebraic CELP (ACELP) [4] provides a good solution to this problem. The term 'Algebraic' means that the excitation codevectors which generate the synthetic speech is created by using simple mathematical and algebraic rules. So now it is not necessary to store the entire excitation codebook physically, which results in saving memory to a large extent. The Conjugate-Structure ACELP (CS-ACELP) [3] coder has adopted this technique.

G.729 algebraic codebook is based on a predefined algebraic codebook structure which follows the concept of an Interleaved Single-Pulse Permutation (ISPP) design [1]. A 40 dimensional codebook vector containing 4 non-zero pulses is defined in this codebook.The amplitudes of each pulse is also pre-defined as +1 or -1. There are total 5 tracks including one non-zero pulse each thus containing all the 40 positions of the pulses altogether. Each pulse can assume the positions as shown in Table I [1]. Algebraic codebook does not need any storage space.

Pulse	Sign	Positions
i_0	s_0 : ±1	m_0 :0, 5, 10, 15, 20, 25, 30, 35
i_1	s_1 : ±1	m_1 : 1, 6, 11, 16, 21, 26, 31, 36
i_2	s_2 : ±1	m_2 : 2, 7, 12, 17, 22, 27, 32, 37
i_3	s_3 : ±1	m_3 : 3, 8, 13, 18, 23, 28, 33, 38 4, 9, 14, 19, 24, 29, 34, 39

There are 40 positions in above codebook structure which contains the sample values of the speech signal per subframe and it represents 40-bit excitation codebook vector. The excitation codebook vector $C_k(n)$ is created by considering a 40 dimensional zero vector, and putting all the 4 non-zero pulses multiplied with their respective sign values at the found locations:

$$C_k(n) = \sum_{j=0}^{M-1} s_j\, \delta(n - m_j) \ldots\ldots(1)$$

Where, s_j denotes the sign value of the corresponding pulse and m_j is its position. So, every pulse has a requirement of 1 bit per sign. 3 bits are required for position i.e for, i_0, i_1 and i_2; while 4 bits are needed for i_3. Thus, a total of 17 bits per subframe is required to index the whole codebook.

II. Present Focused Search Approach for Codebook

For searching an algebraic codebook during encoding of a sound signal, wherein the algebraic codebook comprises a set of codevectors formed of a number of pulse positions and a number of pulses each having a sign and distributed over the pulse positions, and wherein the algebraic codebook searching device comprises:

(1)Reference signal for use in searching the algebraic codebook.

(2) Determining, in a first stage, a position of a first pulse in relation with the reference signal and among the number of pulse positions

(3)Recomputing an algebraic codebook gain in each of a number of stages subsequent to the first stage.

(4)For updating, in each of the subsequent stages, the reference signal using the recomputed algebraic codebook gain.

(5)For determining, in each of the subsequent stages, a position of another pulse in relation with the updated reference signal and among the number of pulse positions.

(6)Determining codevector of the algebraic codebook using the signs and positions of the pulses determined in the first and subsequent stages, wherein a number of the first and subsequent stages corresponds to the number of pulses in the codevectors of the algebraic codebook.

The objective of searching the fixed (innovative) codebook (FCB) contribution in CELP-based codecs is to minimize the residual error after the use of the adaptive codebook

$$E = \min\{\sum_{n=0}^{N-1}[\, x_2(n) - g_c * y_2^k(n)\,]^2\}......(2)$$

Where g_c is the fixed codebook gain, and $y_2^k(n)$ is the filtered innovative codevector k is the fixed codebook index and the filtered innovative codevector $y_2^k(n)$ is the codevector $C_k(n)$ from the fixed codebook at index k convolved with the impulse response h(n) of the weighted synthesis filter H(z). The fixed codebook contribution is calculated by multiplying the filtered innovative codevector $y_2^k(n)$ by the fixed codebook gain g_c.

The algebraic fixed codebook target signal $x_2(n)$ is computed by subtracting the adaptive codebook contribution from the adaptive codebook target signal $x_1(n)$

$$x_2(n) = x_1(n) - g_p\, y_1(n) \quad ......(3)$$

Minimizing E from Equation (1) results in the optimum fixed codebook gain g_c,

$$g_c^{opt} = \sum_{n=0}^{N-1} x_2(n)\; y_2^k(n) \,/\sum_{n=0}^{N-1} \quad y_2^k(n)......(4)$$

and the minimum error from Equation (1) then results in

$$E = \{\sum_{n=0}^{N-1} [x_2(n)]^2\} - \{(\sum_{n=0}^{N-1} x_2(n)\; y_2^k(n))^2\}/\sum_{n=0}^{N-1} \quad (y_2^k(n))^2 \;......(5)$$

Thus, the search is performed by maximizing the term

$$Ↄ_k = \{(\sum_{n=0}^{N-1} x_2(n)\; y_2^k(n))^2\}/\sum_{n=0}^{N-1} \quad (y_2^k(n))^2...(6)$$

In Algebraic CELP (ACELP (Algebraic Code Excited Linear Prediction)) codecs, the algebraic fixed codebook vector hereinafter denoted as fixed codevector $C_k(n)$ contains M unit pulses with respective signs s_j and positions m_j, and is thus given by the following relation:

$$C_k(n) = \sum_{j=0}^{M-1} s_j\, \delta(n - m_j)......(7)$$

Where Sj and $\delta(n) = 1$ for n = 0, and $\delta(n) = 0$ for n = 1,2….etc. The fixed codevector after filtering through the filter can be then expressed in the form

$$y_2^k(n) = C_k(n) * h(n) = \sum_{j=0}^{M-1} s_j\, h(n - m_j)...(8)$$

Let us denote $C_k(n)$ the algebraic codevector at the codebook index k, and $y_2^k(n)$ the corresponding codevector filtered through the filter H(z). The algebraic codebook search in Equation (5) can be then described using matrix notation as a maximization of the following criterion:

$$Ↄ_k = \frac{(x_2^T y_2^k)^2}{(y_2^k)^2\, y_2^k} = \frac{(x_2^T\, HC_k)^2}{(HC_k)^T\, HC_k} = \frac{(d^T C_k)^2}{(C_k)^T\, \Theta C_k} = \frac{(C_k)^2}{E_k}......(9)$$

Where T denotes vector transpose and H is the lower triangular Toeplitz convolution matrix with diagonal h (0) and lower diagonals h (l), . . . ,h (N-l)Vector $d = H^T X_2$ is the correlation between $x_2(n)$ and h(n), also known as the backward filtered target vector since it can be computed using time-reversed filtering of $x_2(n)$ through the weighted synthesis filter

$$d(n) = \sum_{k=0}^{N-1} x_2(k)\, h(k - n)......(10)$$

and matrix $\Theta = H^T H$ is the matrix of correlations of h(n). Both d and Θ are usually computed prior to the codebook search. If the algebraic codebook contains only a few non-zero pulses, the computation of the maximization criterion for all possible indexes k is very fast.

The algebraic fixed codebook with M pulses, the criterion to be maximized can be written as

$$Ↄ_k = \frac{(C_k)^2}{E_k} = \frac{(d^T C_k)^2}{(C_k)^T\, \Theta C_k} = \frac{(\sum_{j=0}^{M-1} s_j\, d(m_j))^2}{\sum_{j=0}^{M-1} \Theta(m_j, m_j) + 2\sum_{i=0}^{M-2}\sum_{j=i+1}^{M-1} s_i s_j \Theta(m_i - m_j)} \quad ......(11)$$

The algebraic codebook gain can be expressed as

$$g_c = \frac{\sum_{j=0}^{M-1} s_j\, d(m_j)}{\sum_{j=0}^{M-1} \Theta(m_j, m_j) + 2\sum_{i=0}^{M-2}\sum_{j=i+1}^{M-1} s_i s_j \Theta(m_i - m_j)}...(12)$$

The general idea behind the method and device for conducting a fast algebraic codebook search is to search pulses sequentially in several iterations The fundamental principle of the method and device resides in updating the fixed code book gain gc and the backward filtered target vector d(n) after each new pulse is determined. The basic search can be summarized by the following steps

(1) Compute both the backward filtered target vector d (n), a reference signal used for searching the algebraic fixed codebook and the matrix Θ in advance, i.e before the iterative part of the search procedure is entered.

(2) In the first stage of each iteration, the first pulse position m0 is set typically at the absolute maximum of the back ward filtered target vector d (n), n being the sample index in the subframe of length N. The pulse sign is given by the sign of d (m_o).

(3) In the following stages (after each new pulse is determined) the algebraic fixed codebook gain g_c is recomputed, and the gain g_c, is then used to update the back ward filtered target vector d(n).

(4) The position of each new pulse m_j is found as an absolute maximum of the updated backward filtered target vector d (n) and the pulse sign is given by the sign of the sample d (m_j).

(5) To achieve higher coding efficiency, the above steps 2-4 can be iterated starting with different positions of m_o (e.g. second largest absolute maximum of d (n) in the 2"' iteration, third largest absolute maximum of d (n) in the 3rd iteration etc.). The iteration that maximizes the search criterion is finally used for the selection of the pulse positions.

The following description explains the use of the method and device for conducting a fast algebraic codebook search in fixed codebooks that consist of several tracks of interleaved positions, where M is the number of pulses, L the number of tracks and N the subframe length. First a description of the specific situation where M=L=4 will be given. The procedure will be then generalized for M pulses (when still M=L) and further extended for the case where M not equal to L

III. PROPOSED GLOBAL PULSE REPLACEMENT APPROACH WITH MULTI PULSE CODEBOOK STRUCTURE

The codebook vector that maximizes a value of Eq. 13 is chosen in each fixed codebook search.

$$\beth_k = \frac{(C_k)^2}{E_k} = \frac{(d^T C_k)^2}{(C_k)^T \Theta C_k} = \frac{(\sum_{j=0}^{M-1} s_j\, d(m_j))^2}{\sum_{j=0}^{M-1} \Theta(m_j, m_j) + 2\sum_{i=0}^{M-2} \sum_{j=i+1}^{M-1} s_i s_j \Theta(m_i - m_j)} \quad \text{……(13)}$$

A k^{th} codebook vector is described as C_k and T denotes a transposed matrix. A correlation vector d and a matrix Θ are described as:

$$d(n) = \sum_{k=0}^{N-1} x_2(k)\, h(k-n) \quad \text{……(14)}$$

$$\Theta(i, j) = \sum_{n=j}^{M-1} h(n-i)\, h(n-j) \qquad i = 0 \text{ ……M}, \quad j = i\text{…...M} \quad \text{……(15)}$$

The proposed fixed codebook structure table shown as follows,

Track	Pulse	Positions
1	i_0, i_5	m_0, m_5 : 0, 5, 10, 15, 20, 25, 30, 35
2	i_1, i_6	m_1, m_6 : 1, 6, 11, 16, 21, 26, 31, 36
3	i_2, i_7	m_2, m_7 : 2, 7, 12, 17, 22, 27, 32, 37
4	i_3, i_8	m_3, m_8 : 3, 8, 13, 18, 23, 28, 33, 38
5	i_4, i_9	m_4, m_9 : 4, 9, 14, 19, 24, 29, 34, 39

A pulse-position likelihood estimator vector b (n) is described as:

$$b(n) = \frac{r_{LTP}(n)}{\sqrt{\sum_{i=0}^{M-1} r_{LTP}(i) r_{LTP}(i)}} + \frac{d(n)}{\sqrt{\sum_{i=0}^{M-1} d(i) d(i)}} \quad \text{……(16)}$$

A pitch residual signal is described as $r_{LTP}(n)$. Therefore, the b (n) is a function of the pitch residual signal and the correlation d (n).

(1) The magnitude of the pulse-position likelihood-estimator vector at step 1 is described as |b (n)|. The magnitudes of the pulse-position likelihood-estimator vectors for each pulse in tracks 0, 1, 2, 3, 4 and 5 in a specific sub-frame are described as:

Track	Absolute values of factors of the pulse-position likelihood-estimator track vectors for each pulse position
1	0.10, 0.31, 0.15, 0.02, 0.10, 0.17, 0.67, 0.35
2	0.29, 0.07, 0.06, 0.21, 0.00, 0.04, 0.32, 0.00
3	0.36, 0.17, 0.06, 0.04, 0.34, 0.29, 0.66, 0.05
4	0.18, 0.08, 0.43, 0.06, 0.10, 0.48, 0.16, 0.12
5	0.33, 0.05, 0.13, 0.26, 0.11, 0.11, 0.11, 0.05

(2) At the second step, the initial codebook vectors are obtained for N_P pulses in each track and M pulses in a sub-frame by choosing a position having the largest magnitudes computed at the first step. For example, referring to Table 3, pulse positions of initial codebook vectors (i_0, i_5, i_1, i_6, i_2, i_7, i_3, i_8, i_4, i_9) become (30, 35, 1, 31, 2, 32, 13, 28, 4, 19).

(3) At the third step, $\beth_k$ values are computed by replacing pulse positions of each track in the codebook vector. For example, referring to Table 3, the pulse positions of the initial codebook vector (30, 35, 1, 31, 2, 32, 13, 28, 4, 19) are changed to (0, 35, 1, 31, 2, 32, 13, 28, 4, 19), (5, 35, 1, 31, 2, 32, 13, 28, 4, 19), (10, 35, 1, 31, 2, 32, 13, 28, 4, 19), (15, 35, 1, 31, 2, 32, 13, 28, 4, 19), (20, 35, 1, 31, 2, 32, 13, 28, 4, 19), (25, 35, 1, 31, 2, 32, 13, 28, 4, 19) by replacing 30 at track 0 and $\beth_k$ is computed. Also, the pulse positions of the initial codebook vector (30, 35, 1, 31, 2, 32, 13, 28, 4, 19) are changed to (30, 0, 1, 31, 2, 32, 13, 28, 4, 19), (30, 5, 1, 31, 2, 32, 13, 28, 4, 19), (30, 10, 1, 31, 2, 32, 13, 28, 4, 19), (30, 15, 1, 31, 2, 32, 13, 28, 4, 19), (30, 20, 1, 31, 2, 32, 13, 28, 4, 19), (30, 25, 1, 31, 2, 32, 13, 28, 4, 19) by replacing 35 at the track 0 and $\beth_k$ is computed.

The pulse positions of the initial codebook vector (30, 35, 1, 31, 2, 32, 13, 28, 4, 19) are changed to (30, 35, 6, 31, 2, 32, 13, 28, 4, 19), (30, 35, 11, 31, 2, 32, 13, 28, 4, 19 (30, 35, 16, 31, 2, 32, 13, 28, 4, 19), (30, 35, 21, 31, 2, 32, 13, 28, 4, 19), (30, 35, 26, 31, 2, 32, 13, 28, 4, 19), (30, 35, 36, 31, 2, 32, 13, 28, 4, 19) by replacing 1 at track 1 and $\beth_k$ is computed. Also, the pulse positions of the initial codebook vector (30, 35, 1, 31, 2, 32, 13, 28, 4, 19) are changed to (30, 35, 1, 6, 2, 32, 13, 28, 4,19), (30,35, 1,11, 2, 32, 13, 28, 4, 19), (30,35, 1,16, 2, 32, 13, 28, 4, 19), (30, 35, 1, 21, 2, 32, 13, 28, 4, 19), (30, 35, 1, 26, 2, 32, 13, 28, 4, 19), (30, 35, 1,36, 2, 32, 13, 28, 4, 19) by replacing 31 at the track 1 and $\beth_k$ is computed.

The pulse positions of the initial codebook vector (30, 35, 1, 31, 2, 32, 13, 28, 4, 19) are changed to (30, 35, 1, 31, 7, 32, 13, 28, 4, 19), (30, 35, 1, 31, 12, 32, 13, 28, 4, 19), (30, 35, 1, 31, 17, 32, 13, 28, 4, 19), (30, 35, 1, 31,22, 32, 13, 28, 4, 19), (30, 35, 1, 31, 27, 32, 13, 28, 4, 19), (30, 35, 1, 31, 37, 32, 13, 28, 4, 19) by replacing 2 at track 2 and $\beth_k$ is computed. Also, the pulse positions of the initial codebook vector (30, 35, 1, 31, 2, 32, 13, 28, 4, 19) are changed to (30, 35, 1, 31, 2, 7, 13, 28, 4, 19), (30, 35, 1, 31, 2, 12, 13,28, 4, 19), (30,35, 1,31, 2, 17, 13,28, 4, 19), (30, 35, 1,31, 2,22, 13,28, 4,19), (30, 35, 1, 31, 2,27, 13, 28, 4, 19), (30, 35, 1,31, 2, 37, 13, 28, 4, 19) by replacing 32 at the track 2 and $\beth_k$ is computed.

The pulse positions of the initial codebook vector (30, 35, 1, 31, 2, 32, 13, 28, 4, 19) are changed to (30, 35, 1, 31, 2, 32, 3,28, 4, 19), (30, 35, 1, 31,2, 32, 8, 28,4, 19), (30,35, 1,31, 2,32, 18,28, 4, 19), (30, 35, 1, 31, 2, 32, 23, 28, 4, 19), (30, 35, 1, 31, 2,32, 33, 28, 4, 19), (30, 35, 1,31, 2, 32,38, 28, 4, 19) by replacing 13 at track 3 and $\beth_k$ is computed. Also, the pulse positions of the initial codebook vector (30, 35, 1, 31, 2, 32, 13, 28, 4, 19) are changed to (30, 35, 1, 31, 2, 32, 13, 3, 4, 19), (30,35,1,31,2,32,13,8,4,19), (30,35,1,31,2,32,13, 18, 4, 19), (30, 35, 1,31, 2,32, 13,23,4, 19), (30,35, 1,31, 2, 32, 13, 33, 4, 19), (30, 35, 1, 31, 2, 32, 13, 38, 4, 19) by replacing 28 at the track 3 and $\beth_k$ is computed.

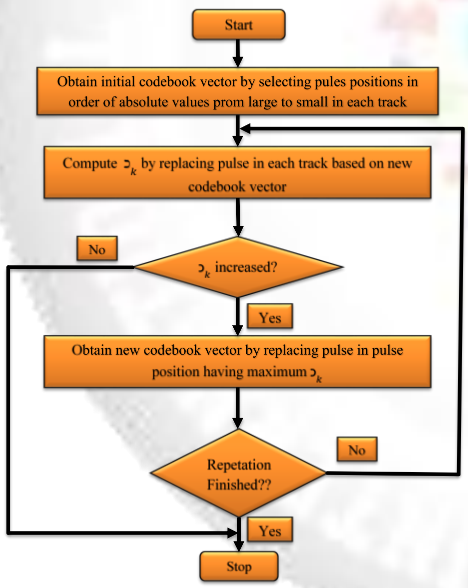
The pulse positions of the initial codebook vector (30, 35, 1, 31, 2, 32, 13, 28, 4, 19) are changed to (30, 35, 1, 31, 2, 32, 13, 28, 9, 19), (30, 35, 1, 31, 2, 32, 13, 28, 14, 19), (30, 35, 1, 31, 2, 32, 13, 28, 24, 19), (30, 35, 1, 31,2, 32, 13, 28, 29, 19), (30, 35, 1, 31, 2, 32, 13, 28, 34, 19), (30, 35, 1, 31, 2, 32, 13, 28, 39, 19) by replacing 4 at track 4 and $ↄ_k$ is computed. Also, the pulse positions of the initial codebook vector (30, 35, 1, 31, 2, 32, 13, 28, 4, 19) are changed to (30, 35, 1, 31,2, 32, 13, 28, 4, 9), (30, 35, 1, 31, 2, 32, 13,28,4, 14), (30,35, 1,31, 2, 32, 13, 28, 4, 24), (30, 35, 1, 31, 2, 32, 13, 28, 4, 29), (30, 35, 1, 31, 2, 32, 13, 28, 4, 34), 30, 35, 1, 31, 2, 32, 13, 28, 4, 39) by replacing 19 at track 4 and $ↄ_k$ is computed.

(4) At the fourth step, it is determined whether $ↄ_k$ is increased by replacing the pulses. If the $ↄ_k$ is not increased, it is determined that the codebook vector before replacing the pulses is an optimal codebook vector and the pulse replacement procedures are finished.

(5) At the fifth step, if $ↄ_k$ is increased by replacing the pulses, the pulse position which has a maximum $ↄ_k$ is replaced with the old pulse position. Therefore, speech quality can be enhanced.

(6) At the sixth step, if the pulse replacement procedures are repeated for the predetermined times, the pulse replacement procedures are finished. The pulse replacement procedures are repeated if a new codebook vector is obtained each time the pulse is replaced. If the codebook vector is not changed, the operator can set the pulse replacement procedure to be finished

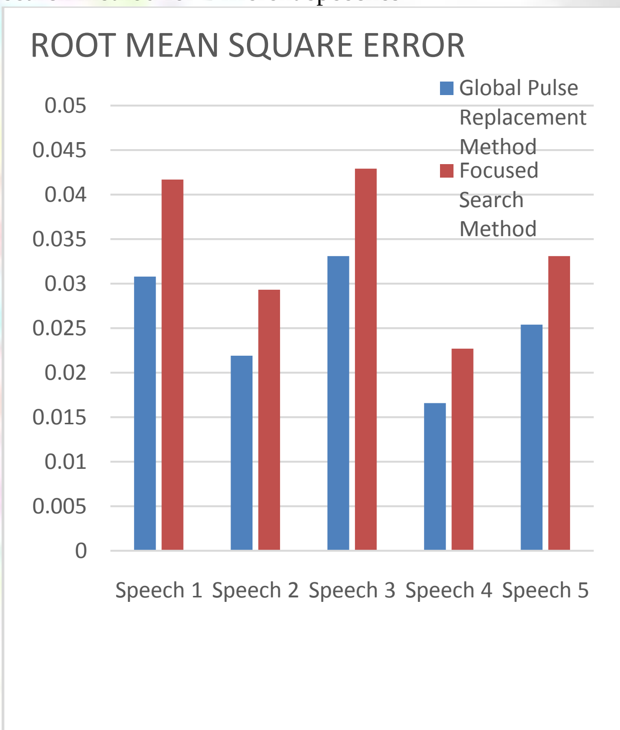
IV. Proposed Flowchart



V. Simulation and Result

Comparitive analysis of Mean Square Error (MSR) between Global Pulse Replacement Method and Focused search method for Different speeches

Comparitive analysis of Root Mean Square Error (RMSE) between Global Pulse Replacement Method and Focused search method for Different speeches



VI. Conclusion

Paper address concept of speech signal with enhanced multi-pulse excitation codevector with increased mean square error.In a present, G.729 speech codec have used “Focused Search Method” for finding excitation pulse frame which contain four pulse. Proposed “Global Pulse Replacement Approach” have minimized MSR, RMSR of speech signal.

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