Fast CELP Code Book Search Method

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Abstract – **In this paper it is present a method for fast search in stochastic code book for CELP speech coding. It is found that it is possible to reduce the mathematical complexity in the minimization of error and to proposed an efficient and much fastest method, with some predefined error value.**

Keywords – **Speech coding, CELP, Code book, Search methods.**

I. Introduction

The analysis of the basic mathematical functions in CELP speech coding showns, that the difficulties are in the realization of algorithms of code book search [1]. The most of the efforts are directed for creating of effectives methods in the limits of federal standards FS1016 for improving the speech of code book search [2, 3].

In this article it is proposed a method for fast code book search in CELP speech coding, which is based on mathematical complexity estimation, and on an assumption of minimum quality degradation of decoding speech.

II. Basic Algorithm

The algorithm of excitation signal d_{ij} calculation from code book in CELP speech coding used the minimization of error e_{ij}defined as the difference between real speech signal S^r and synthesized signal S^s_{ij} (Fig. 1).

The minimization of error e_{ij} is shown in fig.1 as a block **min**, in which it is estimation the value of error e_{ij} for minimum and the index i and j are changed iteratively for choosing the next excitation signals b_i and c_i collecting in stochastic SCB and adaptive ACB code book, respectively. The current value of error e_{ij} is calculated from the expression:

$$e_{ij} = W.e'_{ij} \ , \tag{1}$$

where e'_{ij} is the error from the evaluation:

$$e'_{ij} = S^r - S^s_{ij} \ , \tag{2}$$

in which there are not involved the perceptual characteristics of human - ear;

W – matrix, describing the perceptual human – ear filter characteristics :

$$W = \begin{bmatrix} w_1 & 0 & ... & 0 \\ w_2 & w_1 & ... & 0 \\ . & . & ... & 0 \\ w_{SF} & w_{SF-1} & ... & 0 \end{bmatrix} \ , \tag{3}$$

where SF is the number of samples in a subframe (SF=60).

From (1) and (2) it can see, that in the execution of iterations the synthesized signals S^s_{ij} is changed and is defined from the expression:

$$S^s_{ij} = F.d_{ij} \ , \tag{4}$$

where d_{ij} is the excitation signals b^g_i and c^g_j from stochastic and adaptive code book, respectively:

$$d_{ij} = b^g_i + c^g_j \ ; \tag{5}$$

F – matrix, describe the linear prediction filter coefficients a, defined current frame of real speech signals S^r :

$$F = \begin{bmatrix} f_1 & 0 & ... & 0 \\ f_2 & f_1 & ... & 0 \\ . & . & ... & 0 \\ f_{SF} & f_{SF-1} & ... & f_1 \end{bmatrix} \ . \tag{6}$$

Each from the excitation signals b^g_i and c^g_j are extracted from the collection of these signals in stochastic and adaptive code book, respectively (b_i and c_j), and are multiplied with the current gains for current iteration g_i and g_j:

$$b^g_i = g_i.b_i \tag{7}$$

$$c^g_j = g_j.c_j \ . \tag{8}$$

From (1) and with respect of (2) and (7) it is seen, that in the general case the number of iterations for minimization of error e_{ij} dependent from the range of indexes i and j:

$$i = 1,\ 2,\ 3,\ ...\ ,\ n_{SCB} \tag{9}$$

$$j = 1,\ 2,\ 3,\ ...\ ,\ n_{ACB} \ , \tag{10}$$

where n_{SCB} and n_{ACB} are respectively the number of excitation signals in stochastic and adaptive code books (n_{SCB} =512 and n_{ACB} =256).

If a full search algorithm is used for error e_{ij} minimization in both stochastic and adaptive code books in each moment, then the number of iterations is extremely grown, because it is involved all possible combinations between each two excitation signals b_i and c_j and g_i, g_j from stochastic and adaptive code books. The main part of the time in CELP coding algorithms is spend for minimization of error e_{ij}.

III. Fast Code Book Search Method

An essential decrease of time for minimization of error can be realized, it if is assumed a sequential implementation of search algorithm. For example if the search is made first for adaptive code book, and then for stochastic, the expression (4) and (5) gives:

$$S^s_{ij} = F.\left(b^g_i + c^g_j\right) + S_z \ , \tag{11}$$

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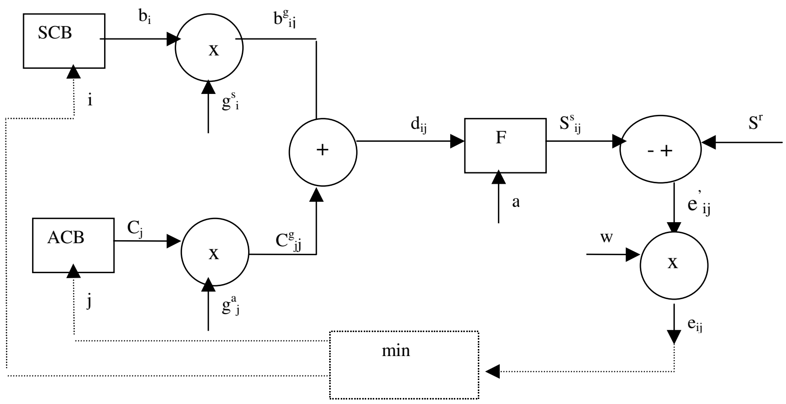

Fig. 1.

where S_z is zero input response of the linear prediction filter F.

The expression (1) can be changed as:

$$e_{ij} = W.S^r - W.F.b_i^g - W.F.c_j^g - W.S_z \, . \qquad (12)$$

If in (12) the minimization is only for stochastic code book, then c_j^g is calculated and it is assumed constant. Then (12) can be transformed as:

$$e_{ij} = S^t - L.b_i^g \, , \qquad (13)$$

where: $S^t = W.S^r - W.F.c_j^g - W.S_z$ is part of expression (12), which rest unchanged for stochastic code book minimization (j=const; i=1, 2, $\ldots$, n_{SCB}; $L = W.F$ – matrix from multiplication of W and F).

Matrix L is defined from (3) and (6), describing W and F, which are lower triangular. Matrix L is too a lower triangle matrix:

$$L = \left| \begin{array}{ccccc} l_{11} & l_{12} & l_{13} & \ldots & l_{1,SF} \\ l_{21} & l_{22} & l_{23} & \ldots & l_{2,SF} \\ . & & & & \\ . & & & & \\ l_{SF,1} & l_{SF,2} & l_{SF,3} & \ldots & l_{SF,SF} \end{array} \right| \, , \qquad (14)$$

where

$$l_{ij} = 0 \ \text{ for } j > i \text{ and } i = 1 \div SF \, . \qquad (15)$$

From (14) and (15) it is possible to make assumption, that the number of calculations:

$$N_L = SF.SF \qquad (16)$$

in (13) decrease two time:

$$N_L' = \frac{N_L}{2} \, . \qquad (17)$$

A supplement analysis of lower triangular part of matrix L shows, that most of the members l_{ij} of lowest triangle are nearly zeros and cal be replaced by zeros:

$$l_{ij} \approx 0 \ \text{ for } j < \theta \text{ and for } i > \theta \, . \qquad (18)$$

This analysis and the expression (18) shows, that the matrix L can be transformed as a band matrix:

$$L = \left| \begin{array}{llllll} l_{11} & 0 & 0 & \ldots & & 0 \\ l_{21} & l_{22} & 0 & \ldots & & 0 \\ l_{\theta,1} & l_{\theta,2} & l_{\theta,3} & \ldots & & 0 \\ 0 & l_{\theta+1,2} & \ldots & & & \\ . & \ldots & & & & \\ 0 & \ldots & l_{SF,\theta} & l_{SF,\theta+1} & \ldots & l_{SF,SF} \end{array} \right| \, . \qquad (19)$$

From expressions (19) it is possible to calculate the value of a supplementary decreasing of calculations in (13):

$$N_L'' = N_L' - \frac{(SF - \theta)^2}{2} \, . \qquad (20)$$

This results are made only from analysis of matrix L in expression (13). It is possible to make an analysis of expressions of square error follow from expressions (13) and (17):

$$\vec{e_i} \, . \, \vec{e_i}' = \vec{S^t} . \vec{S^t}' - 2. \vec{S^t} . g_i . \vec{B_i}' + g_i^2 . \vec{B_i}' \, . \vec{B_i} \, . \qquad (21)$$

In first member in expression (21) didn't depend from index i of code book and is constant in the time of minimization. Then it is possible to transform the algorithm for finding the minimum of expression (21) as a finding of maximum of the rest part of (21):

$$mx = 2. \vec{S^t} . g_i . \vec{B_i}' - g_i^2 . \vec{B_i}' \, . \vec{B_i} \, . \qquad (22)$$

In the same time it is possible to make the partial minimization of (21) with respect to g_i:

$$\frac{\partial \vec{e_i}}{\partial g_i} = -2. \vec{S^t} . \vec{B_i}' + 2. g_i . \vec{B_i}' \, . \vec{B_i} = 0 \, , \qquad (23)$$

and to define g_i as:

$$g_i = \frac{\vec{S^t} \, . \vec{B_i}'}{\vec{B_i}' \, . \vec{B_i}} \, . \qquad (24)$$

With substitution of (24) in (22) it is possible to find:

$$mx = \frac{\left(\vec{S^t} \, . \vec{B_i}' \right)^2}{\vec{B_i}' \, . \vec{B_i}} \, . \qquad (25)$$

In the expression (25) $\vec{S}^t . \vec{B}_i$ is correlation between real signal $\vec{S}^t$ and excitation signal $\vec{B}_i{}'$, in relation of energy $\vec{B}_i{}' . \vec{B}_i$ of excitation signal $\vec{B}_i$ from stochastic code book.

The decrease of calculation in (21) with respect of (25) for minimization of error e_i follows from substitution of minimization of e_i with searching maximum of a part of expression (21). This substitution give some advantages for practical implementation of minimization algorithm, but still in (25) the calculations are relatively complex. It is possible to analyzes expression (25) and to shows that the essential calculations are in numerator and enumerator make normalization of the expression.

It is possible to taking only the numerator from the equation (25) and to use only the absolute correlation:

$$\vec{S}^t . \vec{B}_i{}' = \vec{S}^t .L' . \vec{b}_i{}' = SL. \vec{b}_i{}' , \qquad (26)$$

where $SL = \vec{S}^t .L'$ did'nt depend from index i and can be recalculated for all iterations of minimization.

IV. Conclusion

The proof of this possibility for simplification of algorithm of minimization can be made first with a statistical analysis and estimation of numerator of expression (25) and with analysis of decoded speech signal error with using expression (26) as a simplification of (25). The results from this analysis are the object of a next work.

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