METHOD FOR DETERMINING OPTIMUM LINEAR PREDICTION COEFFICIENTS

Field of the Invention

This invention relates to a method of signal prediction, and having particular application to linear predictors.

Background

The signal prediction has been widely used in the transmission or storage of signals. Predictors essentially estimate a future value of the signal based on preceding values and it can be used to remove the redundancy among the signals. With a predictor, the error signal (between the predicted signal and the actual signal) and the coefficients need to be transmitted or stored. This means that less data needs to be transmitted or stored. Thus, signal prediction is utilized in many data compression systems, such as, speech or audio compression systems. To apply linear predictor in such systems, the signal is usually split into short, equal, and possibly overlapping segments, in which prediction is carried out. Within each segment, the linear predictor is characterized by its linear prediction coefficients (LPC). The correlation method and the lattice method are two examples of conventional frame based optimization methods for calculating the LPC.

The conventional methods work on the assumption that signal variation within each windowed segment is negligible. Although this is generally true, there are situations where the signal undergoes abrupt transitions within the windowed segment. The segment size, or the window size, also affects the accuracy of the prediction. On one hand, it is expected that the accuracy of the signal prediction is improved with a larger window size. On the other hand, the probability of abrupt signal transitions increases as the window size increases.

It has been suggested to implement a flexible segmentation scheme such that the boundaries of the segments coincide with the transitions in the signal. At the same time, the lengths of the segments are set such that error is minimized. Although this may deal with the problem of non-stationarity, this method is very complex and it is very difficult to implement it in practice.

The effectiveness of the prediction can also be considered in terms of the prediction gain of the predictor. Traditionally, a better prediction gain needs the use of a higher order linear predictor. However, it is observed that, for some audio signals the prediction gain becomes saturated when the linear predictor order is higher than 20, while for other audio signals the prediction gain continues to increase even when the linear predictor order is higher than 90. Therefore, as in a conventional linear predictor system, some redundancy will inevitably remain in the signal waveform.

There is accordingly a need for an improved method of implementing linear prediction. As will be evident from the following description of a preferred embodiment, the present invention addresses the problems described above, as well as offering advantages over the prior art.

Summary of the Invention

The present invention may provide a method for determining an optimum LPC for a linear predictor. The method may include the steps of: constructing a multi-stage linear predictor (having two or more stages); calculating the LPC for each stage; and combining all of the LPC stages together to form a single stage linear predictor. The method can be used for determining an optimum number of stages for the multi-stage linear predictor. For example, combined linear predictor coefficients can be worked out for a two-stage linear predictor, a three-stage linear predictor and a four-stage linear predictor, and then compared to determine the linear predictor that best suits the application under consideration. The order of the first stage of the multi-stage linear predictor

preferably is much lower than the order of the last stage of the multi-stage linear predictor.

The present invention may provide a linear predictor that can achieve higher prediction gain compared with a conventional linear predictor having a higher prediction order. The proposed linear predictor may maintain the robustness of a conventional linear predictor but may offer advantages of simplicity and reduced redundancy in the signal waveform. Specifically, the present invention may offer improved performance in narrow bandwidth speech coding, wide bandwidth speech coding as well as audio coding.

According to one aspect of the present invention there is provided a method for determining optimum linear prediction coefficients (LPCs) in a linear predictor system, said method including the steps of:

providing a linear predictor system having at least two stages in tandem;

calculating an LPC for each stage using a conventional optimal method; and

combining the calculated LPCs to form a composite LPC which defines an equivalent single stage linear predictor system.

According to a further aspect of the present invention there is provided a method for determining an optimum number of stages for a linear predictor system, said method including the steps of:

(a) providing a linear predictor system having n stages wherein $n \geq 2$;

(b) calculating a linear prediction coefficient (LPC) for each stage using a conventional optimal method;

(c) combining the calculated LPCs to form a composite LPC which defines an equivalent single stage linear predictor system;

(d) evaluating suitability of the n-stage linear predictor for an application under consideration against objective criteria;

(e) incrementing n by one and repeating steps (a) to (d);

(f) comparing the result of the evaluation against a prior result; and

(g) repeating step (e) if the result of the comparison shows an improvement in suitability.

According to a still further aspect of the present invention there is provided apparatus for determining optimum linear prediction coefficients (LPCs) in a linear predictor system, said apparatus including:

a linear predictor system having at least two stages in tandem;

means for calculating an LPC for each stage using a conventional optimal method; and

means for combining the calculated LPCs to form a composite LPC which defines an equivalent single stage linear predictor system.

According to a still further aspect of the present invention there is provided apparatus for determining an optimum number of stages for a linear predictor system said apparatus including:

(a) a linear predictor system having n stages wherein $n \geq 2$;

(b) means for calculating a linear prediction coefficient for each stage using a conventional optimal method;

(c) means for combining the calculated LPCs to form a composite LPC which defines an equivalent single stage linear predictor system;

(d) means for evaluating suitability of the n-stage linear predictor for an application under consideration against objective criteria;

(e) means for incrementing n by one if the result of the comparison shows an improvement in suitability; and

(f) means for comparing the result of the evaluation against a prior result.

Brief Description of the Drawings

Preferred embodiments of the present invention will now be described with reference to the attached drawings wherein:

FIG. 1 is a functional block diagram of a multi-stage linear predictor according to a preferred embodiment of the present invention;

FIG. 2 shows an encoder including a two-stage linear predictor according to a preferred embodiment;

FIG. 3 is a flowchart illustrating a preferred embodiment of the present invention;

FIG. 4 shows a decoder including the two-stage linear predictor of FIG. 2; and

FIG. 5 shows a decoder corresponding to FIG. 4 including an equivalent single stage linear predictor.

Detailed Description of the Invention

FIG. 1 shows a functional block diagram of a multi-stage linear predictor having a plurality of linear predictors LP_1 to LP_i in a cascade arrangement. A first predicted signal is subtracted from the original input signal x(n) to the first linear predictor LP_1 to produce a first error signal $e_1(n)$. This first error signal is fed to the next linear predictor LP_2 as a second input signal. The difference between this second input signal and a second predicted signal is provided as the output $e_2(n)$ of the second linear predictor LP_2. This output signal or the second error signal $e_2(n)$ is then fed to the subsequent linear predictor. This carries on until the last linear predictor LP_i has produced a final error signal $e_i(n)$.

For ease of explanation, the present invention will be described with reference to a two-stage linear predictor system although it is applicable to linear predictors having more than two stages. Where a linear predictor has more than two stages the first two stages can be combined to form a new single stage linear predictor. The new single stage linear predictor can be combined with the third stage to form a second new single stage linear predictor which may be combined with the fourth stage to form a third new single stage linear predictor and so on.

Making reference therefore to FIG. 2, there is shown a representation of an encoder including a two-stage linear predictor. The input signal waveform *x(n)* is framed into *N* samples and fed to the first linear predictor LP_1. The first linear predictor LP_1 is configured to provide the first predicted signal $y_1(n)$ which is subtracted from the input signal *x(n)* to give the residual or error signal $e_1(n)$ at the output.

In general, linear predictor LP_i *(i=1,2)* has a transform in the Z domain of

$$P_i(z)=\sum_{j=1}^{N_{fi}} a_j(i)z^{-j} \qquad (1)$$

where *i* is the index for each different stage and N_{fi} is the LP order for the *i*th stage.

The residual or error signal $e_1(n)$, is given in the time domain by equation (2):

$$e_1(n) = x(n) - y_1(n) \qquad (2)$$

where

$$y_1(n)=\sum_{j=1}^{N_{f1}} a_j(1)x(n-j) \qquad (3)$$

The residual signal $e_1(n)$ is again framed into *N* samples and passed through the second linear predictor LP_2 to obtain the second residual or error signal $e_2(n)$. In this example, because there are only two linear predictors in the system, the second residual or error signal $e_2(n)$ is also the final residual or error signal. The final residual or error signal is given in the time domain by equation (4):

$$e_2(n)=e_1(n)-\ y_2(n) \qquad (4)$$

where

$$y_2(n) = \sum_{i=1}^{N_{f2}} a_i(2)e_1(n-i) \qquad (5)$$

Substituting equations (2), (3) and (5) into equation (4), gives equation (6), which is also a linear predictor.

$$e_2(n)=x(n) - \sum_{i=1}^{N_{f1}+N_{f2}} b_i x(n-i) \qquad (6)$$

New combined linear predictor coefficients $\{b_i\}$ may be determined by the coefficients in $y_1(n)$ and $y_2(n)$: $\{a_j(1)\}$ and $\{a_i(2)\}$ and are given in detail as follows.

$$b_i = \sum_{\substack{l+j=i \\ 1\le l\le N_{f1} \\ 1\le j\le N_{f2}}} \hat{a}_l(1)\hat{a}_j(2) + \hat{a}_i(1) + \hat{a}_i(2); \qquad 1 \le i \le N_{f1}+N_{f2} \qquad (7)$$

In the above equation, the values $\hat{a}_l(1)$ and $\hat{a}_j(2)$ are defined by

$$\hat{a}_l(1)=\begin{cases} a_l(1), 1\le l\le N_{f1} \\ 0, \quad otherwise \end{cases}, \qquad \hat{a}_j(2)=\begin{cases} a_j(2), 1\le j\le N_{f2} \\ 0, \quad otherwise \end{cases} \qquad (8)$$

It can be seen from equation (6) that the two-stage linear predictor can be represented by a linear predictor having the linear predictor coefficients $\{b_i\}$, referred to as composite linear predictor coefficients. The composite linear predictor coefficients $\{b_i\}$ are not derived directly by any conventional optimal method, but are instead based on equations (7) and (8).

The novel method involves first calculating $\{a_l(1)\}$ and $\{a_l(2)\}$ using any conventional optimal method, then combining them to form a composite LPC

which defines an equivalent single stage linear predictor. An example of a process flowchart illustrating the novel method is given in FIG. 3.

Continuing the example of a two-stage linear predictor, the novel method involves first finding the first N_{f1} LPC, getting the first residual or error signal, and then finding the second N_{f2} LPC. Finally, using equations (7) and (8), a composite LPC is obtained. Thus, when $N_{f1} = 2$, $N_{f2} > 2$, the combined coefficients can be represented in the following manner:

$$\begin{cases} b_1 = a_1(1) + a_1(2) \\ b_2 = a_2(1) + a_2(2) - a_1(1)a_1(2) \\ b_i = a_i(2) - a_1(1)a_{i-1}(2) - a_2(1)a_{i-2}(2), \; i = 3,4,\ldots,N_{f2} \\ b_{N_{f2}+1} = -a_1(1)a_{N_{f2}}(2) - a_2(1)a_{N_{f2}-1}(2) \\ b_{N_{f2}+2} = -a_2(1)a_{N_{f2}}(2) \end{cases} \qquad (9)$$

For a linear predictor having more than two stages, equations (7) and (8) are utilized to combine the first two stages into a new single stage linear predictor. Equations (7) and (8) are then used again to combine the new single stage linear predictor with the third stage to form a second new single stage linear predictor. This procedure is repeated to the last stage of the linear predictor to form a final new single stage linear predictor.

The linear predictor of the present invention is derived from a combination of multiple stages of linear predictors, and is found to be a stable system providing that it is derived from stable stages of linear predictors.

FIG. 4 shows a functional block diagram of a decoder including the two-stage linear predictor described above. The sum of the first predicted signal $y_1(n)$ and the final residual or error signal $e_2(n)$ is added to the second predicted signal $y_2(n)$ to return the original input signal x(n) that was predicted via the linear predictor of FIG. 2.

FIG. 5 shows a functional block diagram of a decoder corresponding to FIG. 4 with a single stage linear predictor derived according to the present invention. The error signal $e_2(n)$ is added to the predicted signal to return the original input signal x(n) that was predicted via the linear predictor of FIG. 2 by using equations (6), (7) and (8).

According to another aspect of the invention, the order of the second linear predictor should be higher than the order of the first linear predictor. In an embodiment having more than two linear predictors in the multi-stage linear predictor, each subsequent or downstream linear predictor should have an order that is higher than the order of a preceding or upstream linear predictor.

In an alternative embodiment, the multi-stage linear predictor is an adaptive linear predictor in which individual linear predictors may or may not have an effect on the respective input signals, depending whether certain predetermined criteria have been satisfied.

It is to be understood that even though numerous characteristics and advantages of various embodiments of the present invention have been set forth in the foregoing description, together with details of the structure and function of various embodiments of the invention, this disclosure is illustrative only, and changes may be made to the details without departing from the scope and spirit of the present invention.

CLAIMS

1. A method for determining optimum linear prediction coefficients (LPCs) in a linear predictor system, said method including the steps of:

providing a linear predictor system having at least two stages in tandem;

calculating an LPC for each stage using a conventional optimal method; and

combining the calculated LPCs to form a composite LPC which defines an equivalent single stage linear predictor system.

2. A method according to claim 1 wherein the step of combining is applied to the LPCs for the first two stages of the linear predictor system.

3. A method according to claim 2 including the step of combining said composite LPC and the calculated LPC for a third stage to form a second composite LPC which defines an equivalent single stage linear predictor system.

4. A method according to claim 3 including the step of combining said second composite LPC and the calculated LPC for a fourth stage to form a third composite LPC which defines an equivalent single stage linear predictor system.

5. A method according to claim 4 including repeating the steps of combining said composite LPC and said calculated LPC to the last stage of the linear predictor system to form a final composite LPC which defines an equivalent single stage linear predictor system.

6. A method according to any one of the preceding claims wherein the order of an upstream stage of the linear predictor system is lower than the order of a downstream stage of the linear predictor system.

7. A method according to any one of the preceding claims wherein said linear predictor system includes an adaptive linear predictor in which individual stages of said system have an effect on respective input signals in response to predetermined criteria.

8. A method for determining an optimum number of stages for a linear predictor system, said method including the steps of:

(a) providing a linear predictor system having n stages wherein $n \geq 2$;

(b) calculating a linear prediction coefficient (LPC) for each stage using a conventional optimal method;

(c) combining the calculated LPCs to form a composite LPC which defines an equivalent single stage linear predictor system;

(d) evaluating suitability of the n-stage linear predictor for an application under consideration against objective criteria;

(e) incrementing n by one and repeating steps (a) to (d);

(f) comparing the result of the evaluation against a prior result; and

(g) repeating step (e) if the result of the comparison shows an improvement in suitability.

9. A method according to claim 8 wherein said prior result is a result of an immediately preceding evaluation.

10. Apparatus for determining optimum linear prediction coefficients (LPCs) in a linear predictor system, said apparatus including:

a linear predictor system having at least two stages in tandem;

means for calculating an LPC for each stage using a conventional optimal method; and

means for combining the calculated LPCs to form a composite LPC which defines an equivalent single stage linear predictor system.

11. Apparatus according to claim 10 wherein the means for combining is applied to the LPCs for the first two stages of the linear predictor system.

12. Apparatus according to claim 11 including means for combining said composite LPC and the calculated LPC for a third stage to form a second composite LPC which defines an equivalent single stage linear predictor system.

13. Apparatus according to claim 12 including means for combining said second composite LPC and the calculated LPC for a fourth stage to form a third composite LPC which defines an equivalent single stage linear predictor system.

14. Apparatus according to claim 13 including means for repeating the steps of combining said composite LPC and said calculated LPC to the last stage of the linear predictor system to form a final composite LPC which defines an equivalent single stage linear predictor system.

15. Apparatus according to any one of claims 10 to 14 wherein the order of an upstream stage of the linear predictor system is lower than the order of a downstream stage of the linear predictor system.

16. Apparatus according to any one of claims 10 to 15 wherein said linear predictor system includes an adaptive linear predictor in which individual stages of said system have an effect on respective input signals in response to predetermined criteria.

17. Apparatus for determining an optimum number of stages for a linear predictor system said apparatus including:

(a) a linear predictor system having n stages wherein $n \geq 2$;

(b) means for calculating a linear prediction coefficient for each stage using a conventional optimal method;

(c) means for combining the calculated LPCs to form a composite LPC which defines an equivalent single stage linear predictor system;

(d) means for evaluating suitability of the n-stage linear predictor for an application under consideration against objective criteria;

(e) means for incrementing n by one if the result of the comparison shows an improvement in suitability; and

(f) means for comparing the result of the evaluation against a prior result.

18. Apparatus according to claim 17 wherein said prior result is a result of an immediately preceding evaluation.

19. An encoder incorporating a multistage linear predictor system having an optimum number of stages determined by a method according to claim 8 or 9.

20. A decoder incorporating a multistage linear predictor system having an optimum number of stages determined by a method according to claim 8 or 9.

21. A method for determining an optimum number of stages for linear predictor system substantially as herein described with reference to the accompanying drawings.

22. Apparatus for determining an optimum number of stages for a linear predictor system substantially as herein described with reference to the accompanying drawings.

23. An encoder substantially as herein described with reference to the accompanying drawings.

24. A decoder substantially as herein described with reference to the accompanying drawings.