METHOD AND APPARATUS FOR THE PREDICTION OF AUDIO SIGNALS

Field of the Invention

This invention relates to a method and apparatus for the prediction of audio signals. The invention has particular utility in relation to lossless compression of audio signals.

Background Art

High quality audio signals represent a significant amount of information. For instance a compact-disc quality 16-bit stereo audio signal represents over 1.4 million bits of information per second of audio signal. It is desirable to compress the information in the audio signal so that less data is required to be transmitted or stored.

Compression systems are either lossless or lossy. Lossy compression systems do not allow the original audio signal to be fully recovered but generally provide for greater compression ratios than lossless compression systems.

Lossless compression systems allow the original audio signal to be accurately recovered. Conventional lossless compression algorithms, like the Lempel-Ziv algorithm, are not directly suited for use in compressing audio signals because of the wide dynamic range and extended redundancy of audio signals. The invention seeks to utilise prediction to remove the redundancy of audio signals for the application of lossless audio compression.

In a paper by Peter Craven and Michael Gerzon, "Lossless Coding for Audio Discs", J. Audio Eng. Soc., Vol.44, Sept. 1996, pp706-720, the use of linear prediction to enhance the performance of lossless compression of audio signals is described. Linear prediction is an important component of compression systems that utilise predictors to estimate the future value of the audio signal based on preceding values. The general principal is that if the prediction is

accurate and the prediction system is known at the transmitter and the receiver, then only the error signal between the predicted signal and the actual signal needs to be transmitted, which may require less information. In the abovementioned literature, the authors mentioned an n-cascaded simple differential prediction system with a transfer function of $(1-z^{-1})^n$, and discussed the limitations of this kind of prediction system. However, the authors did not realize that their prediction system has limitations arising from the use of non-adaptive predictors rather than only on the adaptation of n.

Summary of the Invention

In accordance with a first aspect of this invention, there is provided a signal prediction apparatus, comprising:

a plurality of predictor means provided in a cascaded configuration from a first predictor means to a last predictor means, each predictor means having an input and an output, the first predictor means responsive to an input signal to produce a first error signal at its output, subsequent predictor means in the cascade being responsive to the output of the previous predictor means to produce further error signals at their outputs, the last predictor means producing a final error signal;

control means in communication with each of the predictor means, said control means arranged to compare whether a prediction gain of each predictor means in turn is less than a predetermined threshold and if so, to instruct the remaining predictor means in the cascade to pass any signal at its input to its output without acting on the signal, said control means being further arranged to produce a control signal representing which predictor means were used in producing the final error signal; and

means for combining the control signal and the final error signal to produce an output signal.

Preferably, said control means is further arranged to instruct the predictor means with a prediction gain less than the predetermined threshold to also pass any signal at its input to its output without acting on the signal.

Preferably, each predictor means comprises an adaptive predictor.

Preferably, said adaptive predictors are linear predictors.

Preferably, each adaptive predictor has at least as many taps as the preceding adaptive predictor in the cascade.

Preferably, the signal prediction apparatus comprises three adaptive predictors that have 2, 2 and 10 taps, respectively.

Preferably, the means for combining comprises a multiplexer.

Preferably, said apparatus further comprises means for losslessly compressing the output signal.

In accordance with a second aspect of this invention, there is provided a signal recovery apparatus, comprising:

means for separating an input signal into a control signal and an error signal;

a plurality of predictor means provided in a reverse cascaded configuration from a last predictor means to a first predictor means, each predictor means having an input and an output, the last predictor means responsive to the error signal to produce a first output signal at its output, subsequent predictor means in the cascade being responsive to the output of the previous predictor means to produce further output signals at their outputs, the first predictor means producing a final output signal;

control means in communication with each predictor means and responsive to the control signal, said control signal representing which predictor means are to be used in producing the final output signal, said control means arranged to instruct predictor means that are not to be used in producing the final output signal to pass any signal at its input to its output without acting on the signal.

Preferably, each predictor means comprises an adaptive predictor.

Preferably, said adaptive predictors are linear predictors.

Preferably, each adaptive predictor has no more taps than the preceding adaptive predictor in the cascade.

Preferably, the signal recovery apparatus comprises three adaptive predictors that have 10, 2 and 2 taps, respectively.

Preferably, the means for separating comprises a demultiplexer.

Preferably, said apparatus further comprises means for losslessly decompressing the input signal prior to being input to the means for separating.

In accordance with a third aspect of this invention, there is provided a method for predicting a signal, comprising the steps of:

(a) producing an error signal as the difference between an input signal and a predicted value of said input signal;

(b) comparing whether a prediction gain from the previous step is less than a predetermined threshold;

(c) if the prediction gain is less than the predetermined threshold, using the current input signal as a final error signal, otherwise repeating steps (a) and (b) with the error signal as a new input signal;

(d) producing a control signal representing how many times step (a) was performed in producing the final error signal; and

(e) combining the control signal and the final error signal to produce an output signal.

Preferably, the step of producing an error signal includes using an adaptive predictor to produce each predicted value of the input signal.

Preferably, said adaptive predictors are linear predictors.

Preferably, each adaptive predictor has at least as many taps as the preceding adaptive predictor.

Preferably, the step of combining comprises multiplexing the final error signal and the control signal.

Preferably, said method further comprises the step of losslessly compressing the output signal.

In accordance with a fourth aspect of this invention, there is provided a method for recovering a source signal from an input signal, comprising the steps of:

(a) separating the input signal into a control signal and an error signal;

(b) producing a further error signal as the sum of the error signal and a predicted value of said source signal;

(c) determining from the control signal whether to repeat step (b), whereby if step (b) is not to be repeated the current error signal is the recovered original source signal , otherwise repeating step (b) with the further error signal as a new error signal.

Preferably, the step of producing a further error signal includes using an adaptive predictor to produce each predicted value of the source signal.

Preferably, said adaptive predictors are linear predictors.

Preferably, each adaptive predictor has no more taps than the preceding adaptive predictor.

Preferably, the step of separating comprises demultiplexing the input signal into the error signal and the control signal.

Preferably, said method further comprises the step of losslessly decompressing the input signal prior to the step of separating.

Brief Description of the Drawings

One embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows a signal prediction apparatus in accordance with the embodiment of the invention;

Figure 2 is a block diagram of an adaptive predictor used in the signal prediction apparatus shown in Figure 1;

Figure 3 shows a signal recovery apparatus in accordance with the embodiment of the invention; and

Figure 4 is a block diagram of an adaptive predictor used in the signal recovery apparatus shown in Figure 3.

Best Mode(s) for Carrying Out the Invention

The embodiment is directed towards a signal prediction apparatus and to a signal recovery apparatus for lossless compression and recovery of an audio signal.

The signal prediction apparatus 10 of the embodiment is shown in Figure 1 and comprises first, second and third adaptive predictors 12, 14 and 16 respectively, a controller 18 and a multiplexer 20.

The adaptive predictors 12, 14 and 16 are provided in a cascaded configuration so that the output of the first adaptive predictor 12 is input to the second adaptive predictor 14 and so on.

The adaptive predictors 12, 14 and 16 are connected to the controller 18 so as to be in communication therewith. The controller 18 acts to control operation of the adaptive predictors 12, 14 and 16 as will be described in further detail below.

Each of the adaptive predictors 12, 14 and 16 are linear predictors in the embodiment. Further, the first adaptive predictor 12 has two taps, the second adaptive predictor 14 has two taps and the third adaptive predictor 16 has ten taps in the embodiment.

A block diagram of the structure of each of the adaptive predictors 12, 14 and 16 is shown in Figure 2. Each adaptive predictor receives an input signal, shown in Figure 2 as i(n), where n is a discrete time slot. A predicted signal, shown in Figure 2 as p(n), that is produced by a predictor circuit 22 is subtracted from the input signal i(n) using a summing circuit 24 to produce an output signal, shown in Figure 2 as o(n). The output signal o(n) represents the error between the predicted signal p(n) and the actual input signal i(n). The output signal o(n) and the predicted signal p(n) are combined at a summing circuit 26 to recreate the input signal which is then input to the prediction circuit 22.

In the adaptive predictor 12 shown in Figure 1, the input signal i(n) is shown as s(n), and the output signal o(n) is $e_1(n)$. In the adaptive predictor 14 shown in Figure 1, the signal i(n) is $e_1(n)$, and the signal o(n) is $e_2(n)$, and so on.

For a linear predictor P(z), the predictor circuit 22 has a Z-transform transfer function of:

$$P(z) = \sum_{i=1}^{N_{taps}} a_i z^{-i}$$

where: N_{taps} is the number of taps in the predictor, also known as the predictor order; and

a_i are the predictor coefficients.

The predictor coefficients, a_i, of each predictor can be chosen by either block-based or sample-based optimisation as described in the paper by L. Adams and Steven W. McLaughlin, "Lossless Compression of High Fidelity Audio and Adaptive Linear Prediction", proceedings of IEEE ICASSP'95, pp3091-3094, the disclosure of which is incorporated herein by reference.

Further, the predictor coefficients a_i can also be found either by the auto-correlation method, the covariance method or by the lattice method as described by N. S. Jayant and Peter Noll, "Digital Coding of Wave Forms: Principles and Applications to Speech and Video", Prentice-Hall, Inc. 1984.

The predictor coefficients a_i are then quantized and encoded in order to be suitable for storage or transmission. For lossless compression of an audio signal, the error signal will be losslessly encoded and multiplexed with the encoded predictor coefficients, a_i, as well as a control signal, as described in further detail below. The multiplexed bit stream is then ready for either transmission or store.

The operation of the signal prediction apparatus 10 shown in Figure 1 will now be described.

The input signal s(n) is received by the first adaptive predictor 12, which produces a first error signal shown in Figure 1 as $e_1(n)$. The controller 18 then records the prediction gain from the first adaptive predictor 12. If the prediction gain is greater than a threshold value (e.g. 0.5 dB), the first error signal $e_1(n)$ output from the first adaptive predictor 12 is processed by the second adaptive predictor 14 in normal fashion to produce a second error signal shown in Figure 1 as $e_2(n)$.

The controller 18 then records the prediction gain of the second adaptive predictor 14 and compares it to the threshold value (e.g. 0.5 dB). Again, if the adaptive gain is greater than the threshold value, the second error signal $e_2(n)$ produced by the adaptive predictor 14 is processed by the third adaptive predictor 16 in normal fashion to produce a third error signal shown in Figure 3 as $e_3(n)$.

If the controller 18 records that the prediction gain from the first or second adaptive predictors 12 or 14 is less than the predetermined threshold (e.g. 0.5 dB), then the controller 18 commands that adaptive predictor and the remaining adaptive predictors to not process the error signals input to them, but simply to pass the error signals unprocessed to their outputs. For example, if the controller 18 records that the adaptive predictor 14 had a prediction gain lower than the threshold (e.g. 0.5 dB), the controller 18 would command the adaptive predictors 14 and 16 not to process the first error signal but to simply pass it to their respective outputs. The output from the third adaptive predictor 16 is input to the multiplexer 20. Consequently, the output from the first adaptive predictor 12 would be passed to the multiplexer 20.

The controller 18 records which set of the adaptive predictors {12}, {12,14} and {12,14,16} were used in producing the error signal input to the multiplexer 20 and

produces control information representing which set of adaptive predictors were used. The controller 18 passes the control information to the multiplexer 20.

In the embodiment, the controller stores the control information encoded in two bits, for four different statuses:

"00" means that there is no correlation at all for the input signal and all of the predictors 12, 14 and 16 are bypassed;

"01" means that the second predictor 14 has resulted in a prediction gain less than the threshold (e.g. 0.5 dB), only the first predictor 12 is used;

"10" means that the third predictor 16 has resulted in a prediction gain less than the threshold (e.g. 0.5 dB), only the first and the second predictors 12 and 14 are used;

and "11" means that all three predictors 12, 14 and 16 are used.

The multiplexer 20 produces an output signal, shown in Figure 1 as h(n) (sometimes called residual signal), which is then losslessly compressed.

From extensive experiment we found that a cascade of three adaptive predictors is usually sufficient. It is very rare for the prediction gain to still exceed 0.5 dB after a cascade of three adaptive predictors.

The lossless compressed audio signal can be stored or transmitted, as desired, for later reconstruction.

After losslessly decompression, the reconstruction of the audio signal will now be described with reference to Figures 3 and 4.

Reconstruction of the audio signal is achieved using the signal recovery apparatus 30 shown in Figure 3. The signal recovery apparatus 30 comprises a

demultiplexer 32, a controller 34, and first, second and third adaptive predictors 36, 38 and 40, respectively.

The demultiplexer 32 receives an input signal that has been losslessly decompressed, shown in Figure 3 as h(n), and demultiplexes the signal into an error signal and control information. The control information is passed to the controller 34 whilst the error signal is input to the third adaptive predictor 40.

The adaptive predictors 36, 38 and 40 are arranged in a cascaded configuration in a reverse order to the cascade of adaptive predictors used in the signal prediction apparatus 10 shown in Figure 1. That is, the error signal from the demultiplexer 32 is input to the third adaptive predictor 40, the output of which is input to the second adaptive predictor 38 and so forth.

The controller 34 responds to the control information from the demultiplexer 32 which includes information concerning which of the set {first}, {first, second} and {first, second, third} of adaptive predictors were used to produce the residual audio signal h(n). The controller 34 instructs the corresponding adaptive predictors 36, 38 and 40 in the signal recovery apparatus 30 to pass on or act on the signal at their inputs, so that the same adaptive predictors are used to reconstruct the audio signal as were used to predict it. For instance, if the control signal indicated that the first and second adaptive predictors only were used in producing the predicted signal, the controller 34 would instruct the third adaptive predictor 40 to not process the signal at its input but rather to simply pass it through to the second adaptive predictor 38. The processed signal from the adaptive predictor 38 would then be input to the first adaptive predictor 36 which would further process the signal to produce the reconstructed audio signal.

Figure 4 is a block diagram of each of the adaptive predictors 36, 38 and 40 used in the decoder. Each adaptive predictor receives an input signal denoted in Figure 4 as i(n). A predictor circuit 42 produces a predicted signal p(n) which is combined with the input signal using a summing circuit 44 to produce an output

signal denoted in Figure 4 as o(n). The predictor circuit 42 takes the same form as the predictor circuit 22 in the adaptive predictors of the prediction apparatus 10.

In the adaptive predictor 36 shown in Figure 3, the input signal i(n) is shown as $e_1(n)$, and the output signal o(n) is s(n). In the adaptive predictor 40 shown in Figure 3, the signal i(n) is $e_3(n)$, and the signal o(n) is $e_2(n)$, and so on.

The signal prediction apparatus described in the embodiment can achieve higher predictor gain than single-stage adaptive predictor that have been previously used. Further, the adaptive, multi-stage arrangement of adaptive predictors allows the computational burden in prediction and recovery of the audio signal to be reduced according to the audio signal characteristics whilst maintaining predictor gain.

It should be appreciated that the scope of this invention is not limited to the particular embodiment described above.

Claims

1. A signal prediction apparatus, comprising:

a plurality of predictor means provided in a cascaded configuration from a first predictor means to a last predictor means, each predictor means having an input and an output, the first predictor means responsive to an input signal to produce a first error signal at its output, subsequent predictor means in the cascade being responsive to the output of the previous predictor means to produce further error signals at their outputs, the last predictor means producing a final error signal;

control means in communication with each of the predictor means, said control means arranged to compare whether a prediction gain of each predictor means in turn is less than a predetermined threshold and if so, to instruct the remaining predictor means in the cascade to pass any signal at its input to its output without acting on the signal, said control means being further arranged to produce a control signal representing which predictor means were used in producing the final error signal; and

means for combining the control signal and the final error signal to produce an output signal.

2. A signal prediction apparatus as claimed in claim 1, wherein said control means is further arranged to instruct the predictor means with a prediction gain less than the predetermined threshold to also pass any signal at its input to its output without acting on the signal.

3. A signal prediction apparatus as claimed in claim 1 or 2, wherein each predictor means comprises an adaptive predictor.

4. A signal prediction apparatus as claimed in claim 3, wherein said adaptive predictors are linear predictors.

5. A signal prediction apparatus as claimed in claim 3 or 4, wherein each adaptive predictor has at least as many taps as the preceding adaptive predictor in the cascade.

6. A signal prediction apparatus as claimed in claim 3, wherein the signal prediction apparatus comprises three adaptive predictors that have 2, 2 and 10 taps, respectively.

7. A signal prediction apparatus as claimed in any one of claims 1 to 6, wherein the means for combining comprises a multiplexer.

8. A signal prediction apparatus as claimed in any one of claims 1 to 7, further comprising means for losslessly compressing the output signal.

9. A signal recovery apparatus, comprising:

means for separating an input signal into a control signal and an error signal;

a plurality of predictor means provided in a reverse cascaded configuration from a last predictor means to a first predictor means, each predictor means having an input and an output, the last predictor means responsive to the error signal to produce a first output signal at its output, subsequent predictor means in the cascade being responsive to the output of the previous predictor means to produce further output signals at their outputs, the first predictor means producing a final output signal;

control means in communication with each predictor means and responsive to the control signal, said control signal representing which predictor means are to be used in producing the final output

signal, said control means arranged to instruct predictor means that are not to be used in producing the final output signal to pass any signal at its input to its output without acting on the signal.

10. A signal recovery apparatus as claimed in claim 9, wherein each predictor means comprises an adaptive predictor.

11. A signal recovery apparatus as claimed in claim 10, wherein said adaptive predictors are linear predictors.

12. A signal recovery apparatus as claimed in claim 10 or 11, wherein each adaptive predictor has no more taps than the preceding adaptive predictor in the cascade.

13. A signal recovery apparatus as claimed in claim 10, wherein the signal recovery apparatus comprises three adaptive predictors that have 10, 2 and 2 taps, respectively.

14. A signal recovery apparatus as claimed in any one of claims 9 to 13, wherein the means for separating comprises a demultiplexer.

15. A signal recovery apparatus as claimed in any one of claims 9 to 14, wherein said apparatus further comprises means for losslessly decompressing the input signal prior to being input to the means for separating.

16. A method for predicting a signal, comprising the steps of:

(a) producing an error signal as the difference between an input signal and a predicted value of said input signal;

(b) comparing whether a prediction gain from the previous step is less than a predetermined threshold;

(c) if the prediction gain is less than the predetermined threshold, using the current input signal as a final error signal, otherwise repeating steps (a) and (b) with the error signal as a new input signal;

(d) producing a control signal representing how many times step (a) was performed in producing the final error signal; and

(e) combining the control signal and the final error signal to produce an output signal.

17. A method for predicting a signal as claimed in claim 16, wherein the step of producing an error signal includes using an adaptive predictor to produce each predicted value of the input signal.

18. A method for predicting a signal as claimed in claim 17, wherein said adaptive predictors are linear predictors.

19. A method for predicting a signal as claimed in claim 17 or 18, wherein each adaptive predictor has at least as many taps as the preceding adaptive predictor.

20. A method for predicting a signal as claimed in any one of claims 16 to 19, wherein the step of combining comprises multiplexing the final error signal and the control signal.

21. A method for predicting a signal as claimed in any one of claims 16 to 20, wherein said method further comprises the step of losslessly compressing the output signal.

22. A method for recovering a source signal from an input signal, comprising the steps of:

(a) separating the input signal into a control signal and an error signal;

(b) producing a further error signal as the sum of the error signal and a predicted value of said source signal;

(c) determining from the control signal whether to repeat step (b), whereby if step (b) is not to be repeated the further error signal as the source signal, otherwise repeating step (b) with the further error signal as a new error signal.

23. A method for recovering a source signal as claimed in claim 22, wherein the step of producing a further error signal includes using an adaptive predictor to produce each predicted value of the source signal.

24. A method for recovering a source signal as claimed in claim 23, wherein said adaptive predictors are linear predictors.

25. A method for recovering a source signal as claimed in claim 23 or 24, wherein each adaptive predictor has no more taps than the preceding adaptive predictor.

26. A method for recovering a source signal as claimed in any one of claims 22 to 25, wherein the step of separating comprises demultiplexing the input signal into the error signal and the control signal.

27. A method for recovering a source signal as claimed in any one of claims 22 to 26, wherein said method further comprises the step of losslessly decompressing the input signal prior to the step of separating.