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(54) Echo control system

(57) An echo control system for an adaptive echo canceller (1) which forms a pseudo-echo or its residual signal ($\hat{y}_j$) by combining respective outputs from a tapped delay line (8) holding an estimated characteristic of an echo path as a tap weight and receiving a received signal or its residual signal (x_j) as an input signal, subtracts the pseudo-echo or its residual signal ($\hat{y}_j$) from an echo signal of its residual signal (y_j), and corrects (9) the tap weight using an amount of correction obtained by the resulting residual echo signal or its residual signal (e_j) and the received signal or its residual signal (x_j). There is provided a circuit noise estimation circuit (12) for estimating circuit noise (n_j) of the echo path, a parameter error estimation circuit (13) for estimating a parameter error ($\| \Delta|h_j \|^2$) between the characteristic of the echo path and its estimated characteristic, and a coefficient calculator (11) for determining a correction coefficient (α_j) obtained with the circuit noise, the parameter error and the received signal (x_j), wherein the said tap weight is corrected in accordance with the result of multiplication of the amount of correction and the correction coefficient. The system may be further provided with a device (21, 22) Fig. 2, not shown for transferring, as the said tap weight, the tap weight of the tapped delay line in the circuit noise estimation circuit (12) when the circuit noise (n_j) formed in the circuit noise estimation circuit (12) is smaller than the residual echo signal (e_j).

Fig. I

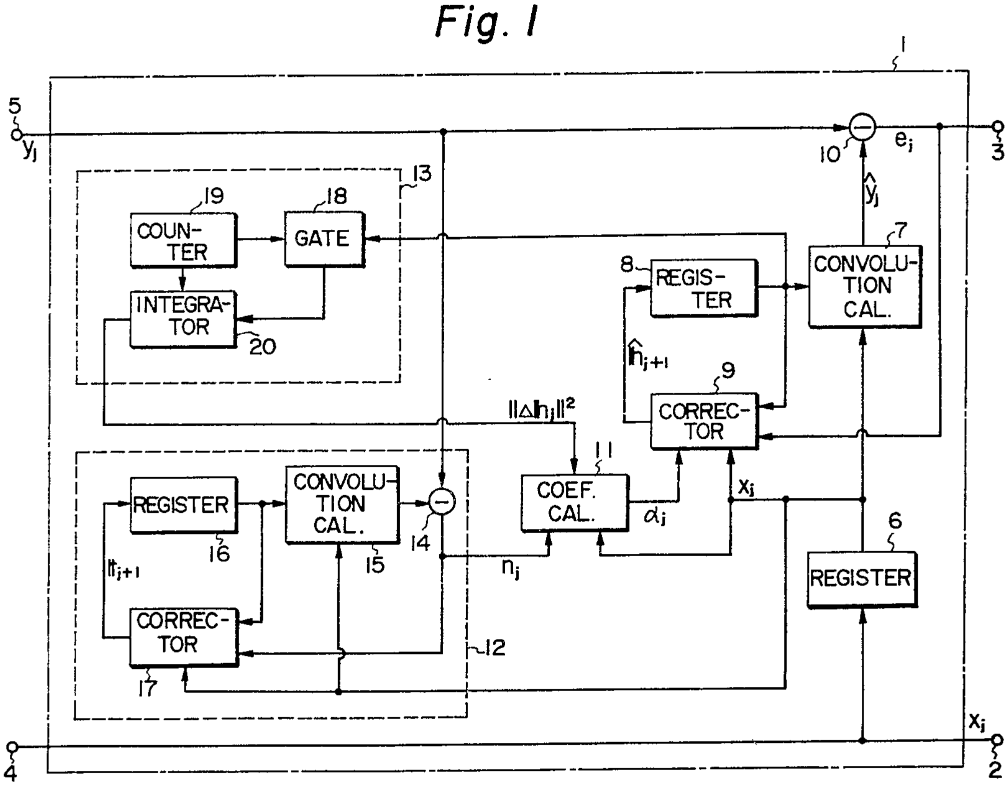

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Fig. 1

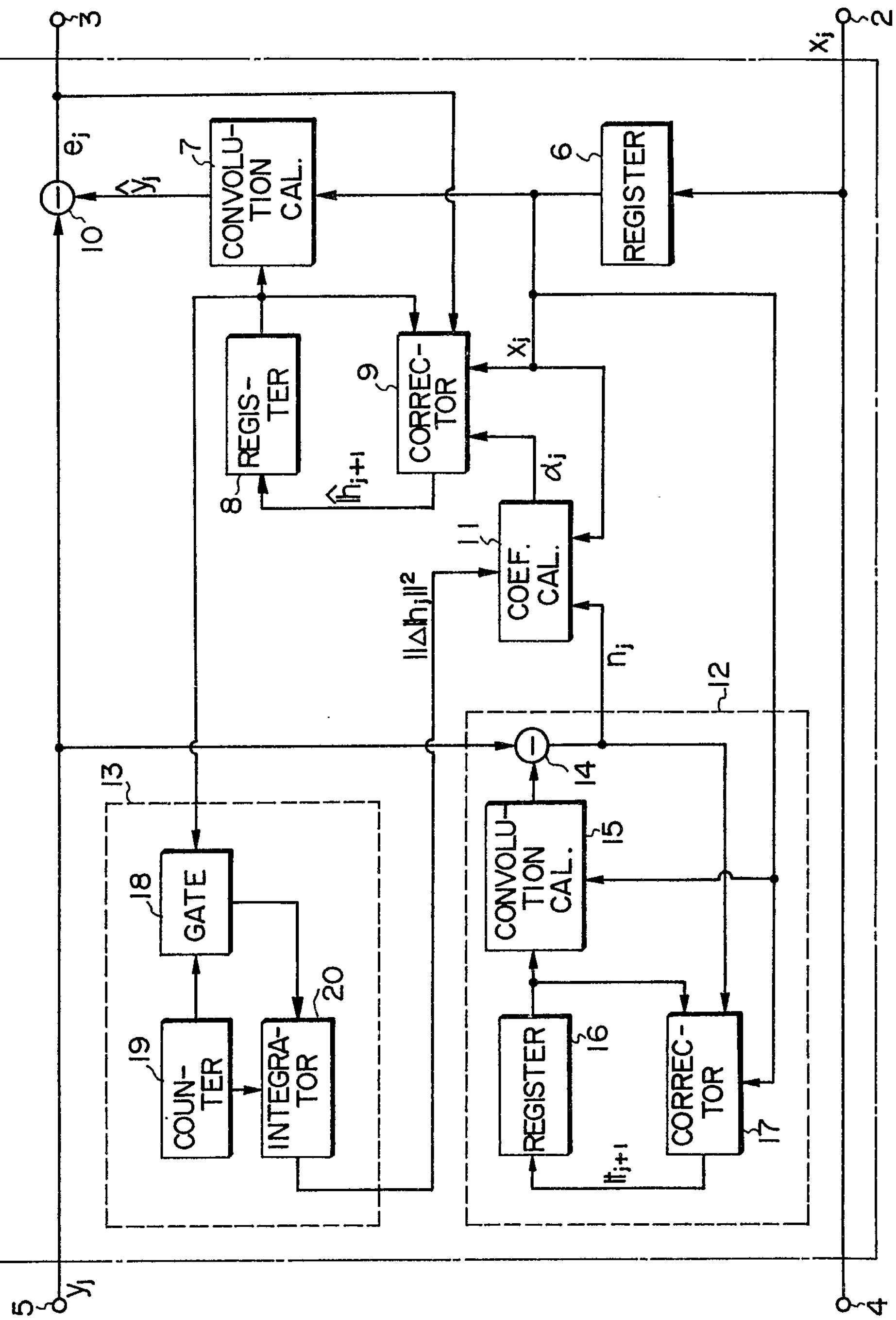
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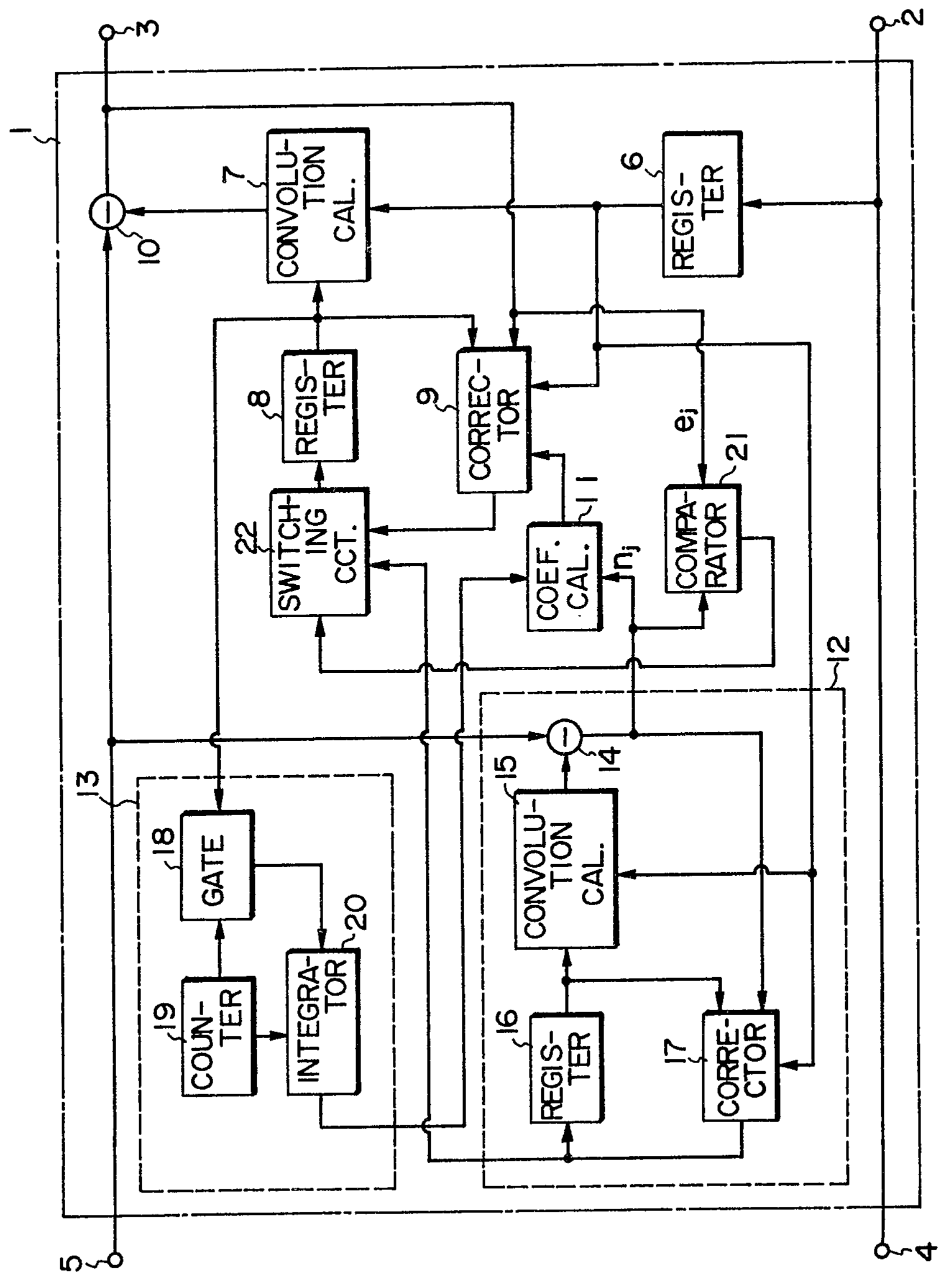
Fig. 2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SPECIFICATION

Echo control system

The present invention relates to an adaptive echo cancellor which cancels an echo while estimating the transmission characteristic of an echo path through the use of a received signal and an echo signal.

The principle of operation of an echo canceller is to estimate the transmission characteristic of an echo path using a received signal and an echo signal, form a pseudo-echo signal on the basis of the result of the estimation and subtract the pseudo-echo signal from a true echo signal, thereby cancelling the echo. The echo canceller basically is better than conventional echo suppressors but has a defect in that since it successively estimates the transmission characteristic of the echo path, a mis-estimation is likely to occur when the noise level of a signal or the like of a near-end talker is high relative to an echo signal level as in a case of double talking.

To avoid such a defect, there have been proposed a method using a double talking detector and a method which employs two echo path models, successively corrects only one of the models and sets, as a new echo path model, the model with a smaller error signal (Kazuo Ochiai, *et al*: "Echo Cancellor with Two Echo Path Models", IEEE Trans Vol. COM-25, No. 6, June 1977, pp. 589–595). The former is an application to an echo canceller of a device widely employed in echo suppressors, but the detector of this method is basically insufficient in sensitivity and poses a problem that a mis-estimation is already formed before double talking is detected. In contrast thereto, the latter exhibits a relatively excellent characteristics even in a case of double talking but has the drawback that it cannot follow up a gentle variation in the SN ratio.

An object of the present invention is to provide an echo control system which successively estimates circuit noise and a parameter error of an echo path model and successively changes a step gain α concerning the estimation of the model using the estimated values, thereby to permit echo cancellation not only during double talking but also when the SN ratio changes slowly.

According to the present invention there is provided an echo control system for an adaptive echo canceller which forms a pseudo-echo or its residual signal by combining respective outputs from a tapped delay line holding an estimated characteristic of an echo path as a tap weight and receiving a received signal or its residual signal as an input signal, subtracts the pseudo-echo or its residual signal from an echo signal or its residual signal, and corrects the tap weight using an amount of correction obtained by the resulting residual echo signal or its residual signal and the received signal or its residual signal, comprising a circuit noise estimation circuit for estimating circuit noise of the echo path, a parameter error estimation circuit for estimating a parameter error between the characteristic of the echo path and its estimated characteristic, and a coefficient calculator for determining a correction coefficient obtained with the circuit noise, the parameter error and the received signal, wherein the said tap weight is corrected in accordance with the result of multiplication of the amount of correction and the correction coefficient.

The system may be further provided with a device for transferring, as the said tap weight, the tap weight of the tapped delay line in the circuit noise estimation circuit when the circuit noise formed in the circuit noise estimation circuit is smaller than the residual echo signal.

Embodiments of the present invention will be described below, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram illustrating an embodiment of an echo canceller of the present invention; and

Figure 2 is a block diagram showing another embodiment of the present invention.

The principle of the invention will first be described.

Now, let an impulse response h(t) of an echo path and a received signal x(t) be respectively represented by

$$\mathbb{h} = (h_0, h_1, \ldots, h_{N-1})' \qquad (1)$$

$$\mathbb{x}_j = (x_j, x_{j-1}, \ldots, x_{j-(N-1)})' \qquad (2)$$

and let an estimated value of $\mathbb{h}$ at a moment jT be represented by

$$\hat{\mathbb{h}}_j = (\hat{h}_0, \hat{h}_1, \ldots, \hat{h}_{N-1})' \qquad (3)$$

in accordance with the learning identification method which is an identification algorithm usually employed in echo cancellers, the estimated value $\hat{\mathbb{h}}_{j+1}$ is given by

$$|\hat{h}_{j+1} = |\hat{h}_j + \alpha \frac{\mathbf{x}_j e_j}{\| \mathbf{x}_j \|^2} \qquad (4)$$

where α is a constant such that $0<\alpha<2$.

In a case in which circuit noise is negligible, a step gain $\alpha = 1$ provides the most excellent convergence characteristic but when the circuit noise is not negligible, the following step again α_j

$$\alpha_j = \frac{1}{1 + \dfrac{E[n_j^2]}{E[x_j^2]} \cdot \dfrac{1}{\| \Delta|h_j \|^2}} \qquad (5)$$

that is,

$$|\hat{h}_{j+1} = |\hat{h}_j + \alpha_j \frac{\mathbf{x}_j e_j}{\| \mathbf{x}_j \|^2} \qquad (6)$$

is optimum in almost all cases, where $E[x_j^2]$ is an expected value of x_j^2. $E[n_j^2]$ shows an expected value of the power of the circuit noise at the moment jT and a parameter error $\| \Delta|h_j \|^2$ is defined by $\| \Delta|h_j \|^2 = \| (|h - |\hat{h}_j) \|^2$.

Of the parameters in the expression (5), the input signal level x_j^2 is directly measureable but the circuit noise level n_j^2 and the parameter error $\| \Delta|h_j \|^2$ are not directly measurable and hence must be estimated.

Now, letting another estimated value $|t_j$ of the impulse response of the echo path be represented by

$$|t_j = (t_0, t_1, \ldots, t_{N-1}) \qquad (7)$$

an estimated value $\hat{n}_j^2$ of the circuit noise can be obtained by the following recurrence formula:

$$|t_{j+1} = |t_j + \frac{\mathbf{x}_j}{\| \mathbf{x}_j \|^2} (z_j - \mathbf{x}_j\, |t_j) \qquad (8)$$

where z_j is a value that a circuit noise n_j is super-imposed on an echo y_j, that is $z_j - y_j + n_j$.

Setting $\Delta|t_j\ \Delta|t_{j+1} - |t_j$,
it follows that

$$\Delta|t_j = \frac{\mathbf{x}_j}{\| \mathbf{x}_j \|^2} (z_j - \mathbf{x}'_j\, |t_j) \qquad (9)$$

obtaining expected values of squares of the both sides, if n_j and x_j are considered to be white noises and uncorrelated, it follows that

$$E[\, \| \Delta|t_j \|^2] = E[\frac{1}{\| \mathbf{x}_j \|^2} \Delta\omega'_j x_j x'_j \Delta\omega_j + n_j^2] \qquad (10)$$

where $\Delta\omega_j = |h - t_j$. Accordingly, for a sufficiently large value of j, it follows that

$$E[\, \| \Delta|t_j \|^2] = \frac{1}{2N} \cdot \frac{E[n_j^2]}{E[x_j^2]} \qquad (11)$$

Thus it is possible to estimate the magnitude of the circuit noise using the input signal x_j and the impulse response $|t_j$ of the echo path. Usually a voice signal is not regarded as white noise but it can easily be rendered into white noise by the methods proposed in Japanese Patent Applications Number 57129/78 "Echo Control System" and Number 165196/78 "Echo Control System" filed previously.

It is also possible to use, as an estimated value of circuit noise, a signal from an input terminal of the transmitting side instead of the above. In this case, the convergence characteristic is degraded as compared with that in the case of the above-described system but since a register for indicating $\mathbf{t}_j$ and a convolution calculation become unnecessary, this has the effect that the amount of hardware used is reduced.

The parameter error $\| \Delta \mathbf{h}_j \|^2$ can be estimated in the manner described below.

Now, let the impulse response characteristic $\mathbf{h}$ of the echo path be represented by

$$\mathbf{h} = (h_0, h_1, \ldots, h_N)' \qquad (12)$$

as described previously and let a function $\mathbf{h}^*$ be newly defined as follows:

$$\mathbf{h}^* = (0', \mathbf{h}')' = (0, \ldots, 0, h_0, \ldots, h_N)' \qquad (13)$$

On the other hand, as estimated value of the function $\mathbf{h}^*$ at the moment jT

$$\hat{\mathbf{h}}_j^* = (\hat{h}_{-M}, \ldots, \hat{h}_{-1}, \hat{h}_0, \ldots, \hat{h}_N)' = ({}^{(-)}\hat{\mathbf{h}}, \hat{\mathbf{h}})' \qquad (14)$$

is similarly given, according to the learning identification method which is an identification algorithm usually employed in echo cancellers, by

$$\hat{\mathbf{h}}_{j+1}^* + \hat{\mathbf{h}}_j^* + \alpha \frac{\mathbf{x}_j^* e_j}{\| \mathbf{x}_j^* \|^2} \qquad (15)$$

where α is an error correction coefficient but $0 < \alpha \leqq 1$, $\mathbf{x}_j^*(x_{j+M}, \ldots, x_{j+1}, x_j, x_{j-1}, \ldots x_{j-N})'$ and $e_j = y_j - \mathbf{x}_j^{*\prime} \hat{\mathbf{h}}_j^*$.

Setting approximate accuracies of the model in the time-lag and time-lead portions of the impulse response characteristic as follows:

$${}^{(+)}e_j^2 = \| \hat{\mathbf{h}}_j - \mathbf{h} \|^2 \qquad (16)$$

$${}^{(-)}e_j^2 = \| {}^{(-)}\hat{\mathbf{h}}_j - 0 \|^2 \qquad (17)$$

it follows that

$$\overline{{}^{(-)}e_{j+1}^2} \simeq \left(1 - \frac{2\alpha}{N} + \frac{\alpha^2(M+2)}{N(N+2)}\right) \overline{{}^{(-)}e_j^2} + \frac{\alpha^2 M}{N(N+2)} \overline{{}^{(+)}e_j^2} + \frac{M\alpha^2}{N} \overline{n^{*2}} \qquad (18)$$

and that

$$\overline{{}^{(+)}e_{j+1}^2} \simeq \left(1 - \frac{2\alpha}{N} + \frac{\alpha(M+2)}{N(N+2)}\right) \overline{{}^{(+)}e_j^2} + \frac{\alpha^2 M}{N(N+2)} \overline{{}^{(-)}e_j^2} + \frac{M\alpha^2}{N} \overline{n_j^{*2}} \qquad (19)$$

where

$$\overline{n_j^{*2}} = \overline{\left(\frac{n_j}{\| x_j \|^2}\right)^2}$$

A limit value is approximately given by

$$\lim_{j \to \infty} \overline{{}^{(+)}e_j^2} \simeq \frac{N}{M} \lim_{j \to \infty} \overline{{}^{(-)}e_j^2} \qquad (20)$$

Since $\overline{{}^{(-)}e_{j+1}^2}$ is as defined by the expression (17) and is measurable at all times, $\overline{{}^{(+)}e_{j+1}^2} = \| \mathbf{h}_{j+1} - \mathbf{h} \|^2$, that is, the magnitude of a parameter error can be estimated on the basis of the expression (20).

With the principles described above, it is possible to obtain an excellent cancellation characteristic by changing the step gain α_j on the basis of the estimated values of the circuit noise and the identification error not only during the overlap talking but also while the SN ratio undergoes gentle changes. Furthermore, as is evident from the expression (17), the present system is capable of following up gentle variations of the echo path as well. In a case where the echo path rapidly changes, however, the present system poses some problems in the follow-up characteristic. For the solution of them, there are two methods described below.

A first one of them is a method in which the value of the parameter error is selected to be constant, for example, in the range of 10^{-1} to 10^{-2} taking into account an echo loss of an ordinary echo path. With this method, the arrangement used is simple and a relatively excellent follow-up characteristic can be obtained but there is the defect that the convergence characteristic is degraded when the parameter error is large as in a case where the echo path is changed over. The other method is one in which a residual echo of the echo canceller proper and a residual echo of a circuit noise estimation circuit are compared with each other and, when the latter is larger than the former, the tap weight of a tapped delay line in the circuit noise estimation circuit is transferred as the tap weight of a tapped delay line of the echo canceller proper, thereby to correct values of parameters of an echo path model. With this method, the arrangement used becomes somewhat complex as compared with the arrangement for the above said method but even a sudden change as is caused by the change-over of the echo path can be followed up. This method is subject to the limitation that the measurement be made and the tap weight be transferred only at the time when the SN ratio is relatively good in the relation between the residual echoes and the near-end talker and that the tap weight be transferred. However, since the time during which the SN ratio is very poor as in the case of double talking is extremely short as compared with the double talking time, the above-said limitation scarcely presents a problem.

The above should provide the gist of the present invention.

With reference to the accompanying drawings, the present invention will hereinafter be described in more detail.

Fig. 1 is a block diagram illustrating the arrangement of an embodiment of the echo canceller using the present invention. In the Figure, an echo canceller 1 comprises an input terminal 2 of a receiving side; an output terminal 3 of a transmitting side; an output terminal 4 of the receiving side; an input terminal 5 of the transmitting side; a register 6; a convolution calculator 7; a register 8; a corrector 9; a subtractor 10; a coefficient calculator 11; a circuit noise estimation circuit 12; a parameter error estimation circuit 13; to a subtractor 14; a convolution calculator 15; a register 16; a corrector 17; a gate 18; a counter 19 and a square integrator 20. For convenience of description, let it be assumed that signals are digitized ones in the echo canceller 1 and, though not shown in Fig. 1, clock pulses are supplied to respective parts of the echo canceller.

A description will now be given of the operation of the echo canceller. A received signal x_j supplied from the input terminal 2 of the receiving side to the output terminal 4 of the receiving side but a portion of the received signal is returned as an echo y_j to the input terminal 5 of the transmitting side. In the echo canceller 1, the signal x_j is applied to the register 6. The received signal x_j from the register 6 is applied to the convolution calculator 7, in which it is subjected to a convolution calculation with an estimated value of an impulse response in the register 8, and the calculation result is transferred as a pseudo-echo signal $\hat{y}_j$ to the subtractor 10. In the subtractor 10, a residual echo signal e_j, which is a difference signal between the echo signal y_j from the input terminal 5 of the transmitting side and the pseudo-echo signal $\hat{y}_j$, is formed and the residual echo signal is transferred to the output terminal 3 of the transmitting side and the corrector 9. In the corrector 9, a new estimated value $|\hat{h}_{j+1}$ is formed according to the expression (6) using the signal x_j which is transferred from the register 6, a coefficient α_j which is transferred from the coefficient calculator 11 and the residual echo e_j, and the estimated value thus obtained is transferred to the register 8. In this case, the coefficient calculator 11 determines the coefficient α_j according to the expression (5) using an estimated noise n_j which is transferred from the circuit noise estimation circuit 12 and a parameter error $\| \Delta|h_j \|^2$ which is transferred from the parameter error estimation circuit 13.

Next, a detailed description will be given of the circuit noise estimation circuit 12 and the parameter error estimation circuit 13. In the circuit noise estimation circuit 12, the signal x_j which is transferred from the register 6 is subjected to a convolution calculation with a signal from the register 16 in the convolution calculator 15, and the calculation result is transferred to the subtractor 14. In the subtractor 14 a difference signal between the output from the convolution calculator 15 and the signal from the input terminal 5 of the transmitting side is produced, and the difference signal is transferred to the coefficient calculator 11 and the corrector 17. In the corrector 17 a new estimated value $|t_{j+1}$ is formed according to the expression (8) using the signal from the register 6 and the difference signal from the subtractor 14.

In the parameter error estimation circuit the gate 18 is opened and closed in accordance with the counting state of the counter 19, by which only a predetermined portion of a signal transferred from the register 8 is transferred to the square integrator 20. The square integrator

20 integrates the square of the signal transferred from the gate 18 and a value which is obtained by multiplying the integration result by

$$\frac{N}{M}$$

according to the expression (20) is transferred as a parameter error to the coefficient calculator 11. Thereafter the value in the square integrator 20 is reset in accordance with the signal from the counter 19.

In a case in which a fixed value is selected as the identification error, it is a matter of course that the signal from the parameter error estimation circuit 13 to the coefficient calculator 11 is set to a fixed value.

Fig. 2 illustrates another embodiment of the present invention. In Fig. 2 the same reference numerals as those in Fig. 1 indicate the parts having the same functions as in Fig. 1. Reference numeral 21 designates a comparator and 22 identifies a switching circuit. The illustrated embodiment will hereinbelow be described in detail. Since the embodiment of Fig. 2 is almost identical in construction with the embodiment of Fig. 1, a description will be given only of the differences between them for the sake of brevity. The power of the difference signal n_j from the subtractor 14 in the circuit noise estimation circuit 12 and the power of the residual echo e_j are compared with each other by the comparator 21 and when the value obtained by dividing the power of the residual echo e_j by the power of the difference signal is larger than a predetermined value, the comparator 21 changes over the switching circuit 22 to transfer the signal from the corrector 17 to the register 8 instead of the signal from the corrector 9. Compared with the embodiment of Fig. 1, the embodiment of Fig. 2 is free from the defect of the former in that an error in the estimation of the parameter error at the start of convergence becomes very large to decrease the convergence rate; the amount of hardware used increases a little but the overall characteristics are improved as compared with those of the embodiment of Fig. 1.

The embodiment of Fig. 2 adopts the system that transfers the content of the register 16 in the circuit noise estimation circuit 12 when the error in the estimation of the parameter error has become large. It is also possible, however, to employ such a system in which when the estimation error has become large, the coefficient value from the coefficient determining circuit 11 is set to a predetermined value, for example, "1", thereby to increase the convergence rate.

Furthermore, the embodiment of Fig. 2 employs the system of comparing a residual echo signal with a residual echo signal in the circuit noise estimation circuit 12 for the detection of a large error in the estimation of the parameter error. It is also possible, however, to adopt such a system in which the product of an estimated value

$$\overline{\frac{N}{M}{}^{(-)}e_j^2}$$

of the parameter error and the power $\|\mathbf{x}_j\|^2$ of a received signal is compared with the residual echo signal and when $\|\Delta h\|^2 \cdot \|\mathbf{x}_j\|^2$ is smaller than the residual echo signal, the coefficient value from the coefficient determining circuit is set to a predetermined value, for example, "1". The principle of this system is considered as described below.

Assuming that the received signal x_j is white noise, the power of the residual echo signal e_j is regarded as follows:

$$e_j^2 = \|\Delta h_j\|^2 \|\mathbf{x}_j\|^2$$

Accordingly, if the value of

$$\overline{\frac{N}{M}}{}^{(-)}e_j^2 \|\mathbf{x}_j\|^2$$

is appreciably smaller than e_j^2, then an error in the estimation of $\overline{{}^{(-)}e_{j2}}$ may be considered large.

Moreover, if the present invention is combined with means for whitening the received signal by linear prediction as referred to previously, then the accuracy of the estimation of the circuit noise is enhanced to improve the convergence characteristic and the amount of cancellation, as compared with the case of using the voice signal itself.

It is possible, of course, to apply to the two embodiments described in the foregoing techniques by which the sums of the estimated circuit noise n_j^2, the power of the residual echo e_j

and the power of the difference signal to be compared by the comparator 21 are each obtained over a predetermined number thereby to smooth an abrupt change which would occur when they take individual values.

The present invention provides an echo control system which is capable of performing its function even in the case of double talking and in the case of the SN ratio gently changing and which exhibits an excellent cancellation characteristic with simple control. Although the foregoing embodiments have been described in connection with the case of using the received signal x_j itself as an input signal to the echo path model of the echo canceller, the present invention is applicable to the case of employing, instead of the received signal x_j, a residual signal $\tilde{x}_j$ of the received signal as the input signal to the echo path model of the echo canceller, as described in the aforesaid prior applications, Japanese Patent Applications Number 57129/78 "Echo Control System" and Number 165196/78 "Echo Control System"; and in such a case, the accuracy of the estimated value of the circuit noise is raised, resulting in the convergence characteristic and the amount of cancellation being improved, as described previously. In this case, the residual signal of the received signal is employed in place of the received signal as mentioned above and use is made of residual signals of the echo signal and the residual echo signal instead of them.

CLAIMS

1. An echo control system for an adaptive echo canceller which forms a pseudo-echo or its residual signal by combining respective outputs from a tapped delay line holding an estimated characteristic of an echo path as a tap weight and receiving a received signal or its residual signal as an input signal, subtracts the pseudo-echo or its residual signal from an echo signal or its residual signal, and corrects the tap weight using an amount of correction obtained by the resulting residual echo signal or its residual signal and the received signal or its residual signal, comprising a circuit noise estimation circuit for estimating circuit noise of the echo path, a parameter error estimation circuit for estimating a parameter error between the characteristic of the echo path and its estimated characteristic, and a coefficient calculator for determining a correction coefficient obtained with the circuit noise, the parameter error and the received signal, wherein the said tap weight is corrected in accordance with the result of multiplication of the amount of correction and the correction coefficient.

2. An echo control system for an adaptive echo canceller which forms a pseudo-echo or its residual signal by combining respective outputs from a tapped delay line holding an estimated characteristic of an echo path as a tap weight and receiving a received signal or its residual signal as an input signal, subtracts the pseudo-echo or its residual signal from an echo signal or its residual signal, and corrects the tap weight using an amount of correction obtained by the resulting residual echo signal or its residual signal and the received signal or its residual signal, comprising a circuit noise estimation circuit for estimating circuit noise of the echo path, a parameter error estimation circuit for estimating a parameter error between the characteristic of the echo path and its estimated characteristic, a coefficient calculator for determining a correction coefficient obtained with the circuit noise, the parameter error and the received signal, and a device for transferring, as the said tap weight, the tap weight of the tapped delay line in the circuit noise estimation circuit when the circuit noise formed in the circuit noise estimation circuit is smaller than the residual echo signal, wherein the said tap weight is corrected in accordance with the result of multiplication of the amount of correction and the correction coefficient.

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