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Subband Echo Canceller with an Exponentially Weighted Step Size NLMS Adaptive Filter

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This paper proposes a new adaptive algorithm for subband echo cancellers with double the convergence speed at almost the same computational load as the conventional normalized LMS (NLMS). This algorithm, called the subband ES (exponentially weighted step size) algorithm, implements a different step size (feedback constant) for each weight of an adaptive transversal filter, and these step sizes are different in each subband. The step sizes in each subband are time-invariant and weighted proportional to the expected variation of a room impulse response in the subband.

This algorithm is based on the fact that the expected variation of a room impulse response becomes progressively smaller along the series by the same exponential ratio as the impulse response energy decay [1], and that the exponential attenuation ratio is different in different subbands. As a result, the algorithm adjusts coefficients with large errors in large steps and coefficients with small errors in small steps.

A transition formula is derived for the mean-square coefficient error of the proposed algorithm. The mean step size in each subband determines the convergence condition and the final excess mean-square error. By modifying this algorithm, it requires almost the same amount of computation as the conventional NLMS. Computer simulations demonstrate the fast convergence of the proposed algorithm.

Reference

[1] S. Makino and Y. Kaneda, "Acoustic Echo Canceller Algorithm Based on the Variation Characteristics of a Room Impulse Response," *Proc. ICASSP90*, pp.1133-1136, 1990.

SUBBAND ECHO CANCELLER WITH AN EXPONENTIALLY WEIGHTED STEP SIZE NLMS ADAPTIVE FILTER

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1. ABSTRACT

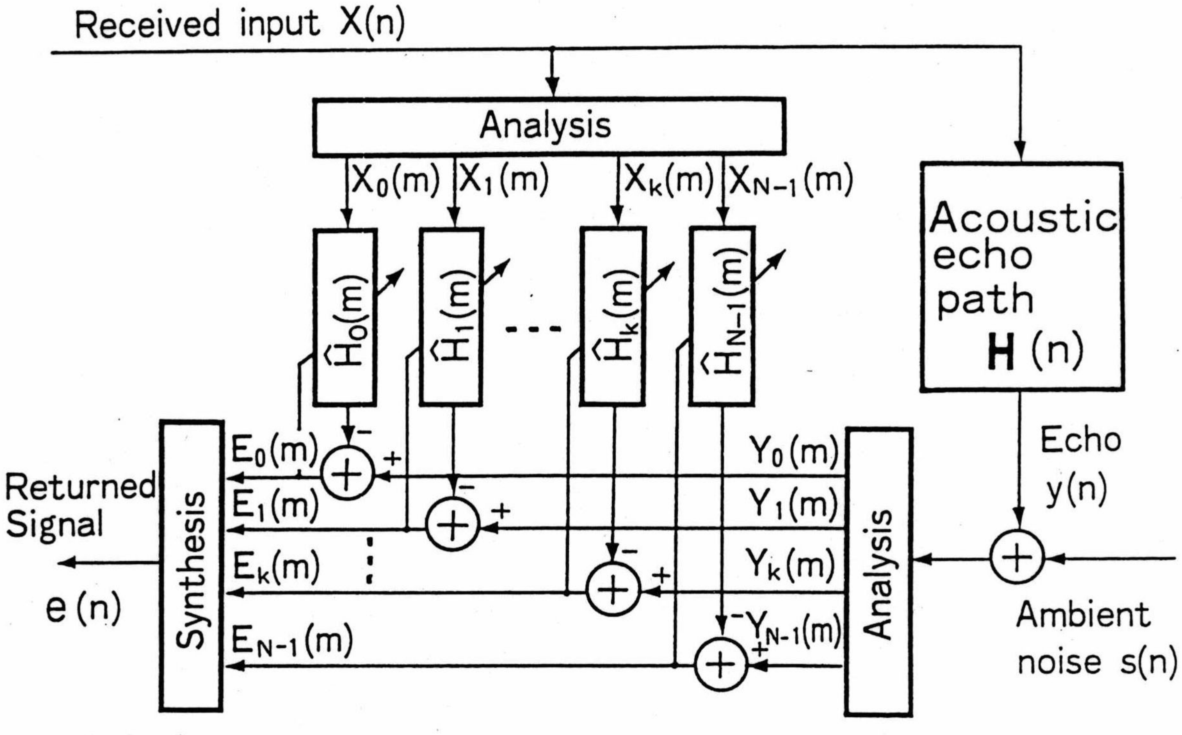
This paper proposes a new adaptive algorithm for subband echo cancellers with double the convergence speed at almost the same computational load as the complex normalized LMS (CNLMS). This new algorithm uses a different step size for each weight of an adaptive transversal filter, and these step sizes are time-invariant and weighted proportional to the expected variation of a room impulse response [1] in each subband. Computer simulations demonstrate the fast convergence of the proposed algorithm.

Reference

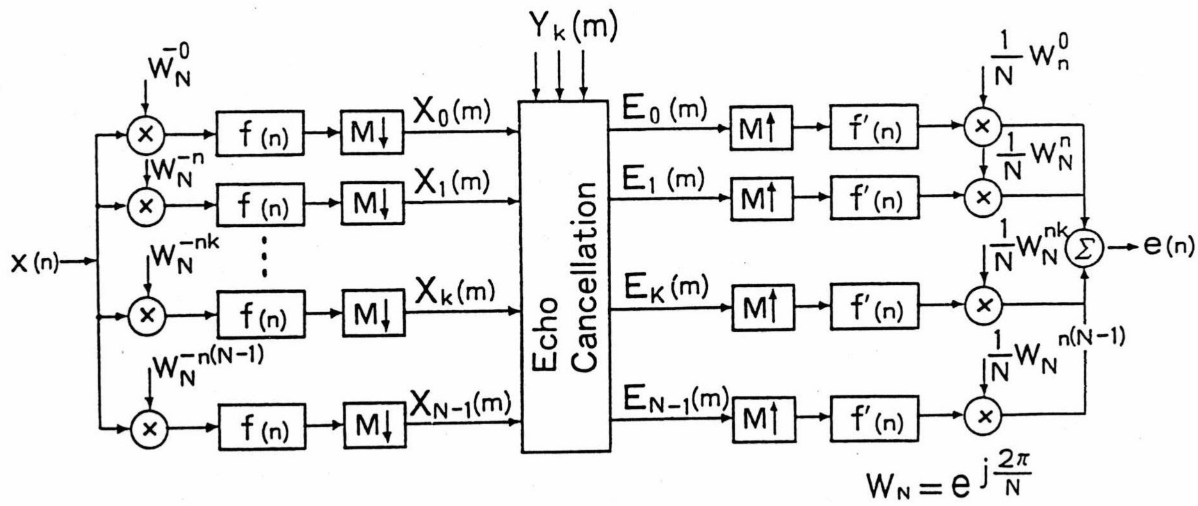
[1] S. Makino and Y. Kaneda, Proc. ICASSP90, pp.1133-1136, 1990.

2. SUBBAND ECHO CANCELLERS AND CONVENTIONAL ALGORITHM

2.1 Configuration of a Subband Echo Canceller



- **Signals are analyzed into N subbands.**
- **Echoes are independently cancelled in each subband.**



- Polyphase filter bank is used.
- Subband signals are down sampled by M.
- $X_k(m)$, $Y_k(m)$, $E_k(m)$, and $\hat{H}_k(m)$ are complex.

Advantages

- Parallel processing at reduced sampling rate helps computational complexity.
- Decomposition of the received input signal results in fast convergence.

Disadvantages

- Delay due to subband processing.
- Complicated structure.

2.2 Conventional CNLMS Adaptive Algorithm (in subband k)

$$\hat{\mathbf{H}}_k(m+1) = \hat{\mathbf{H}}_k(m) + \alpha \frac{E_k(m)}{\mathbf{X}_k(m)^T \mathbf{X}_k(m)^*} \mathbf{X}_k(m)^* \qquad (1)$$

where

$\hat{\mathbf{H}}_k(m) = [\hat{H}_{k1}(m), \hat{H}_{k2}(m), \cdots, \hat{H}_{kL}(m)]^T$,

$\hat{H}_{ki}(m)(i = 1, \cdots, L)$: coefficients of an FIR filter in subband k,

L: filter order in subband k,

α: scalar step size in subband k ($|1-\alpha| < 1$),

$E_k(m) = Y_k(m) - \hat{Y}_k(m)$: residual echo in subband k,

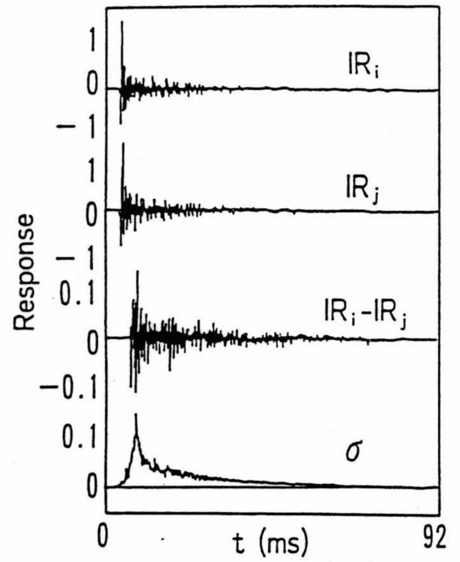
$\mathbf{X}_k(m) = [x_k(m), x_k(m-1), \cdots, x_k(m-L+1)]^T$: received input vector in subband k,

*: complex conjugate.

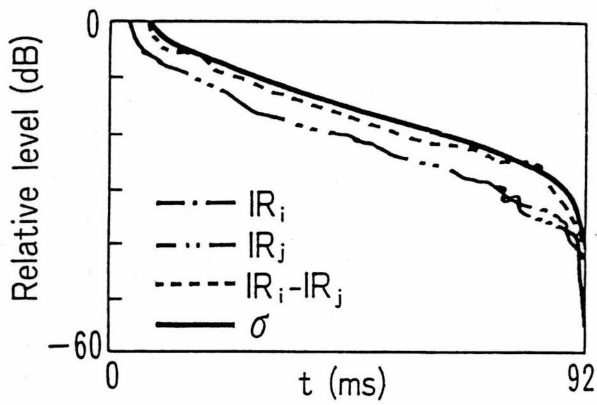
- **In the conventional CNLMS, convergence speed is fastest at α=1.**

3. NEW ADAPTIVE ALGORITHM

3.1 Variation of a Room Impulse Response



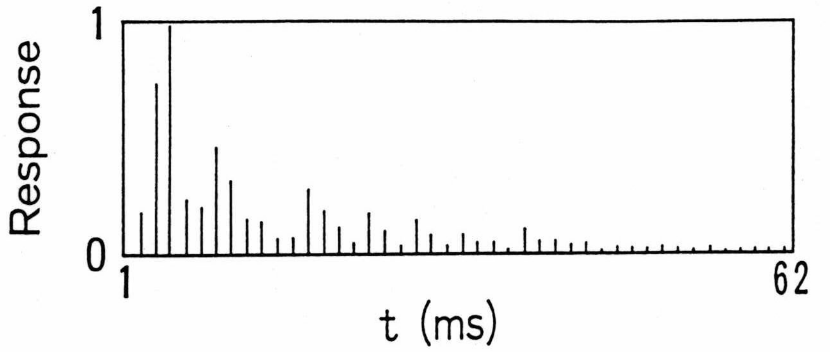
(a) Impulse responses and their variation



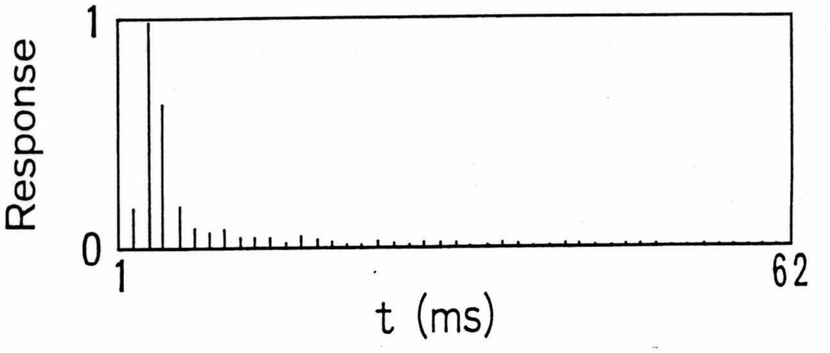
(b) Reverberent energy decay curves

• **IR_i and IR_j are impulse responses. σ is the standard deviation of the variation ($\mathrm{IR}_i - \mathrm{IR}_j$) ($i, j$=1,$\cdots$, 21) of the impulse response.**

Impulse responses attenuate exponentially, and the expected variation of the impulse response attenuates by the same exponential ratio.



(a) 250-750 Hz subband



(b) 2350-3750 Hz subband

The exponential attenuation ratio is different in different subbands.

• **The expected error in each coefficient,** *i.e.* $H_k(m) - \hat{H}_k(m)$ **becomes progressively smaller along the series by the same exponential ratio as the impulse response in each subband.**

⇓

We propose to update coefficients that have large errors in large steps, and coefficients with small errors in small steps in each subband.

3.2 Subband ES (Exponentially Weighted Step Size) Algorithm (in subband k)

$$\hat{\mathbf{H}}_k(m+1) = \hat{\mathbf{H}}_k(m) + \mathbf{A}_k \frac{E_k(m)}{\mathbf{X}_k(m)^T \mathbf{X}_k(m)^*} \mathbf{X}_k(m)^* \quad (2)$$

where

$$\mathbf{A}_k = \begin{pmatrix} \alpha_{k1} & & & 0 \\ & \alpha_{k2} & & \\ & & \ddots & \\ 0 & & & \alpha_{kL} \end{pmatrix} \quad (3)$$

and

$\alpha_{ki} = \alpha_{k0}\gamma_k^{i-1} (i = 1, \cdots, L)$,

$\gamma_k = \exp(-6.9 T_S / T_{Rk})$ is the exponential attenuation ratio in subband k,

T_S: sampling interval,

T_{Rk}: reverberation time in subband k.

Elements α_{ki} decrease in value exponentially from α_{k1} to α_{kL} with the same exponential ratio as the room impulse response variation in the subband.

⇕

The statistics of the room impulse response variation in each subband is reflected in the echo canceller.

4. DISCUSSION

4.1 Optimum Formula for α_{ki}

$$\alpha_{ki} = \frac{L\, b_{ki}(m)^2}{\Sigma_{j=1}^{L} b_{kj}(m)^2} \quad (i = 1, \cdots, L) \tag{4}$$

where

$$b_{ki}(m)^2 = E[\{\mathbf{H}_{ki}(0) - \hat{\mathbf{H}}_{ki}(m)\}^2].$$

4.2 Time Invariant Step Size

$$\alpha_{ki} \propto b_{ki}(0)^1 \quad (i = 1, \cdots, L). \tag{5}$$

4.3 Convergence Condition

$$0 < \bar{\alpha}_k = \frac{1}{L} \sum_{i=1}^{L} \alpha_{ki} < 2. \tag{6}$$

4.4 Steady-state ERLE

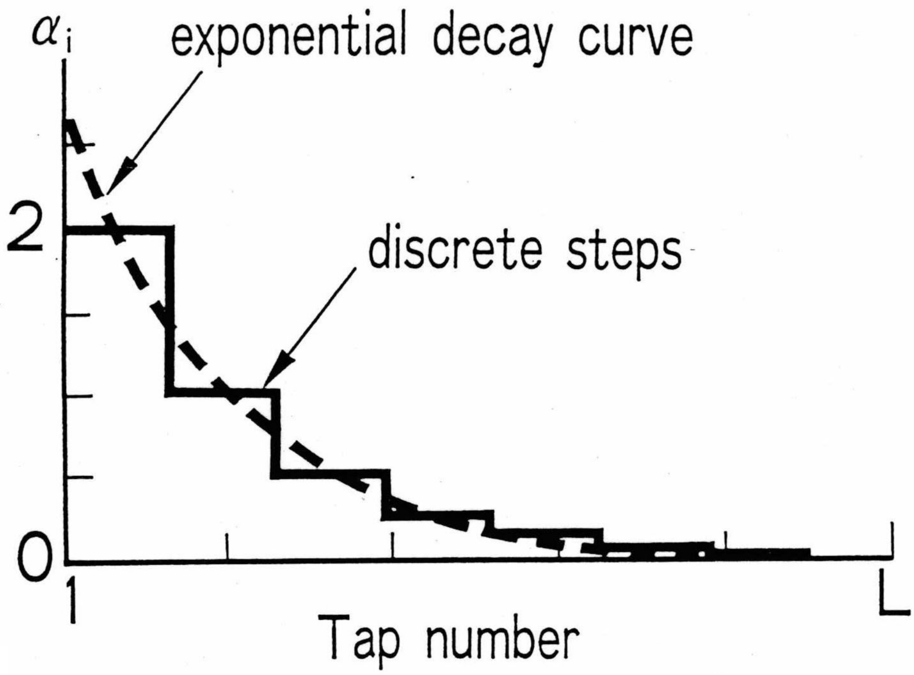
$$\mathrm{ERLE}_{k\infty} = \mathrm{SNR}_k + 10\, log(\frac{2}{\bar{\alpha}_k} - 1)(dB). \tag{7}$$

Details are given in reference [1].

5. PRACTICAL MODIFICATION

- $$0 < \alpha_{ki} < 2 \quad (i = 1, \cdots, L) \quad \text{for speech input.} \tag{8}$$

- **The exponential decay curve is approximated stepwise, and step size α_{ki} is set in discrete steps.**



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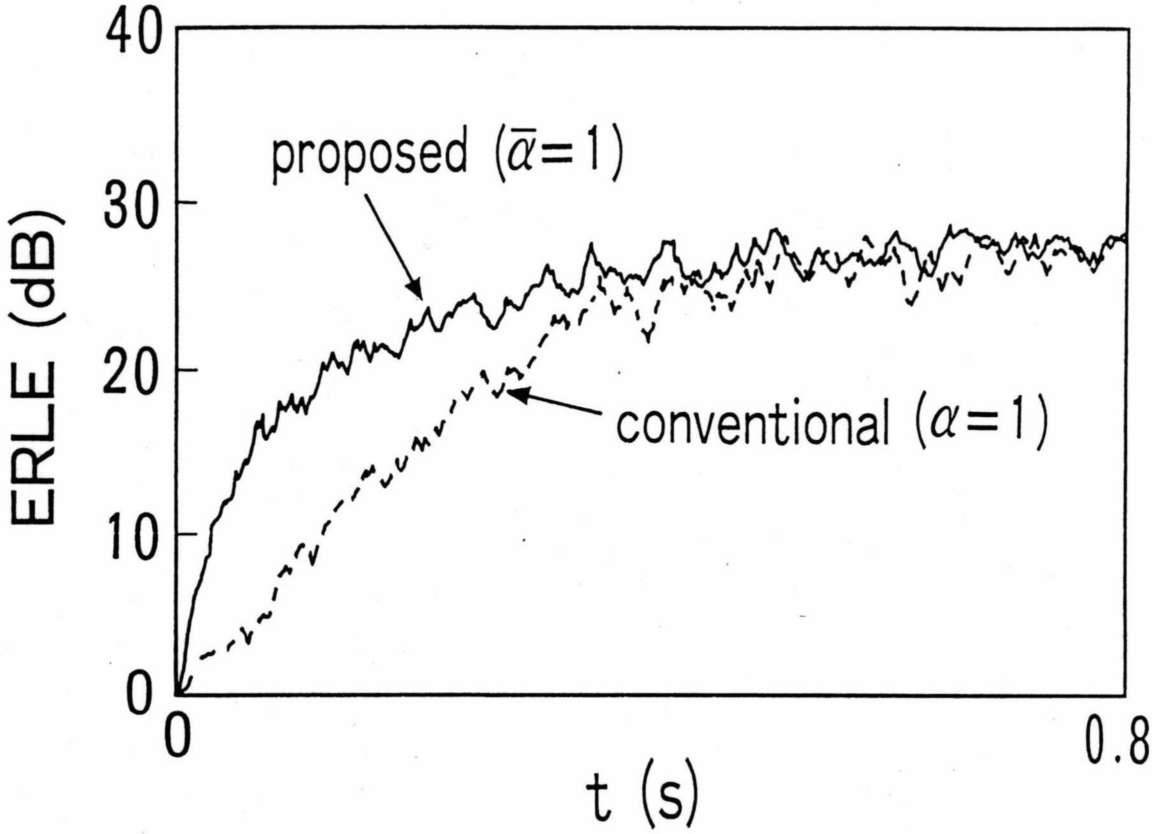
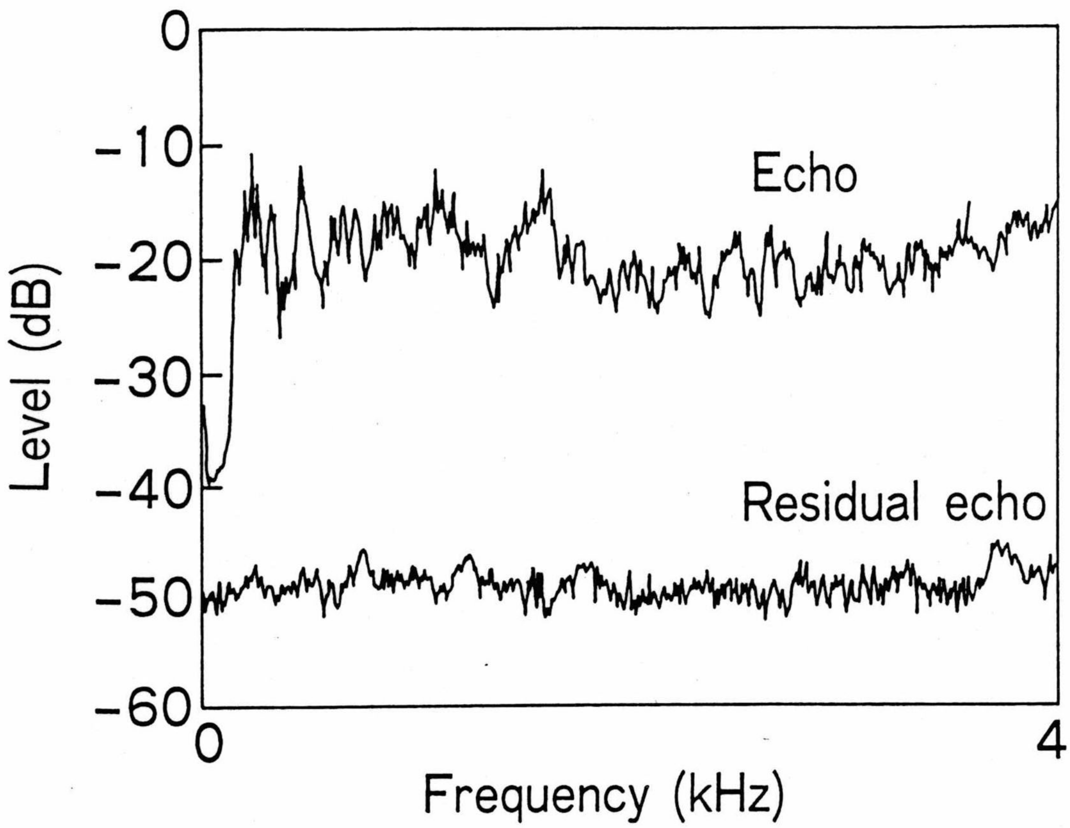
- **This modification allows the proposed algorithm to have almost the same computational load as the CNLMS.**

6. COMPUTER SIMULATION



- **The proposed algorithm converges twice as fast as the CNLMS.**



• **The steady-state ERLE was about 30 dB in the 4-kHz frequency range.**

Simulation conditions

- **total order of the impulse response: 516 taps,**
- **sampling frequency fs=8 kHz,**
- **number of subbands N=16,**
- **down sampling rate M=12,**
- **received input signal: white noise,**
- **SNR=30 dB,**
- α**=1 (CNLMS),**
- $\bar{\alpha}_k$**=1 (proposed).**

7. CONCLUSIONS

• A new adaptive algorithm based on the statistics of a room impulse response variation in each subband is proposed for subband echo cancellers.

• This algorithm has double the convergence speed at almost the same computational load as the conventional CNLMS.