An Implementation of Superior Noise-Robust Step-Size Lattice Structure for Echo Cancellation

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Abstract

The used of adaptive echo canceller is to estimate the impulse response of echo path and synthesizes an echo replica to subtracted from the echo in telephone network. Moreover, most echo paths change their characteristics frequently according to the noisy environment. A number of time-varying of output signal autocorrelation and energy of output control adaptation step-size algorithm is proposed. The goal is to enhance the performance of adaptive filter algorithm. The propose present in Lattice structure because of an excellent structure improve convergence speed. In this paper is improve high performance when compare with LTJ structure [2]. The stability had improved by Echo Return Loss Enhancement (ERLE).

1. Introduction

Disturbing phenomenon by impedance mismatch at hybrids in telephone networks is the occurrence of unavoidable echoes. This echoes may disturb the speaker and the long distance calls the energy of the echo may largely exceed the energy of the subscriber's signal that impaired speed quality. Adaptive filtering algorithms were proposed as solution to the echo problem. The International Telecommunication Union (ITU) has developed a new minimum performance standard for echo canceller (Recommendation G.168: - Digital Network Echo Cancellers) [6]. It is desirable to use echo characteristics such as echo return loss.

The adaptive Least Mean Square (LMS) algorithm is the popular technique for adaptive filtering due to its simplicity and numerical robustness. However, it suffers from the slow convergence since the echo path is usually very long and the speech signals are non-stationary and highly correlated and a large number of filter coefficient are needed. The adaptive lattice filter structure allows fast convergence due to its orthogonalization nature between the backward prediction errors but it require much more computational comparing to LMS algorithm and the Lattice/Transversal Joint structure. The new Lattice/Transversal Joint (LTJ) structure allows less computational complexity and nearly as fast convergence as lattice filter but it has large number of coefficient to provide the fast tracking capability and high performance.

This paper proposed a new noise-robust adaptive step-size algorithm perform in Lattice form structure which takes non-stationary of speech signals into account. Controls of the step-size based on the autocorrelation of the present output signal and the past one and the energy of the output control adaptation speed. We compare this propose with the new LTJ structure and had observed that the propose given the high convergence rate, high performance , small number of adaptation coefficient to improve highly correlation input signal and flexible control of misadjustment of adaptation in noise disturbance.

2. The adaptive echo canceller structure

Consider the adaptive echo canceller described in [1], where *X(n)* and *V(n)* represent the far-end signal and near-end speech signal, respectively. Also *d(n), c(n)* and $\hat{y}(n)$ denote the received input signal to the echo canceller, background noise, and the estimated echo signal. There can be described as

$$\hat{y}(n) = W^T(n)X(n) \tag{1}$$

$$E(n) = d(n) - \hat{y}(n) \tag{2}$$

$$d(n) = V(n) + y(n) + c(n) \tag{3}$$

Where *X(n)* represent the input vector and the filter coefficient vector of the echo canceller defined as

$$X(n) = [x(n) \quad x(n-1)......x(n-L+1)]^T \tag{4}$$

$$W(n) = [w_0(n) \quad w_1(n)......w_{L-1}(n)]^T \tag{5}$$

3. Lattice/Transversal Joint (LTJ) Structure

It is know that the convergence of adaptive filter can be improved when the lattice filter structure is used. A relatively of the backward prediction errors are gradually orthogonalized to each other form one stage to the next. Let *B(n)* is expressed as

$$B(n) = [b_0(n), b_1(n), ..., b_{L-1}(n)] \tag{6}$$

The transformation of the input signal vector to the backward prediction errors can be written in a matrix form as

$$B(n) = HX(n) \tag{7}$$

where the transformation matrix H is the $L\times L$ matrix given by

$$H=\begin{bmatrix} 1 & 0 & 0 & \cdots\cdots & 0 \\ a_1(1) & 1 & 0 & \cdots\cdots & 0 \\ a_2(2) & a_2(1) & 1 & \cdots\cdots & 0 \\ \vdots & \vdots & \vdots & \cdots\cdots & \vdots \\ \vdots & \vdots & \vdots & \cdots\cdots & \vdots \\ a_{L-1}(L-1) & a_{L-1}(L-2) & a_{L-1}(L-3) & \cdots\cdots & 1 \end{bmatrix} \tag{8}$$

The matrix H is a lower triangular matrix and its component $a_i(j)$ $(j \le i)$ is the *j-th* transversal filter coefficient corresponding to the forward prediction filter of order i. Therefore, we have

$$a_{P+k}(i) = \begin{cases} a_P(i) & 1 \le i \le P \\ 0 & P+1 \le i \le P+k \end{cases} \tag{9}$$
$$1 \le k \le L-P-1$$

The LTJ structure is used to eliminate the delays reflection of the backward prediction errors at stage P for *P-th* order of the adaptive lattice filter structure thus it can be considered near the white noise. Therefore, it is quite reasonable to append the computationally more efficient transversal filter structure jointly after the *P-th* stage of the lattice filter. By using the backward prediction $b_P(n)$ at stage P as input to the transversal filter. The LTJ structure update equation is tabulated in Table 1. In general the order P does not exceed more than 16.

4. The Noise-Robust Step-Size Algorithm Lattice Form structure

The modular Lattice structure is very useful to vary filter and easily to consider its stabilization and in this paper we uses the lattice structure. The variable step-size algorithm is useful that when the filter coefficient are close to the optimum solution a small step-size is used to achieve a low level of misadjustment and using large step-size when the solution is far from the optimum but the performance of variable step-size algorithm is quite sensitive to the noise disturbance in the low signal to noise ratio *(SNR)* environment. The new noise-robust step-size algorithm has solve this problem. It is using an estimate of the autocorrelation between the present output signal $y(n)$ and the past one $y(n-1)$ and uses the energy of the output signal to control the adaptation speed. Based on this algorithm it provided fast convergence speed and high performance when signal to noise ratio is still low level.

In this section we describes the adaptive lattice notch filter structure attempt to adjust coefficient $\hat{k}_0$. We

Table. 1

Update equation of the LTJ structure (Filtering)
$b_0(n) = f_0(n) = x(n)$
$d_0(n) = d(n)$
$f_i(n) = f_{i-1}(n) + k_i(n)b_{i-1}(n-1) \quad (1 \le i \le P)$
$b_i(n) = b_{i-1}(n-1) + k_i(n)f_{i-1}(n) \quad (1 \le i \le P)$
$b_i(n) = b_{i-1}(n-1) \qquad (P+1 \le i \le L)$
$d_i(n) = d_{i-1}(n) - w_{i-1}(n)b_{i-1}(n) \quad (1 \le i \le P)$
$e(n) = d_p(n) - \sum_{i=P}^{i=L} w_i(n)b_i(n)$
Updation
$k_i(n+1) = k_i(n) + \frac{(1-\beta)}{S_i(n)}(b_i(n)f_{i-1}(n)$
$+ b_{i-1}(n-1)f_i(n) \qquad for \quad (1 \le i \le P)$
$S_i(n) = \beta S_i(n-1) + (1-\beta)(f_{i-1}^2(n) + b_{i-1}^2(n-1))$
$for \quad (1 \le i \le P)$
$w_i(n+1) = w_i(n) + \frac{(1-\beta)}{t_i(n)}(d_{i-1}(n)b_i(n))$
$for\,(0 \le i \le P-1)$
$w_i(n+1) = w_i(n) + \frac{(1-\beta)}{t_p(n)}(e(n)b_i(n))$
$for \quad (P \le i \le L)$
$t_i(n) = \beta t_i(n-1) + (1-\beta)(b_i^2(n))$
$for \quad (0 \le i \le P)$

assume linearity of a finite duration *(n)* of the echo impulse response path with discrete values $\hat{k}_0$. If the echo-path impulse response with length of n samples Eq. (9) containing the noise $c(n)$ are $x(n)$ and the estimate echo are $\hat{y}(n)$ all can be expressed as

$$Echo \quad path = \sum_{i=0}^{n} R_i \exp[-\frac{(i+1)}{880}]\delta(n-i) \tag{9}$$

Where n is the numbers of samples and R_i is a random justify number with in –2, +2 and $\delta(n)$ is the Dirac function

$$\begin{aligned} \hat{y}(n) &= u(n) + 2\hat{k}_0(n)u(n-1) + u(n-2) \\ u(n) &= x(n) - \hat{k}_0(n)(1+\rho)u(n-1) - \rho u(n-2) \end{aligned} \tag{10}$$

Using the Prediction Error (PE)[5] to adjust k_0 to reduce least mean p-power at lowest output can be define as

$$J(k_0) = \tfrac{1}{N}\sum_{n=1}^{N}\left|y(n)\right|^{p} \tag{11}$$

Eq.(11) is called cost function where N is the number of data and p = 1, 2, .. , From Recursive PE [5] assume k_0 make the cost function has lowest value using steepest decent algorithm, k_0 can be define as

$$k_0(n+1) = k_0(n) - \mu \frac{\partial \left| y(n)^p \right|}{\partial k_0(n)} \quad (12)$$

From Eq. (12) we changed k_0 to $\hat{k}_0$ this value is given from recursion with transient value in Eq. (11), μ is step-size parameter by chosen p value equal to unity and quantization the second term of Eq. (12) that express as :

$$\hat{k}_0(n+1) = \hat{k}_0(n) - \mu \operatorname{sgn} \left\{ \frac{\partial \left| y(n) \right|}{\partial \hat{k}_0(n)} \right\} \quad (13)$$

where

$$\left| y(n) \right| = \operatorname{sgn}\{y(n)\} y(n) \quad (14)$$

Substituting Eq. (14) into Eq. (13), we get

$$\hat{k}_0(n+1) = \hat{k}_0(n) - \mu \operatorname{sgn} \left\{ \operatorname{sgn}[\, y(n)] \frac{\partial y(n)}{\partial \hat{k}_0(n)} \right\} \quad (15)$$

and

$$\frac{\partial y(n)}{\partial \hat{k}_0(n)} \approx 2u(n-1) \quad (16)$$

From Eq. (15), we can not define the region of step-size value because Eq. (11) is nonlinear function, so we used trial and error to define step-size vary in time domain. The uses of step-size $\mu(n)$ serves two objectives. First, the fast convergence speed of the update $\mu(n)$ that we used the energy of the output to control the adaptation express as:

$$p(n) = \sigma p(n-1) + (1-\sigma) y^2(n) \quad (17)$$

At the beginning $p^2(n)$ has highest value that made $\mu(n)$ has highest value and fast convergence. After convergence $p^2(n)$ has lowest value made $\mu(n)$ has lowest value too. Second, to rejects the effect of uncorrelated noise sequence on the step-size update to ensuring low misadjustment that large $\mu(n)$ performs when the solution is far from the optimum and step update $\mu(n)$ decreasing as we approach the optimum even in the presence noise. The estimate in the time-varying of the autocorrelation $y(n) \cdot y(n-1)$ that is described as

$$g(n) = \lambda g(n-1) + (1-\lambda) y(n) \cdot y(n-1) \quad (18)$$

$g(n)$ gives the update $\mu(n)$ depend on how far from the optimum and is not effect by independent disturbance noise. We express the equation for varying step-size as

$$\mu(n+1) = \alpha \mu(n) + \gamma p^2(n) g^2(n) \quad (19)$$

Substituting Eq. (19) into Eq. (15), we get

$$\hat{k}_0(n+1) = \hat{k}_0(n) - \mu(n) \operatorname{sgn} \left\{ \operatorname{sgn}[\, y(n)] \frac{\partial y(n)}{\partial \hat{k}_0(n)} \right\} \quad (20)$$

Where $\sigma, \alpha, \gamma, \lambda$ are constant in the range between 0 and 1. σ is an exponential weighting parameter or forgetting factor. This parameter is to define the coefficient to estimating.

where $\operatorname{sgn}(x) = x/|x|$

$\hat{k}_0(n)$: filter coefficient vector of adaptive filter structure at time n

$e(n)$: echo residue containing the noise $c(n)$

5. Performance Evaluation

The most common measure of adaptive echo canceller performance is Echo Return Loss Enhancement (ERLE)

$$ERLE(dB) = 10 \log_{10} \frac{E[x^2(n)]}{E[e^2(n)]} \quad (21)$$

6. Simulation Results

In this section, the performance of the propose filter structure is compared with Lattice/Transversal Joint (LTJ) structure applied to an echo cancellation. For fair comparison, convergence parameter are selected to equalize the steady state performance. Assume the parameters of the propose are given as $\hat{k}_0(0) = 0$, $p = 1$, $\rho = 0.99995$, $\mu(0) = 0.007$, $\sigma = 1$, $\alpha = 1, \gamma = 0.0000001$, $\lambda = 0.98$. For LTJ structure we assume the parameters is given as $\beta = 0.98, P = 2, L = 2$ and data range N=1000, iteration in 10 times. For the noisy environment the echo to background noise ratio is set to 70 *dB*. The simulation results of ERLE of two structures performance comparison is shows in Fig. 1. The proposed structure has convergence much faster than the LTJ structure and be implemented with a small numbers of coefficient and lower computational complexity.

The focus in this paper is noise robustness adaptive step-size which in low signal to noise ratio *(SNR)* of system input. From Fig. 2 is residual echo power comparison with proposed and the LTJ structure in low *SNR* and Fig. 3 shows residual echo power in *SNR = -10 dB* from the figure improve that the propose has low error.

In order to improve the performance of the echo canceller structure one way that is to improve the estimate echo path in the noisy environment that is the means of ERLE in the changed of *SNR*. We assume *SNR* in the ranges of -10 *dB* to 70 *dB*. From Fig. 4 shows that for the varieties of *SNR* the proposed structure is the excellent structure to improve the performance.

7. Conclusion

In this paper, the noise-robust variable step-size algorithm for lattice form structure is proposed. The proposed structure is excellent to achieve the fast convergence speed and low computational complexity, while it maintains a numbers of adaptive filter coefficient as small as the LTJ structure and the proposed structure provide a good stability of ERLE and noise-robustness provided the low misadjustment in compare with the LTJ structure.

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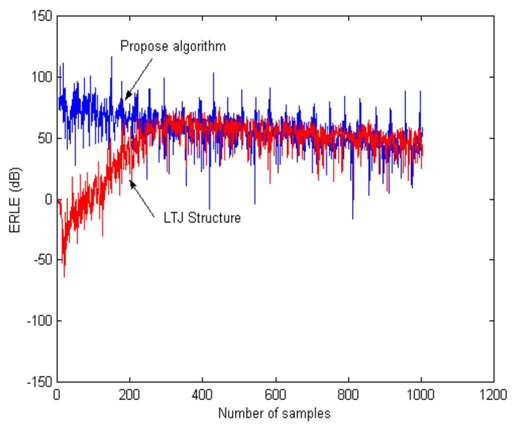

Fig. 1 ERLE (*SNR* = 70 dB)

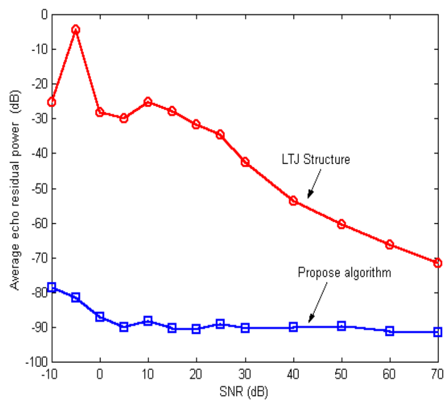

Fig. 2 Average residual echo power

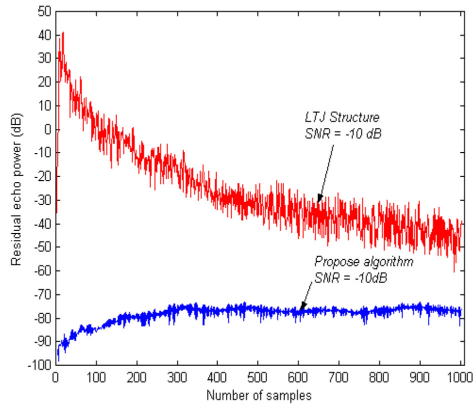

Fig. 3 Residual echo power (*SNR* =-10 dB)

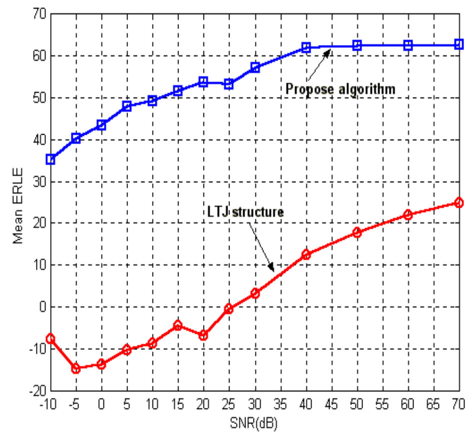

Fig. 4 Mean ERLE vs. *SNR*