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Method for Estimating Amount of Delay of Sparse Channel Based on Phase-Only Correlation

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Abstract: In this paper, we propose a method for estimating an amount of delay of a sparse system using phase-only correlation(POC). The performance of the normalized-least-mean-square(NLMS) algorithm is largely affected by sparse systems, namely its rate of convergence decreases. Although proportionate NLMS(PNLMS) was proposed to improve the performance when the unknown system is a sparse system, only the NLMS algorithm could be used to update the filter. Therefore its performance depends on the correlation of the input signal. By taking advantages of property of POC, we exploit the amount of delay of the sparse system without the effect of the correlation. Simulation results show that the proposed method could provide better estimation of the amount of delay compared to PNLMS when the input signal is correlated, such as speech signals

1. Introduction

Adaptive filters are often used for identifying sparse systems like acoustic echo path. To cancel the echo significantly using acoustic echo canceller, we must use long adaptive filters to model the echo path [1]. The normalized-least-mean-square(NLMS) algorithm is a very popular adaptive algorithm due to its simplicity. However, the performance of the NLMS is affected by a sparse system so that its rate of convergence decreases [1]. Proportionate NLMS (PNLMS) was proposed to improve the performance when sparse systems are to be identified [1]. Although it improves the convergence characteristics, its performance depends on the correlation of input signal. Moreover, it is a modified version of the NLMS algorithm, and we could not apply the idea of PNLMS to other adaptive algorithms such as the RLS algorithm.

In this paper, we propose a method for estimating the amount of delay, or the location of non-zero coefficients, of a sparse system using phase-only correlation (POC). POC has been used in a lot of applications in image processing because it enables us to estimate the displacement between two images from the location of the correlation peak [2]. One of the advantages of POC is that the quality of estimation is not affected by the correlation of signals. The proposed approach exploits the amount of delay of the unknown sparse system without the effect of the correlation using POC.

As a sparse system generally could be modeled as a mixture of the delay part and a few numbers of coefficients, we take advantage of identifying unknown system to estimate location of non-zero value. The estimated amount of delay is used by adaptive filters, thus we expect to decrease the length of adaptive filter.

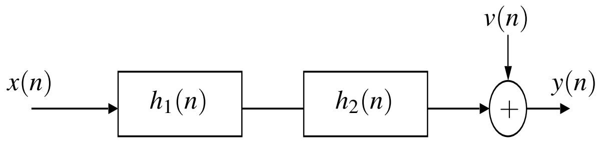

Figure 1. Input-output model

This paper is organized as follows: In section 2, we describe the system model of sparse system that we assume in this paper, derivation of the POC function, and properties of POC function. Section 3 describes the procedure of the proposed method. Section 4 provides results of simulations to evaluate the performance of the proposed method. This result shows that the proposed method correctly estimates the position of non-zero coefficients compared to the performance of PNLMS when speech signals are used as both input signal and background noise.

2. Background

In this section, we show the background of the proposed method. First, the system model assumed in this paper is described. Then, POC function of this model is derived. Properties of the POC function are described using a pure delay system.

2.1. System Model

In the following, we assume that the unknown system can be modeled as the system shown in Fig.1. A small part of its coefficients is expected to have non zero values, and the rest have zero values (we call these delays as delay part in this paper). We assume that the delay part exists at the front of the non-zero valued impulse response of unknown system. Thus, we use the input-output model shown in Fig.1. That is, an unknown system is assumed to be divided into two parts, namely, the delay part $h_1(n)$, and the non-zero part $h_2(n)$. Therefore the delay part $h_1(n)$ is expressed by

$$h_1(n) = \delta(n-L) \qquad (1)$$

where $\delta(n)$ shows the delta function. Note that $x(n)$ and $y(n)$ are the input and the output signals, and $v(n)$ is background noise which is assumed to be uncorrelated with $x(n)$. We note that the relation between $x(n)$ and $y(n)$ is given by

$$y(n) = \sum_{m=0}^{M-1} h(m)x(n-m) \tag{2}$$

$$h(n) = \sum_{m=0}^{M-1} h_1(m)h_2(n-m) \tag{3}$$

where $h(n)$ shows the impulse response of unknown system and M is its length. It is expressed as convolution between $h_1(n)$ and $h_2(n)$. We rewite (3) by

$$h(n) = h_1(n) * h_2(n) \tag{4}$$

$$\begin{aligned} y(n) &= h_1(n) * h_2(n) * x(n) \\ &= h(n) * x(n) \end{aligned} \tag{5}$$

where * shows convolution operation. We assume, as a sparse system, that impulse response of unknown system includes the delay part and non-zero part like $h(n)$.

2.2. Phase-only Correlation

2.2.1. POC function

Let us consider POC function between $x(n)$ and $y(n)$, when $v(n)$ does not exist. Here, we use $X(k)$ and $Y(k)$ respectively to denote the discrete Fourier transforms (DFT) of the two signals. We note that the relation between $X(k)$ and $Y(k)$ is given by

$$\begin{aligned} Y(k) &= (H_1(k)H_2(k))X(k) \\ &= F(k)X(k), \qquad k = 0, 1, \ldots, K-1 \end{aligned} \tag{6}$$

where $F(k) = H_1(k)H_2(k)$, K is the number of DFT, $H_1(k)$ and $H_2(k)$ denote the DFT of $h_1(n)$ and $h_2(n)$ respectively. The cross phase spectrum(or normalized cross spectrum) $R(k)$ between $X(k)$ and $Y(k)$ is given by [2]

$$\begin{aligned} R(k) &= \frac{Y(k)\overline{X(k)}}{|Y(k)\overline{X(k)}|} = \frac{F(k)X(k)\overline{X(k)}}{|F(k)X(k)\overline{X(k)}|} \\ &= \frac{F(k)}{|F(k)|} \end{aligned} \tag{7}$$

where $F(k) = |F(k)|e^{j\theta_F(k)}$, $H_1(k) = e^{-j\omega L}$, $H_2(k) = |H_2(k)|e^{j\theta_{H_2}(k)}$. As a result, $R(k)$ is expressed as

$$\begin{aligned} R(k) &= e^{j\theta_F(k)} = e^{j(\theta_{H_2}(k) - \omega L)} \\ &= e^{j\theta_{H_2}(k)} e^{-j\omega L} \end{aligned} \tag{8}$$

The POC function $r(n)$ is defined as the inverse discrete Fourier transform (IDFT) of $R(k)$ and is given by

$$r(n) = \delta(n-L) * p(n) \tag{9}$$

where $p(n)$ is defined as the IDFT of $e^{j\theta_{H_2}}(k)$. By this process, we could obtain the POC function of the sparse system modeled as Fig.1.

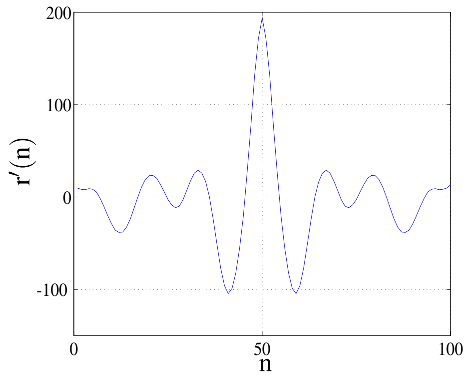

Figure 2. Example of correlation function when L=50

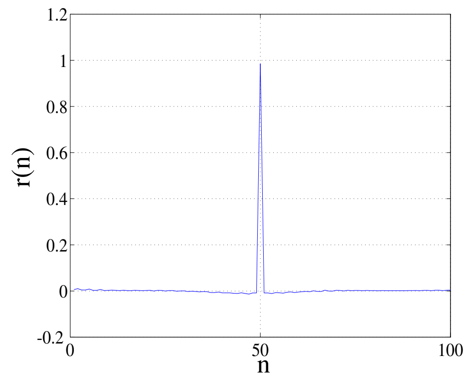

Figure 3. Example of POC function when L=50

2.2.2. property of POC function

Let us consider a pure delay system, namely the case where only $h_1(n)$ exists in Fig.1, and $v(n)$ does not exist. Since $h_1(n)$ is the delay part, amplitude component of $h_1(n)$ has a unit value. We use speech signal to show whether its performance depends on the correlation of input signal. Fig.2 and Fig.3 show the correlation function defined as the IDFT of $Y(k)\overline{X(k)}$ and the POC function when the amount of delay L=50. The correlation function is affected by correlation of input signal as shown in Fig.2. We could confirm that the peak position of POC function corresponds the amount of delay and the value of peak shows similarity between the two signals. In Fig.3, it can be observed that POC function is not affected by the correlation of the input signal. Its result corresponds (9) without $p(n)$.

3. Proposed Method

This section describes the procedure of the proposed method.

3.1. Procedure of the proposed method

Fig.4 shows the procedures of the proposed method.

First, we calculate the DFT of the $x(n)$ and $y(n)$ every N samples of $x(n)$ and $y(n)$ are attained. Then, the cross phase spectrum $R(k)$ is obtained by (7) using $X(k)$ and $Y(k)$. Note that, $R(k)$ represents only the phase components of sparse sys-

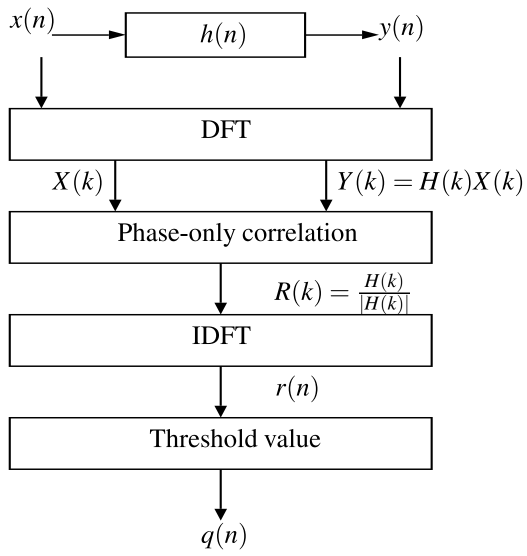

Figure 4. Flowchart of the proposed method

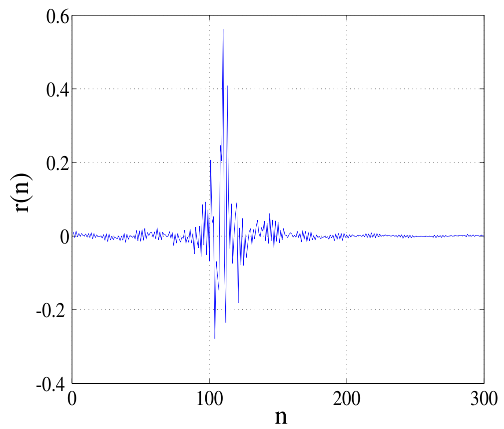

Figure 5. Example of POC function

tem as shown in (8). We calculate the IDFT of the $R(k)$, in this process the POC function $r(n)$ of $x(n)$ and $y(n)$ is obtained. Fig.5 shows an example of the POC function. As we mentioned before, $r(n)$ is not identified as the impulse response of the unknown system, we should estimate the position of non-zero values from $r(n)$.

For this purpose, as would be described in 3.2, $r(n)$ is divided by the threshold value to determine whether each impulse response is zero or non-zero. The value of $r(n)$ larger than the threshold value is regarded as a non-zero value of impulse response of the unknown system. On the other hand, the value of $r(n)$ less than the threshold value is regarded as a zero value. In this process, we could determine the position of the non-zero coefficients. Only the coefficients of non-zero values are identified using an adaptive filter.

By performing this process for every N samples, the location of non-zero parts of unknown sparse system is adaptively estimated.

3.2. Selection of Threshold Value

Here, we describe the detail of the estimation method of the location of non-zero coefficients in the proposed method. The POC function $r(n)$ is defined using only the phase components of $h_2(n)$ by setting the all the amplitude components as the unit value. Hence $r(n)$ and $h(n)$ are not identical generally. Using the information of $r(n)$, we estimate the positions of a non-zero part of impulse response. Therefore we would determine that each of the impulse response of the unknown system is whether zero or non-zero using the two parameters γ and ρ as proposed in [1]. In the proposed method, the following equations are used

$$\begin{aligned} l' &= \max\{|r(0)|, \ldots, |r(M-1)|\} \\ l &= \max\{\gamma, l'\} \\ q(n) &= \max\{\rho l, |r(n)|\} \end{aligned} \tag{10}$$

where $q(n)$ is defined as a function for estimating the amount of delay of $h_1(n)$. The parameter γ is used to avoid the case when all $r(n)$ are zero [1]. l' is defined as the peak value of the POC function. Therefore we use ρl that multiplies the peak value of $r(n)$ by weight parameter of ρ as the threshold value. ρ and γ must satisfy the following relations

$$\rho\gamma < |r(n)| \tag{11}$$

$$\rho < 1 \tag{12}$$

and when ρ is 1.0, we set,

$$q(n) = A \qquad A\text{: constant for all } l \tag{13}$$

The parameter ρ determines the threshold value based on the peak value of $r(n)$. Equivalently, when l equals γ, all values are set to a constant.

4. Simulation

4.1. Conditions of Simulations

To evaluate the performance of the proposed method, we simulated the system identification using the proposed method and PNLMS.

We assumed that the unknown system is modeled by a FIR filter with M=300 (includes delay L=100) and that adaptive filter has same number of coefficients. Unknown system was generated using a $M \times 1$ exponentially decaying window which is defined as [3]

$$e_w = [\overbrace{1/\sigma, \ldots, 1/\sigma}^{L}, e^{-1/\psi}, e^{-2/\psi}, \ldots, e^{-(M-L)/\psi}] \tag{14}$$

where σ is a positive number, and ψ is decay constant. Now we assumed that σ is 0.001, and ψ is 10. The impulse response of the unknown system is obtain by

$$\mathrm{H} = \mathrm{e_w} \star \ddot{\mathrm{W}} \tag{15}$$

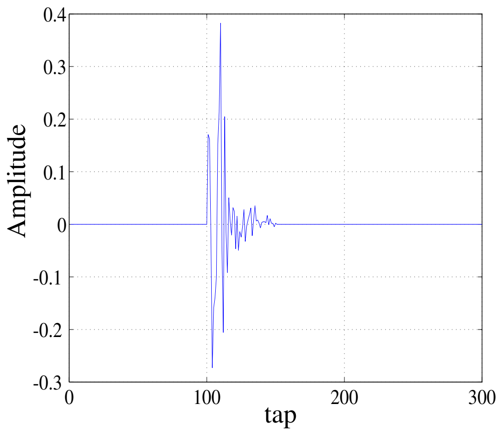

Figure 6. Impulse response of unknown system

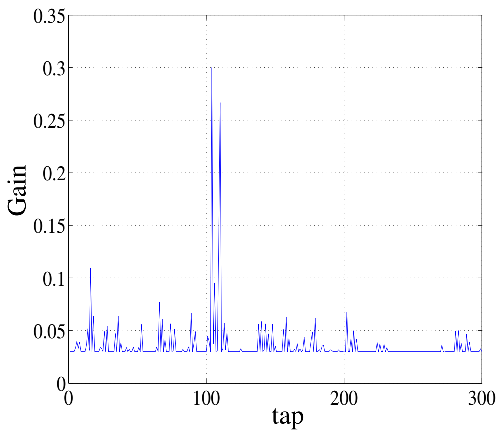

Figure 7. Conventional method using magnitude of PNLMS

where Ẅ is a $M \times 1$ vector of Gaussian sequence with unit variance. $\star$ denotes element-wise multiplication of vectors. Fig.6 shows the impulse response of unknown system used in the simulation which was generated using (15). It is seen that the active part only occupies a small portion of the filter coefficients. The input signal $x(n)$ was speech signal and the disturbance $v(n)$ was another speech signal with signal to noise ratio (SNR) 5dB. Note that $x(n)$ and $v(n)$ are uncorrelated. The number of DFT K is 65536, γ =0.01 and ρ =0.1. The amount of delay is estimated with respect to each data number N=7500. Horizontal axis of Fig.6, Fig.7 and Fig.8 show the index of filter coefficients. The vertical axis of Fig.6 shows amplitude of impulse response.

4.2. Results of Simulations

Fig.7 and Fig.8 show the results of simulations. we show the amount of delay estimated by PNLMS and by the proposed method. The vertical axis of Fig.7 shows magnitude of estimated amount of delay by PNLMS. The vertical axis of Fig.8 shows $q(n)$ defined as (13). The performance of PNLMS is significantly affected due to the cross-correlation between signal and disturbance as shown in Fig.7. The proposed method

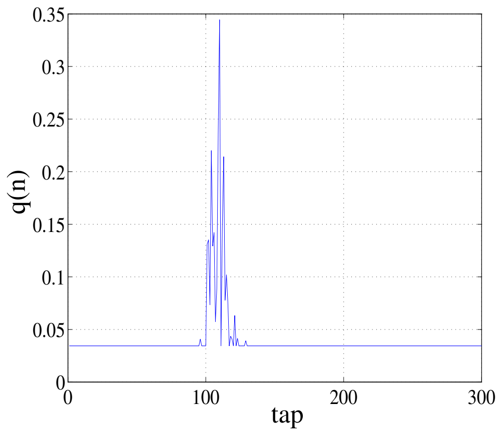

Figure 8. Results of Simulation using the proposed method

estimates without influence of the correlation of the input signal. It can be seen that the proposed method using POC significantly estimate the amount of delay better than PNLMS.

5. Conclusion

In this paper, we proposed a method for estimating the amount of delay of a sparse system using POC. The proposed method exploits the location of non-zero coefficients of an unknown system using POC. The results of simulation show that the proposed method estimates the position of non-zero coefficients of unknown system better than PNLMS when the input signal and the disturbance are correlated.

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