Mechanical Systems and Signal Processing 87 (2017) 180–191

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Active impulsive noise control using maximum correntropy with adaptive kernel size

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ARTICLE INFO

Keywords:
Active noise control
Impulsive noise
Recursive algorithm
Maximum correntropy
Kernel size

ABSTRACT

The active noise control (ANC) based on the principle of superposition is an attractive method to attenuate the noise signals. However, the impulsive noise in the ANC systems will degrade the performance of the controller. In this paper, a filtered-x recursive maximum correntropy (FxRMC) algorithm is proposed based on the maximum correntropy criterion (MCC) to reduce the effect of outliers. The proposed FxRMC algorithm does not requires any *priori information* of the noise characteristics and outperforms the filtered-x least mean square (FxLMS) algorithm for impulsive noise. Meanwhile, in order to adjust the kernel size of FxRMC algorithm online, a recursive approach is proposed through taking into account the past estimates of error signals over a sliding window. Simulation and experimental results in the context of active impulsive noise control demonstrate that the proposed algorithms achieve much better performance than the existing algorithms in various noise environments.

1. Introduction

Active noise control (ANC) has been widely used in many applications, such as road noise [1], active headphones [2], and transformer noise [3]. The ANC technique is based on the principle that a noise can be cancelled by another noise with the same amplitude but an opposite phase [4,5]. Compared with the traditional approach (enclosures, barriers, and silencers etc.), the ANC method is very low-cost and can achieve high attenuation at low frequencies.

The filtered-x least-mean-square (FxLMS) algorithm [4] is the most widely used adaptive algorithm for the feed-forward ANC systems. However, it may become unstable in cases where the primary noise is impulsive noises. To surmount this problem, several variants of FxLMS were proposed [6–13]. In 1995, Leahy et al. proposed the filtered-x least mean p-power (FxLMP) algorithm by minimizing the mean p-power of error instead of the mean-square error [6]. Later, Wu et al. developed the filtered-x logarithmic error LMS (FxLogLMS) algorithm [7], which minimizes the logarithmic error. The FxLogLMS algorithm overcomes the disadvantages of Amplitude Threshold (AT)-based methods [14], and it doesn't need any prior knowledge or estimation of noise. In 2012, George and Panda developed a robust filtered-s LMS (RFsLMS) algorithm for the functional link artificial neural network (FLANN) based adaptive controller [9], which performs with similar levels of efficiency for Gaussian as well as non-Gaussian noise.

Alternatively, to achieve fast convergence rate of the adaptive filter, an interesting and effective way is to use the filtered-x recursive least square (FxRLS) algorithm [4]. But few algorithms aimed at enhancing the stability of FxRLS have been investigated. Reddy et al. proposed the new FxRLS algorithm which employs the hybrid scheme and is capable of obtaining fast convergence rate and stable steady-state error under non-impulsive noise environments [15]. However, the abovementioned algorithms have the risk

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http://dx.doi.org/10.1016/j.ymssp.2016.10.020
Received 11 March 2016; Received in revised form 9 October 2016; Accepted 19 October 2016
Available online 27 October 2016
0888-3270/

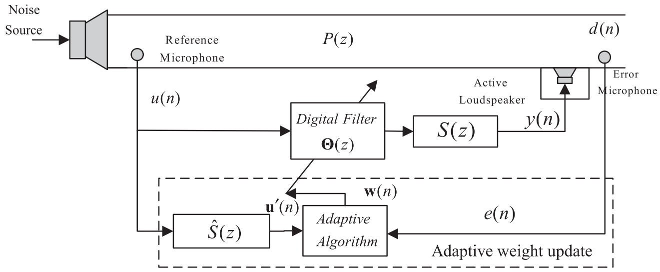

Fig. 1. Block diagram of the single channel feed-forward ANC system based on adaptive algorithm.

of instability in cases where the primary noise is impulsive disturbances.

Under the impulsive (non-Gaussian) noises, the conventional mean square error (MSE) criterion may fail to work since it cannot extract all possible information from the signals. In contrast, the information entropy (IE) method provides a more comprehensive description of the signals, that is, it can include all the possible higher order information of a random variable under the condition of non-Gaussian [16,17]. Due to its simplicity and robustness, the maximum correntropy criterion (MCC) of IE has been developed in the previous studies [18,19]. In these works and other similar references on the topic, the algorithms typically rely on the use of MCC and less attention is paid to the kernel size in MCC.

In this work, a new algorithm based on the MCC of the IE method is proposed to enhance the performance of the existing ANC algorithms. The new algorithm achieves more stable performance than the FxRLS algorithm in the presence of impulsive noise. The filtered-x recursive maximum correntropy (FxRMC) algorithm does not need priori information of the noise characteristics, but the selection of kernel size of Gaussian kernel largely affects the performance of the filtering. To deal with this problem, a kernel adaptive version of FxRMC based on the sliding window approach is further proposed. As the kernel size is updated, this algorithm can remain stable in the presence of impulsive noise.

The remainder of this paper is organized as follows. Section 2 introduces the ANC system model along with the review of the FxLMP and RFxLMS algorithms, then the proposed FxRMC algorithm and adaptive kernel size strategy are presented together with the stability condition. Simulations and experimental studies are performed to evaluate the performance of proposed algorithms in Sections 3 and 4. Finally, Section 5 presents the discussions and conclusions of this work.

2. Proposed algorithms

2.1. Previous work

The block diagram of ANC system is illustrated in Fig. 1, where $d(n)$ represents the primary noise to be cancelled, the transfer function $P(z)$ denotes the primary path from the reference signal $u(n)$ to the error microphone $e(n)$, $S(z)$ is the secondary path transfer function between the output of the adaptive filter $\mathbf{\Theta}(z)$ and the output of the error microphone $e(n)$, and $y(n)$ is the output of the secondary path. The transfer function $\hat{S}(z)$ can be estimated by an adaptive filter using either off-line or on-line secondary path modelling techniques [4].

The error microphone $e(n)$ is given by

$$e(n) = d(n) - y(n) = d(n) - s(n)*[\mathbf{\Theta}^T(n)\mathbf{u}(n)] \tag{1}$$

where * denotes the discrete convolution operator, $s(n)$ is the impulse response of $S(z)$, and $\mathbf{u}(n)=[u(n), u(n-1),..., u(n-L+1)]^{\mathrm{T}}$ is the reference signal vector.

By minimizing a mean square of error signal $|e(n)|^2$, the FxLMS algorithm has been developed in [4]. The weight of this controller is given by

$$\mathbf{\Theta}(n+1) = \mathbf{\Theta}(n) + \mu e(n)\mathbf{u}'(n) \tag{2}$$

where

$$\mathbf{u}(n) = s(n)*\mathbf{u}(n). \tag{3}$$

The robust FxLMS (RFxLMS) algorithm [9] is a modified version of the FxLogLMS algorithm, which employs a new logarithmic cost function. The coefficient vector $\mathbf{\Theta}(n)$ of the algorithm is updated according to the following update equation:

$$\mathbf{\Theta}(n+1) = \mathbf{\Theta}(n) + \mu\frac{e(n)}{e^2(n) + 2\beta^2}\mathbf{u}'(n) \tag{4}$$

where β is the standard deviation of $e(n)$ which is obtained by using a sliding window approach in [20].

2.2. Derivation of the FxRMC algorithm

Based on MCC, the FxRMC algorithm is proposed to provide a robust solution for active impulsive noise control. The MCC