

Experimental Study on Enhanced FXLMS Algorithm for Active Impulsive Noise Control

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ABSTRACT

Active noise control (ANC) technique with the filtered-x least mean square (FXLMS) algorithm has proven its efficiency and drawn increasingly interests in vehicle noise control applications. However, many vehicle interior and/or exterior noises are exhibiting non-Gaussian type with impulsive characteristic, such as diesel knocking noise, injector ticking, impulsive crank-train noise, gear rattle, and road bumps, etc. Therefore, the conventional FXLMS algorithm that is based on the assumption of deterministic and/or Gaussian signal may not be appropriate for tackling this type of impulsive noise. In this paper, an ANC system configured with modified FXLMS (MFXLMS) algorithm by adding thresholds on reference and error signal paths is proposed for impulsive noise control. To demonstrate the effectiveness of the proposed algorithm, an experimental study is conducted in the laboratory. Various impulses with different durations are added in the Gaussian noise to simulate the typical impulsive noise. A series of low pass filters (LPFs) are used to model the various transmission paths, where the multiple reference signals are generated and used for the MFXLMS algorithm. Experimental results demonstrate that the enhanced MFXLMS algorithm exhibits improved robustness and performance for impulsive-type noise control as compared to the conventional FXLMS algorithm, and promising reductions at various impact events are achieved without causing instability.

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INTRODUCTION

Active noise control (ANC) technology is relied on the principle of linear superposition of two destructive waves through generation of a secondary sound with same amplitude and anti-phase of the primary noise [1-2]. During the last decades, interests of ANC in vehicle applications have grown significantly due to its advantage over passive noise control in the effectiveness of low frequency range, and potential beneficiary in size, weight and cost reduction. In 1984, Oswald [3] introduced the first ANC system that was applied on vehicle engine noise control. Since then due to the rapid development of digital signal processing technique and increasing number of passenger cars are equipped with highly advanced electronic control system, the applications of ANC for vehicle engine noise, road noise and exhaust noise control have drawn more attention in industry and academic field [4,5,6]. Very recently in 2012, Ford released its first ANC technology with more advanced targets on actively tuning the

vehicle interior sound quality [7]. However, little research has been done on the ANC of non-Gaussian impulse noise.

The statistical characteristics of common vehicle noises are normally either deterministic or following Gaussian distribution, and typically lie in the low-frequency range [8], which guarantees the successful implementation of ANC system with conventional filtered-x least mean square (FXLMS) algorithm. However, some other vehicle interior and/or exterior noises are exhibiting non-Gaussian type with impulsive characteristic, such as diesel knocking noise, injector ticking, impulsive crank-train noise, gear rattle, and road bumps, etc. In particular, when the vehicle is driven over road bumps or potholes at certain speed, the interior noise response will be with impact characteristic. Therefore, it poses a great challenge to design ANC system using the FXLMS algorithm [9]. Because the common FXLMS algorithm is based on the assumption that the signals processed are deterministic and/or Gaussian type. The vehicle

impulsive noise will pose a stability problem for conventional FXLMS algorithm, which greatly affects the effectiveness of ANC system for impulsive noise because of the divergence of FXLMS algorithm. To deal with this type of impulsive noise, several researchers have studied and proposed effective adaptive algorithms for active control of impulsive noise [9,10,11]. One of the alternatives is modification of current FXLMS algorithm by adding thresholds to remove the peaky impulses effect and improved robustness for impulsive noise were achieved [10].

In this study, an ANC system configured with the enhanced modified FXLMS (MFXLMS) algorithm by adding thresholds on reference and error signal paths is proposed for vehicle impulsive noise control. Different number of impulses with various durations will be added in the Gaussian noise to simulate the typical impulsive noise with certain impulsiveness. A series of low pass filters (LPFs) are used to model the various transmission paths into the cabin space, where the frequency range is constraint to below 600 Hz. Experimental results demonstrate that the enhanced FXLMS algorithm exhibits improved robustness and performance for active impulsive noise control as compared to conventional FXLMS algorithm. The rest of this paper is organized as follows: Section 2 describes the design of ANC system with the MFXLMS algorithm. Experimental set up and results will be presented to verify the effectiveness of the MFXLMS algorithm for various impulsive noises in Section 3. Finally, a summary will be given.

MODIFIED FXLMS ALGORITHM

The common ANC system using feed-forward control configured with FXLMS algorithm is shown in Figure 1, where $x(n)$ is the reference signal that can be picked up by accelerometers or microphones, $d(n)$ is the primary noise, and $e(n)$ is the error signal after superposition of the primary noise and secondary canceling noise. The FXLMS algorithm generates secondary noise adaptively to minimize the error signal $e(n)$ through reference signal $x(n)$. The earlier and more-correlated reference signals are obtained, the better the control performance will be. However, it requires more accurate model of secondary transfer path $\hat{S}(n)$ from the control speaker to error microphone, which can be estimated by using offline or online system identification approach. The residual error signal is expressed as:

$$e(n) = d(n) - y(n) \quad (1)$$

$$y(n) = S(n) * [W^T(n)X(n)] \quad (2)$$

where n is the time index, $S(n)$ is the impulse response of secondary path, $*$ denotes the linear convolution of the adaptive filter output with secondary path, vectors $W(n) = [w_0(n) \ w_1(n) \ \cdots \ w_{L-1}(n)]^T$ and $X(n) = [x(n) \ x(n-1) \ \cdots \ x(n-L+1)]^T$ are the filter weights and reference signal vector of the

controller with order. The filter weight update equation of conventional FXLMS algorithm is obtained:

$$W(n+1) = W(n) + ue(n)X'(n) \quad (3)$$

where u is the step size determining the system performance and convergence. The filtered reference signal vector is $X'(n) = \hat{S}(n) * X(n)$.

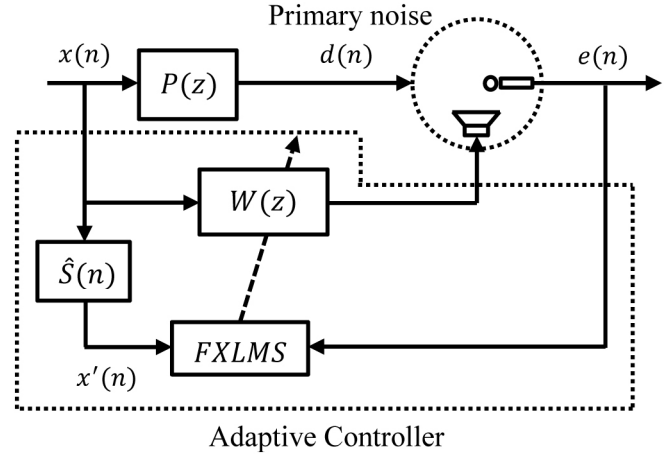


Figure 1. Feed-forward control diagram configured with FXLMS algorithm

The filter weight update equation (3) shows that the highly peaky impulses occurring in the reference and error signals will result into burst of the filter weights and the update process may diverge, which makes the conventional FXLMS algorithm unstable for impulsive noise. To improve its robustness for impulsive samples modified FXLMS algorithms by adding threshold in the reference and/or error signal path [10] is applied for vehicle noise with additional impact responses. The proposed single-input-single-out ANC system configured with the MFXLMS algorithm for impact noise is shown in Figure 2. Here, we notice that the filter weight update equation will become:

$$W(n+1) = W(n) + ue_c(n)[\hat{S}(n) * X_c(n)] \quad (4a)$$

$$x_c(n) = \begin{cases} c_2, x(n) \geq c_2 \\ c_1, x(n) \leq c_1 \\ x(n), \text{otherwise} \end{cases} \quad (4b)$$

$$e_c(n) = \begin{cases} c_2, e(n) \geq c_2 \\ c_1, e(n) \leq c_1 \\ e(n), \text{otherwise} \end{cases} \quad (4c)$$

where c_1 and c_2 are the threshold values, as explained in [10] reference, and they are statistically estimated by calculating the 99 and 1 percentile of the original signal. By adding this