Published in final edited form as:

Mech Syst Signal Process. 2013 April 1; 36(2): . doi:10.1016/j.ymssp.2012.10.017.

Active noise cancellation algorithms for impulsive noise

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Abstract

Impulsive noise is an important challenge for the practical implementation of active noise control (ANC) systems. The advantages and disadvantages of popular filtered-X least mean square (FXLMS) ANC algorithm and nonlinear filtered-X least mean M-estimate (FXLMM) algorithm are discussed in this paper. A new modified FXLMM algorithm is also proposed to achieve better performance in controlling impulsive noise. Computer simulations and experiments are carried out for all three algorithms and the results are presented and analyzed. The results show that the FXLMM and modified FXLMM algorithms are more robust in suppressing the adverse effect of sudden large amplitude impulses than FXLMS algorithm, and in particular, the proposed modified FXLMM algorithm can achieve better stability without sacrificing the performance of residual noise when encountering impulses.

Keywords

Active noise control; Impulsive noise; Adaptive filter; Nonlinear algorithm; FXLMM; Stability

1. Introduction

Active noise control (ANC) has received considerable research attention in the past decades because of its superior advantages in cancelling low frequency noise than passive methods [1]. ANC has been applied in various industrial applications such as long duct noise cancellation system, car cabin noise cancellation, and active noise reduction headset [1]. Although great progress has been made, there are still some limits on the application of ANC systems, one important challenge is the control of impulsive noises. Impulse noises exist in many real applications, such as stamping machines in manufacturing plants, IV pump sounds in the hospital [2].

Impulsive noise control was firstly studied in the literature as non-Gaussian stable processes using fractional lower order moments [3,4]. Sun et al. [5] proposed an algorithm that is a slightly modified version of the FXLMS algorithm by putting fixed thresholds on the reference signal, in order to eliminate the effect of large impulses whose amplitude is above the threshold and prevent the system from becoming unstable. Although this method has advantage of the same computational complexity as that of the FXLMS algorithm, this algorithm may still becomes unstable under highly impulsive circumstance. Akhtar et al. [6,7] modified and extended Sun's algorithm by extending the fixed thresholds to the error

signal and replacing large valued samples in the reference signal and error signal with appropriate threshold values. Faster convergence speed and better stability were achieved. Qiu et al. studied another approach that minimizes the squared logarithmic transformation of the error signal [8], achieved more robust performance. Bergamasco et al. also added online secondary path estimation for controlling impulsive noises [9]. Recently, FXLMM algorithm, a simple and robust method that employs the least mean M-estimation error objective function, was extensively studied [2,10–13].

In this study, a new modified FXLMM algorithm is proposed, aiming to control deterministic impulsive noise such as IV pumps in hospital. The performances of the algorithm are investigated both in computer simulations and experiments.

2. Modified FXLMM algorithm

During noise control experiments, FXLMM algorithm still may become unstable when impulse amplitude increases. This is because the step size of the update weight function increases very fast when encountering large amplitude impulses as the adaptive threshold parameters increasing with the residual noise. To overcome this instability, a new function, a two-part skewed triangular M-estimate function $\Phi(e)$, is proposed to replace the Hampel's three-part redescending M-estimate function of the traditional FXLMM algorithm for step size adaption:

$$\Phi(e) = \begin{cases} e, & 0 \leq |e| < \xi \\ [\xi(|e| - \Delta_2)/\Delta_1 - \Delta_2] \text{sgn}(e), & \xi \leq |e| < \Delta \\ 0, & |e| \geq \Delta \end{cases} \quad (1)$$

and the weight update equation is given as:

$$\mathbf{w}(n+1) = \mathbf{w}(n) + \mu p[e(n)] e(n) \mathbf{x}'(n) \quad (2)$$

where $p[e(n)] = \Phi(e)/e(n)$ is the weight function.

As illustrated in Fig. 1, when $|e| < \xi$, the weight update process is identical to the FXLMS algorithm. Δ_1 and Δ_2 are the threshold parameters. In the interval $[\xi, \Delta]$, the value of the function $\Phi(e)$ begins to decrease, following a line between the points (ξ, ξ) and $(\Delta, 0)$, whose slope is greater than FXLMM in this interval, to achieve faster decrease than the FXLMM algorithm and further reduce the effect of large amplitude impulses in the residual noise on the update process of the weight coefficient vector of adaptive filter $\mathbf{w}(z)$, $\Phi(e)$ reaches 0 when $|e| = \Delta$.

Both simulation and experiments were conducted using FXLMS, FXLMM and modified FXLMM algorithm, and the results are analyzed in the following sections.

3. Simulation results

Computer simulations were carried out using MATLAB Simulink, using sample frequency of 5000 Hz and a primary noise source of combination of 300, 500 and 700 Hz sinusoidal waves, in which 500 Hz component had amplitude of 0.10 and the other two each had amplitude of 0.05. A 600 Hz sinusoidal impulse of amplitude of 0.3 is added as the impulsive noise. Adaptive filter length is 32 bits. Step size is chosen as 1×10^{-5} . The threshold parameters were estimated in real-time online, using the method given in [10]. The probabilities θ_ξ , θ_{Δ_1} and θ_{Δ_2} for determining the threshold parameters were taken to be 0.05, 0.025 and 0.01, respectively. The residual noises of all three algorithms are shown in Fig. 2. The FXLMM and modified FXLMM algorithms achieved much better residual noise

performance than FXLMS algorithm, in addition to give much better transitional performance. There was no significant difference between FXLMM and modified FXLMM algorithms in residual noise performance, but the proposed modified FXLMM algorithm gives much better transit converge performance as show in Fig. 2. Different impulse widths (time duration) and amplitudes were tried and similar results were obtained.

4. Experiment results

Real-time control experiments were carried out using a dSPACE real time control board. The secondary path identification was identified offline using LMS algorithm [1]. Sample frequency is 5000 Hz. Adaptive filter length is 32 bits. Step size is chosen as 1×10^{-5} . The probabilities θ_{ζ} , θ_{Δ_1} and θ_{Δ_2} for determining the threshold parameters were taken to be 0.05, 0.025 and 0.01, respectively. Noise source used in experiments was sinusoid signal (500 Hz, amplitude 0.1) combined with sinusoid impulsive turbulence (600 Hz, amplitude 0.6). Fig. 3 shows the wave form of impulsive noise in the acoustic box used in the experiments.

The experimental residual noises at error microphone are shown in Fig. 4. The FXLMM and modified FXLMM algorithms achieved significantly better performance than FXLMS. While no significant difference in the residual noise was observed between FXLMM and modified FXLMM algorithms, the modified FXLMM algorithm gave smoother converge performance. The $w(n)$ updating trajectories of the three algorithms with presence of impulses are shown in Fig. 5. The weight coefficient updating of FXLMS algorithm was seriously affected by presence of impulses and became unstable after two impulses, while FXLMM algorithm can effectively reduced this negative impact; the modified FXLMM algorithm had even better stability in coefficient updating than FXLMM algorithm (note the different scales in y axis of the three subplots in Fig. 5). Different impulse widths and amplitudes were implemented and similar results were obtained. In the conducted experiments, modified FXLMM was able to achieve better stability than FXLMM without sacrificing residual noise performance, which is consistent with simulation results.

5. Conclusions

Different ANC algorithms for the control of impulsive noises were studied in both simulations and experiments, and their performances were compared. The main advantage of FXLMM and modified FXLMM is that, when sudden large amplitude impulse happens, it can effectively reduce the effect of impulses on the update of weight coefficient $w(n)$ and prevent instability. Compared with FXLMM, through using faster degrading step size optimizing function, the modified FXLMM algorithm presented in this paper can achieve better stability without sacrificing the performance of residual noise when encountering impulses and has potential of further investigation.

Acknowledgments

The authors are grateful for the funding support from the National Institutes of Health (NIH, Grant no. R03DC009673).

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Fig. 1.
Score function of two-part triangular M-estimate function.

Fig. 2. Comparison of simulated residual noises of FXLMS, FXLMM and modified FXLMM algorithms in impulses.

Fig. 3.
The wave form of impulsive noise.

Fig. 4.
Residual noise of FXLMS, FXLMM and modified FXLMM algorithms.

Fig. 5. Comparison of filter coefficient vector $w(n)$ with the updating of FXLMS, FXLMM and Modified FXLMM algorithms when encountering impulses. (a) FXLMS algorithm. (b) FXLMM algorithm and (c) Modified FXLMM algorithm.