



Filtered-x generalized mixed norm (FXGMN) algorithm for active noise control

Pucha Song, Haiquan Zhao*

Key Laboratory of Magnetic Suspension Technology and Maglev Vehicle, Ministry of Education and the School of Electrical Engineering, Southwest Jiaotong University, Chengdu 610031, China



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ABSTRACT

The standard adaptive filtering algorithm with a single error norm exhibits slow convergence rate and poor noise reduction performance under specific environments. To overcome this drawback, a filtered-x generalized mixed norm (FXGMN) algorithm for active noise control (ANC) system is proposed. The FXGMN algorithm is developed by using a convex mixture of l_p and l_q norms as the cost function that it can be viewed as a generalized version of the most existing adaptive filtering algorithms, and it will reduce to a specific algorithm by choosing certain parameters. Especially, it can be used to solve the ANC under Gaussian and non-Gaussian noise environments (including impulsive noise with symmetric α -stable (S α S) distribution). To further enhance the algorithm performance, namely convergence speed and noise reduction performance, a convex combination of the FXGMN algorithm (C-FXGMN) is presented. Moreover, the computational complexity of the proposed algorithms is analyzed, and a stability condition for the proposed algorithms is provided. Simulation results show that the proposed FXGMN and C-FXGMN algorithms can achieve better convergence speed and higher noise reduction as compared to other existing algorithms under various noise input conditions, and the C-FXGMN algorithm outperforms the FXGMN.

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1. Introduction

Noise has always remained as undesired problem and can result in corruption of desired signals. Hence it is very important to eliminate or reduce the effect of noise. Active noise control (ANC) is well known as a useful technique for suppressing acoustic noise [1], which is based on the superposition principle that a noise can be canceled by another noise with the same amplitude but opposite in phase, has attracted increasing attention because of its potential use in low frequency noise control applications [2,3].

Adaptive filtering algorithm plays an important role in active noise control problem encountered in many scenarios. One of the most popular adaptive filtering algorithms is the Filtered-X LMS (FXLMS) algorithm due to its simple structure and ease of implementation in ANC system [4–6]. However, the main disadvantage of FXLMS algorithm is that the fixed step size is used, causing the ANC system to suffer from the trade-off between noise reduction performance and convergence speed. In order to solve the performance limitation of the FXLMS algorithm, several variable step size FXLMS (VSS-FXLMS) algorithms were developed in recent years, all based on modifying the FXLMS algorithm [6]. The most common VSS-FXLMS algorithms

* Corresponding author.

E-mail addresses: pcsong_swjtu@126.com (P. Song), hqzhao_swjtu@126.com (H. Zhao).

were proposed in [7–10]. In particular, the VSS-FXLMS algorithm in [8] was proposed for a typical narrowband active noise control system and shows the superior performance of the VSS-FXLMS algorithm compared to the FXLMS and the FXRLS algorithms. Recently, the convex combination schemes have attracted extensive attention in ANC systems, which combine the outputs of multiple filters to achieve overall quality improvement. More importantly, the idea of convex combination of two adaptive filters has been introduced into the ANC system [11–14]. A single-channel ANC system based on the convex combination of two equal length adaptive filters is embedded in an improved filtering scheme, which was reported first in [11]. The robustness of a convex combination of FXLMF algorithm for two different step sizes was described in [13]. Ferrer et al. [14] applied the convex combination strategy to single-channel and multichannel ANC systems, and for the time-varying system or the system is subject to unexpected interference, the convex combination algorithm shows a fast tracking ability and restores good steady-state performance. Furthermore, the convex combination algorithm has shown to be robust even with inaccurate estimate of the secondary paths. To cope with impulsive noises, several techniques [15–21] have been proposed for active noise control in impulsive interference environments. In [15], the filtered-x least mean p-power (FXLMP) algorithm was presented, it gives better robustness as compared to FXLMS algorithm for active impulsive noise control. Sun et al. [16] proposed a modification of FXLMS algorithm for impulsive ANC. In [17], Akhtar et al. proposed a modification of Sun's algorithm, which clips the samples of reference and error signals instead of ignoring them. However, the main difficulty is the selection of thresholds based on the statistics of the reference signal and error signal that are often obtained off-line. Thus a FXLMS algorithm using logarithmic transformation (FXlogLMS) was reported [18]. To improve the robust behaviour of nonlinear ANC system, a novel robust filtered-s least mean square (RFsLMS) algorithm based on a logarithmic norm has been presented in [19]. Recently, with an objective to further improve the robustness of nonlinear ANC systems, a correntropy based on nonlinear ANC system (FsMCC) was developed [20]. The weight update is expected to tend towards zero for higher values of the error signal, thus offering a robust weight update mechanism.

However, these algorithms may perform very poorly in non-Gaussian noise environments because they capture merely the second-order statistics of the error signal. Thus, the cost function beyond the second-order moment of the error has been proposed to update the filter weights [22]. Most existing algorithms use a single criterion as the cost function to update the weight vectors, which may suffer from slow convergence rate and poor noise reduction performance, similar to the least mean absolute third (LMAT) algorithm [23] and the least mean fourth (LMF) algorithm [24] because their convergence properties are very sensitive to the proximity of the adaptive weights to the optimal solutions. To tackle this problem, convex combination of different norms was proposed, such as the least mean kurtosis (LMK) algorithm [25], the robust mixed-norm (RMN) [26], the least mean mixed-norm (LMMN) [27–30] and the general mixed-norm (GMN) [31].

In this paper, we apply the GMN algorithm as the cost function to improve the performance for ANC system and the inherent stability problems of the higher order moments. This algorithm is called FXGMN algorithm, and it outperforms FXLMS algorithm for a wide range of noise signals. Inspired by the convex combination approaches in [11,32], the C-FXGMN algorithm is proposed in order to further improve the performance of the FXGMN algorithm, namely convergence speed and noise reduction performance. Simulation results show the effectiveness of the proposed algorithms, and demonstrate that the C-FXGMN algorithm can improve the convergence rate and noise reduction performance of the adaptive filter.

2. Problem statement

The block diagram of an adaptive active single-channel feed-forward ANC system is shown in Fig. 1, where $P(z)$ represents the primary path transfer function, $S(z)$ is the secondary path transfer function, $W(z)$ is the ANC controller (adaptive filter), $\tilde{S}(z)$ is an available estimate of $S(z)$, $d(n)$ is the output of primary path, $y(n)$ is the filter response and $e(n)$ is the residual error.

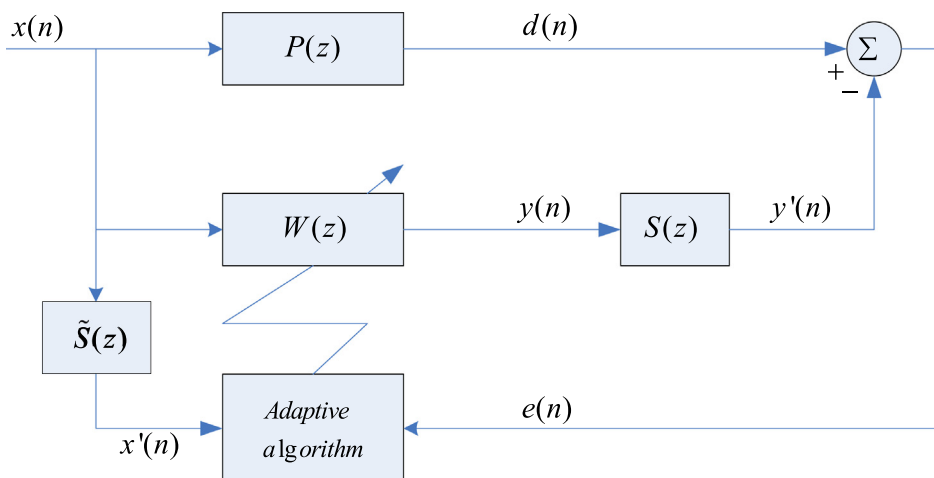


Fig. 1. Block diagram of a single-channel feed-forward ANC system.

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