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A new adaptive strategy to improve online secondary path modeling in active noise control systems using fractional signal processing approach

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ABSTRACT

In this paper, a new adaptive strategy based on fractional signal processing is proposed using multi-directional step size fractional least mean square algorithm for online secondary path modeling, which is a fundamental problem in practical active noise control systems, as opposed to the generally-employed increasing step size strategy that compromises model accuracy for faster convergence. The design approach presents step size strategy in relation with disturbance signal in the desired response of modeling filter which is not available directly so an indirect approach is used to track its variations. Comparative results for narrowband and broadband noise signals show that the proposed technique outperforms other state-of-the-art methods in terms of model accuracy and convergence rate.

1. Introduction

Application of fractional calculus to signal processing has been found in a diverse field of applied science and engineering. For example, fractional Brownian motion [1], description of damping involving fractional operators [2], fractional system identification for lead acid battery state charge estimation [3], continuous-time fractional linear systems [4], transfer function identification from frequency response [5], parameter estimation of input nonlinear control autoregressive system [6] and so on. Introductory material on subject term of fractional signals processing is given in [7,8]. Beside this, the dedicated special issues of reputed journals on fractional signal processing and its applications are also published [9,10]. Moreover, recently, many authors are attracted to the applications of fractional dynamics to signal process such as fractional time integral approach to image structure denoising [11] and Design of adjustable fractional order differentiator [12]. It motivates the author to investigate in applications of fractional signal processing specially in the field of active noise control system.

Acoustic noise becomes a serious problem with the extensive use of industrial equipments and this issue can be addressed by active and passive methods. Active methods outperform passive methods by being more effective at low frequencies and able to block noise selectively. After emergence of successful applications of active noise control (ANC) systems in medical instruments and consumer electronics in the recent years [13–15], interest in this field has grown rapidly. ANC system is applied for mitigation of unwanted signals in scenarios involving small axial flow fans in [16,17], privacy-phone handsets [18], neonatal intensive care units [19], magnetic resonance imaging [20], motorcycle helmets [21] and compressor of an actual heating, ventilation, and air-conditioning system [22].

Development, theoretical performance analysis and real-time experimentation of more effective ANC algorithms are

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open for further research and point of interest in present studies. It would be interesting to investigate, whether we can get better performance by employing fractional least mean square (LMS) based ANC system with a step size parameter that increases from small value to ensure fast stable convergence and then decreases from a certain high value to account for minor adjustments.

2. An overview of active noise control system and problem statement

ANC systems work on the principle of destructive interference between sound fields for reducing unwanted sound (primary noise) [23]. Essentially, primary noise is cancelled around the location of error microphone by generating canceling noise [24]. A single-channel feedforward ANC system is shown in Fig. 1. In this system, one reference microphone is used to pick up reference signal $x(n)$, one error microphone to pick up the residual noise $e(n)$ and a speaker to propagate canceling signal $y(n)$ generated by adaptive noise control filter $W(n)$. A common adaptation algorithm for ANC systems is filtered-x least mean square (FxLMS) algorithm [13], which is a modified version of LMS algorithm [25]. Here $x(n)$ is filtered through an estimated secondary path $\hat{S}(n)$ before being supplied to LMS algorithm for weight updation. This filtering is performed to compensate for the effect of secondary path. The FxLMS algorithm is fairly robust to the modeling errors between the secondary path and the modeling filter [26].

Secondary path may be estimated offline (when primary noise is absent) prior to the operation of ANC system, but presence of fixed modeling errors (as in case of offline modeling), FxLMS converges to a biased solution [27]. Online identification of the secondary path characteristics is preferred to ensure the stability of FxLMS and maintain the noise reduction performance while tracking the variations of secondary path due to the aging of components, thermal variations and environmental modifications [28,29].

Normally, two different approaches are adopted for the secondary path modeling. A first approach involves the injection of additional random noise into the ANC system, thus utilizing a system identification method to model the secondary path $S(n)$ [30–35]. Second approach models it directly from the output $y(n)$ of the control filter $W(n)$. A detailed comparison of these two approaches is given in [36], which concludes that first approach is superior to second approach on convergence rate, updating duration, speed of response to changes of primary noise and computational complexities. However, the injected auxiliary noise damages the noise cancellation performance by contributing to the residual noise and it is preferable to keep it as low as possible.

Eriksson et al. [30] proposed the basic additive random noise technique for online secondary path modeling. As shown in Fig. 2, there are two adaptive filters in this ANC system: FxLMS algorithm-based noise control filter $W(n)$, and the LMS algorithm-based secondary path modeling filter $S(n)$. The system of [30] suffers from slow convergence and the low estimation accuracy of these filters. Signal at the error microphone of this system has two components: the auxiliary noise filtered by the secondary path and the residual noise of the ANC system. First component disturbs the control filter adaptation, while the second component disturbs the secondary path modeling. Third adaptive filter is used to address this problem in [31–33]. In these improved methods, a third adaptive filter is employed to improve the convergence speed and accuracy of the secondary path modeling by removing the residual noise from the error signal of the secondary path modeling filter, thus acting as a noise suppressor. In [24], a cross-update strategy is also employed for removing the auxiliary noise from the error signals of the control filter and noise suppressor. More recently, improved performances were obtained with the ANC system proposed in [35]. This ANC system uses only two adaptive filters, one for adapting the control filter and other secondary path modeling, but an improved convergence speed of the control filter is obtained by introducing the delay compensation scheme of [37]. In FxLMS algorithm, delay introduced by the secondary path slows down the convergence and reduces the upper bound for the step size [23]. Two fixed filters are introduced in modified FxLMS

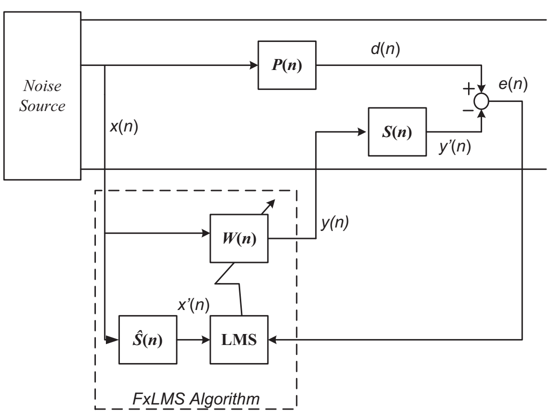

Fig. 1. Feedforward ANC system.

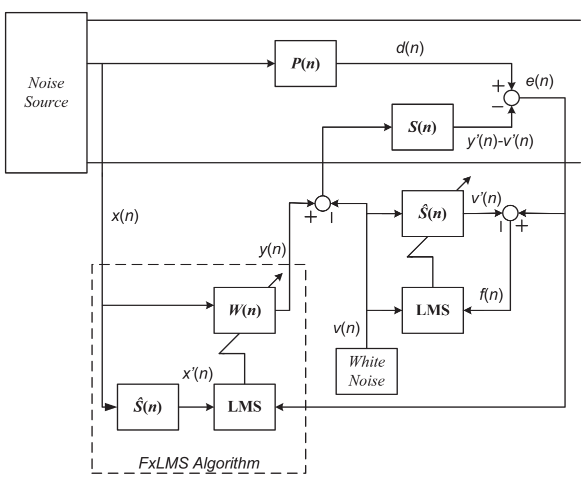

Fig. 2. ANC system of Fig. 1 with online secondary path modeling (Eriksson's method).