The Application of Adaptive IIR Filter in Active Noise Control with Consideration of Strong Acoustic Feedback

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Abstract

In some actual active noise control (ANC) systems, the use of adaptive IIR filter is appealing because the poles of an IIR filter make it possible to obtain well-matched characteristics of sound field with a lower-order structure than an FIR filter. In this paper, the performance of adaptive IIR filter in ANC system under strong acoustic feedback is analyzed. The simulation results demonstrate that although adaptive IIR filter can compensate partly for acoustic feedback, the feedback neutralization technique is still preferred especially for strong acoustic feedback. Furthermore, with consideration in terms of convergence and stability monitoring, the LFRLMS algorithm combined with feedback neutralization is more preferable than the others in dealing with sound path modeling error.

1. Introduction

Most active noise control (ANC) system use adaptive FIR filters and filtered-x LMS (FXLMS) algorithm due to their simplicity and inherent stability [1]. The current adaptive IIR filtering algorithms for ANC, such as FULMS [2] algorithm and LFRLMS [3] algorithm, take the assumption that the acoustic feedback from the output of the control sources to the reference sensors is very weak and the feedback loop gain is much less than unity at all frequencies. The derivation of FVLMS [4] algorithm took full consideration of the feedback path, but the complexity of the algorithm increases and the coefficients of the control filter become more sensitive to the sound path modeling error [3]. On the other hand, the deduction of FULMS algorithm ignores the dependency of the gradient vector on the feedback path and implies that the magnitude response of the open-loop transfer function is very weak. The combination of FULMS algorithm with the feedback neutralization technique [1], which needs an estimate of the feedback path, can be a thorough approach to solving the feedback problem. Since in FVLMS algorithm the estimation of the feedback path is also inevitable, it

\[ H(z) = \frac{B(z)}{A(z)} = \frac{\sum_{i=0}^{\infty} b_i z^{-i}}{1 + \sum_{i=0}^{\infty} a_i z^{-i}}. \]  

Set \( z \) as the unit delay operator and the error signal can be expressed as

\[ e(n) = P(z)x(n) - S(z)y'(n) = P(z)x(n) - S(z)\frac{H(z)}{1-H(z)F(z)}x(n). \]  

2. Analysis of adaptive IIR filter for active noise control under strong acoustic feedback

Active noise control schemes can be portrayed as in Fig. 1, in which \( H \) represents the control filter and in this paper can be described as

\[ H(z) = \frac{B(z)}{A(z)} = \frac{\sum_{i=0}^{\infty} b_i z^{-i}}{1 + \sum_{i=0}^{\infty} a_i z^{-i}}. \]  

\[ \frac{\partial}{\partial w_i}[e^2(n)] = 2e(n)[-S(z)\frac{\partial y'(n)}{\partial w_i}], \]  

\[ w_i = \{b_0, b_1, \cdots b_{n-1}, a_1, a_2, \cdots a_{m-1}\} \]

and it can be easily deduced that

\[ \frac{\partial y'(n)}{\partial b_i} = \frac{1}{A(z)}\left(z'x(n) + B(z)F(z)\frac{\partial y'(n)}{\partial b_i}\right) \]  

\[ \frac{\partial y'(n)}{\partial a_i} = \frac{1}{A(z)}\left(-z'H(z)x(n) + B(z)F(z)\frac{\partial y'(n)}{\partial a_i}\right). \]  

Obviously the estimated gradient vectors are dependent on the feedback path and it can be found that the feedback loop in the ANC system will be close to instability if the magnitude response of \( H(z)F(z) \), i.e. \( |H(e^{j\omega})F(e^{j\omega})| \) is close to unity. Introducing some approximations to (3)-(5) under the assumption of slow adaptation can lead to FVLMS algorithm. However, the complexity of the algorithm increases and the coefficients of the control filter become more sensitive to the sound path modeling error [3]. On the other hand, the deduction of FULMS algorithm ignores the dependency of the gradient vector on the feedback path and implies that the magnitude response of the open-loop transfer function is very weak. The combination of FULMS algorithm with the feedback neutralization technique [1], which needs an estimate of the feedback path, can be a thorough approach to solving the feedback problem. Since in FVLMS algorithm the estimation of the feedback path is also inevitable, it

\[ Figure 1: Schematic diagram of ANC system\]
makes sense to make comparison between the performance of these algorithms.

2.2 Lattice form adaptive IIR filter for ANC
The inherent stability and fast convergence rate are two advantages of lattice form adaptive IIR filtering algorithm for ANC (LFRLMS algorithm). The deduction of LFRLMS algorithm without the consideration of the feedback path can be found in [3]. In this paper, the performance of LFRLMS algorithm combined with feedback neutralization technique will also be investigated.

3. Simulations
The comparison of the three algorithms for ANC, (a) LFRLMS algorithm with feedback neutralization, (b) FULMS algorithm with feedback neutralization and (c) FVLMS algorithm, is made based on the following acoustic path assumptions:

\[ P(z) = 0.05 - 0.0001z + 0.0001z^2 + 0.8z^3 + 0.6z^4 - 0.2z^5 - 0.5z^6 - 0.1z^7 + 0.4z^8 - 0.05z^9 \]
\[ S(z) = 0.005 - 0.01z + 0.95z^2 + 0.01z^3 - 0.9z^4 \]
\[ F(z) = 0.8z - 0.5z^2 - 0.3z^3 + 0.4z^4 \]

Figure 2 demonstrates the learning curve of the three algorithms when the feedback path estimate is perfect. It can be seen that there is not much difference between these algorithms because all of them are gradient based adaptive algorithm and seek the minimum points on the error surface in different parameter spaces. If the estimate of the feedback path is not perfect and the signal to noise ratio (SNR) of the feedback path estimate is 10 dB, it can be seen from Fig. 3 that (a) converges much faster than the other two algorithms. (c) converges most slowly because the introduction of the feedback path estimate into the calculation of the gradient vectors makes it more sensitive to the feedback path modeling error. Some further simulations demonstrate that (a) and (b) will have about 7.5 dB increase of noise attenuation than (c) after the convergence of the ANC process.

\[ \text{Figure 2: Comparison of three algorithms with perfect feedback path estimation} \]

With the decrease of the SNR in feedback path estimate, the differences between the performance of the three algorithms are becoming increasingly apparent. If the SNR of the feedback path model decreases to 0 dB, it can be found that (c) might not converge. However, from some further simulations it can be found that (b) can settle on a level approximately the same as that of (a), i.e. 12 dB.

4. Conclusions
In this paper, the comparison of the performance of three adaptive IIR filtering algorithms for ANC was made and it is proposed that when the magnitude response of the feedback path is quite large and cannot be neglected, the LFRLMS algorithm with feedback neutralization technique is preferred.

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6. References