Adaptive Feedforward Cancellation (AFC) in Sound Fields: Computer-Based Approach for Active Noise Control (ANC)

Suparoek Junsupasen, Witthawas Pongyart, Nantakrit Yodpijit

Abstract— **Many scientific scenarios are now investigated by computer-based approach. The advantage of computer-based design is the deterministic solution that can rerun different experiments where same inputs result in same outputs under identical experiments. Generally, the real experiments are complicated and expensive to run. The main purpose of setting experiments is to determine cheaper and more reliable variables of the outputs from the expected range of data. This paper presents the computer-based model of adaptive feedforward cancellation (AFC) for active noise control (ANC) system in open sound fields. Findings indicate that AFC can reduce low frequency noise in a certain range of noise levels and the anti-windup technique can make the ANC system more effective. Demonstrations of a new active noise reduction, applications, discussion, and limitations are also provided in this paper.**

Index Terms— **computer-based approach, adaptive feedforward cancellation (AFC), active noise control (ANC), sound fields**

I. INTRODUCTION

NOISE is virtually everywhere. Noise becomes one of the most common environmental problems in many regions of the world. Noise exposure is a large public concern. The extent of the environmental noise pollution is getting larger since the population in the world has grown continuously. In contrast to many other environmental issues, noise problem continues to grow and causes an increase in complaints. Many studies indicates that noise leads to several health problems (i.e., high blood pressure [1], cardiovascular system [2] [3]), physiological/mental stress, sleep disturbance [1], [2], [4], [5], [6], [7] and results in a significant increase in medical expenses in many industrial companies [8].

Noise annoyance is always a topic of interest and public debate, especially among workers, local residents and scientists [9]. Regulations of noise exposures to workers and local residents have been one of major concerns for private and public organizations all over the world. Research reveals that workplace noise generating from several types of manual and machine operations, and many contributions from environmental noise sources (i.e. construction, road traffic, public work, and the neighborhood) can adversely affect human health and quality of life even at low levels [10], [11].

In Bangkok, the Thailand’s capital city there are over 8 million residents living within 1,568.7 square kilometers and over 14 million people living within the surrounding Bangkok Metropolitan Region. Several million residents are exposed to the environmental noise level exceeding 70 dBA, typically coming from road traffic noise. A recent study explores noise complaints from local residents nearby an electric power plant located in Bangkok [12]. This study indicates that low frequency noise (20 – 200 Hz) generated from cooling towers is the dominant noise source in the electric power plant.

The objective of the current study is to determine an effective noise control method for reducing noise exposures to plant workers and local residents around the electric power plant using engineering control.

II. METHODS

Noise problems become more and more critical due to a continuing increase in the use of large industrial equipment (i.e., turbines, engines, transformers, compressors, etc.) in many industries. In most cases, the priority for noise reduction is the elimination of the hazardous noise or substitution of quieter equipment with an emphasis on engineering control methods. If the hazardous noise cannot be controlled through engineering controls, the use of administrative controls (i.e., changes in work schedule or work location for reducing the worker exposure to hazardous noise, etc.) is preferred.

In this study, a new design of ANC system is developed and proposed for noise control in the electric power plant. The traditional approach for noise control is the use of passive techniques (i.e., barriers, enclosures, etc.) to reduce

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noise. However, the disadvantage of using passive approach is the higher cost and it does not work well with the low frequency noise. In addition to the ANC system, two types of controls exist: feedforward and feedback controls. The feedforward ANC is used when a coherent reference noise input is sensed before it propagates through the secondary path, whereas the feedback ANC attempts to cancel the noise without the benefit of an upstream reference input. According to findings from the previous study on environmental noise at the electric power plant, it is found that cooling tower generates noise over 85 dBA in low frequency ranges [3]. Thus, the current study is to develop a new ANC concept for reducing the noise level (see Fig. 1).

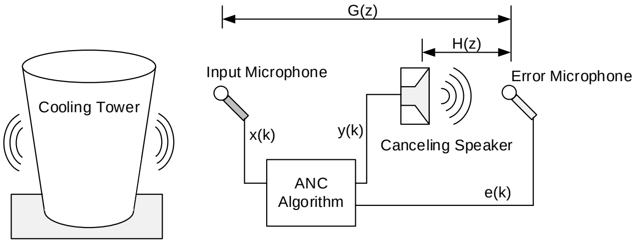

Fig. 1 The design model of AFC for ANC system in the electric power plant.

According to the Fig. 1, the diagram of ANC system with feedforward is given in Fig. 2; where (1) FIR Filter generates the anti-noise signal; (2) adaptive algorithm helps adjust FIR Filter to have optimal parameters; (3) limiter is the constraint on the output; and (4) secondary path (Ĥ(z)) compensates delay and attenuation in the H(z) [13].

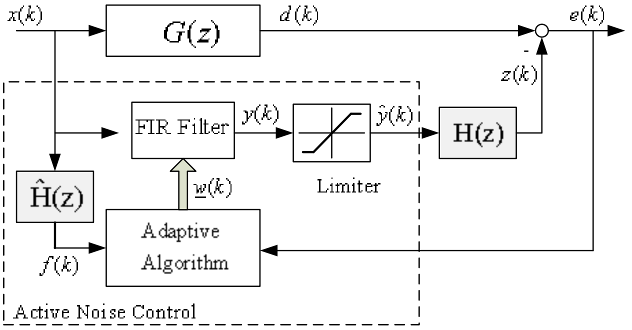

Fig. 2 Block diagram of ANC system with feedforward feedback.

In fact, the secondary path, Ĥ(z), is the mathematical model of the H(z), and any error in this model affects the performance of the feedforward ANC system. If the error is above a certain acceptable limit, the system will become unstable. To avoid problems relating modeling error, the ANC system without secondary path needs to be considered. In comparison to several algorithms, the AFC model is one of the most effective methods for this project. It is because the AFC is a feedback ANC system that has been developed to control a certain range of noise frequencies without reference input [14], [15]. The block diagram of ANC system with AFC used in this study is given in Fig. 3.

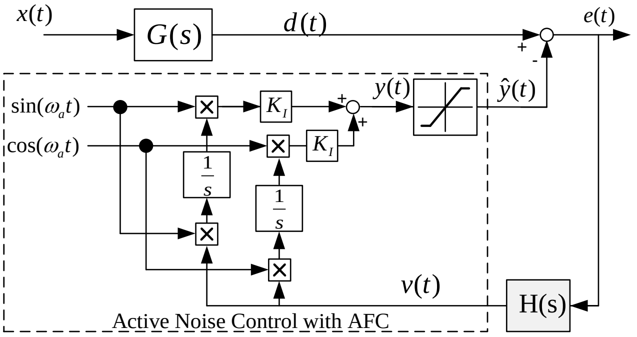

Fig. 3 Block diagram of ANC system with AFC.

The idea of AFC is developed from Internal Model Principle (IMP). Thus, AFC can deal with a small range of noise frequencies [16], [17]. The algorithm in continuous time is given in Fig. 1. Signal from error microphone *v*(t) is calculated from sin(ω$_a$t) and cos(ω$_a$t) functions for the magnitude and phase of anti-noise signal *y*(t). The learning rate in the AFC algorithm is determined by the K_I constant. The speed of noise reduction depends upon learning rate adjustment [18].

In Fig. 4, the transfer function *C*(s) represents the input-output model of the AFC as illustrated in equation (1). The relationship between the primary path *G*(s), secondary path *H*(s), and *C*(s) is shown in equation (2). The transfer function *T*(s) represents the coupling between the noise d(t) source and the error microphone [16]. Since the magnitude of the *C*(s) is very high at ω$_a$, the gain of the *T*(s) will be very low, and the error signal will be reduced.

$$\frac{Y(s)}{V(s)} = C(s) = K_I \frac{s}{s^2 + \omega_a^2} \tag{1}$$

$$\frac{E(s)}{D(s)} = T(s) = \frac{H(s)}{1 + C(s)H(s)} \tag{2}$$

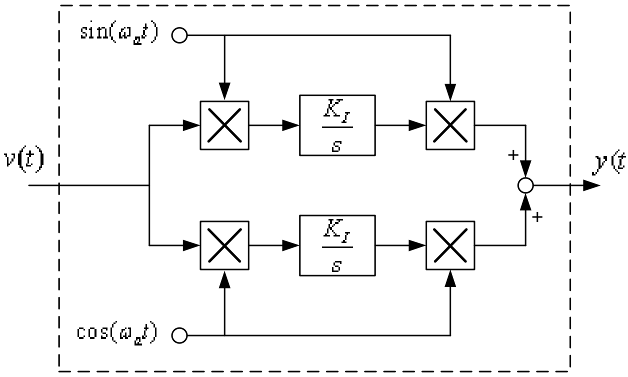

Fig. 4 The AFC algorithm in a continuous time.

III. RESULTS

In the computer simulation, where ω_a = 40 rad/sec and H(s) is a second order low pass filter which has a cutoff frequency = 50 rad/sec, the result shows the deep attenuation in a very narrow band at ω_a, which is the usual characteristics of the AFC. However, an AFC with high learning rate has different behavior. The high learning rate value increases the effective range of frequencies (20-60 Hz) for a 10 dB noise reduction as given Fig. 5. Since the characteristics of the AFC with high learning rate are suitable for low frequency noise from the cooling tower, the modified AFC is made for noise reduction in this project.

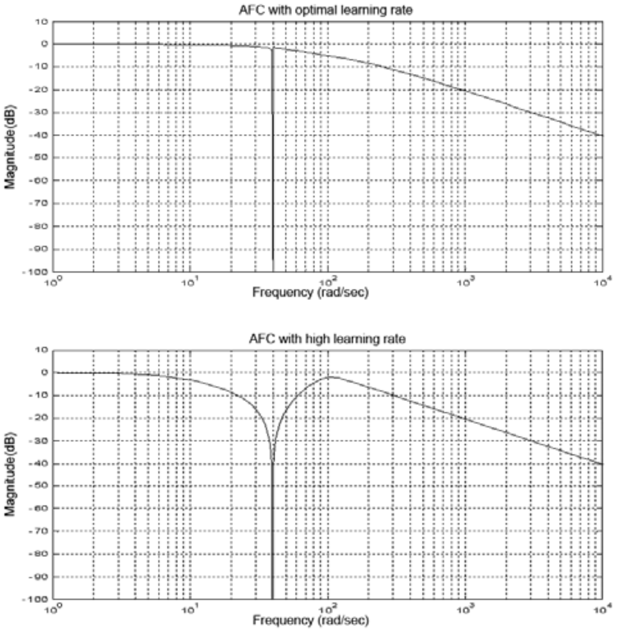

Fig. 5 Frequency response in ANC system with AFC.

However, an increase in the parameter K_I leads to another problem called “integrator windup.” It happens when the output signal of the integrator is larger than the constraint.

As the output of the integrator is amplified by the high value of K_I, the effect of the integrator windup will increase, and lead to a performance drop. Therefore, the anti-windup is implemented in the AFC to reduce this problem. The modified AFC is shown in Fig. 6.

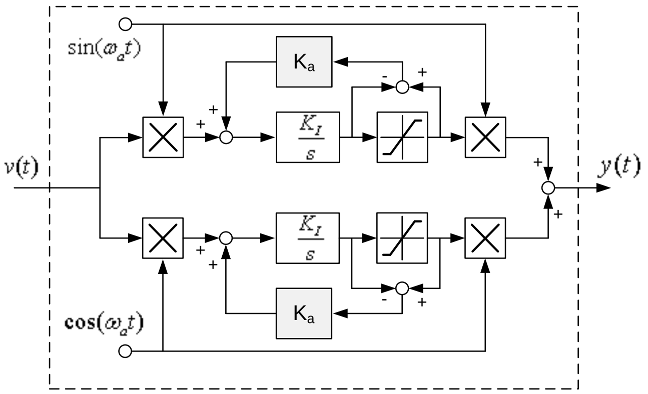

Fig. 6 The AFC system with an anti-windup scheme.

In this study, the recorded noise from cooing tower at the electric power plant is used as an input signal x(t) in the computer simulation (see Fig. 3). Random transfer functions G(s) and H(s) are used for the AFC ANC system testing. Firstly, the AFC is disabled and the signal from the error microphone, v(k) is observed. Results from signal v(k) in noise frequencies ranged 10-200 Hz without AFC ANC system are given in Fig. 7.

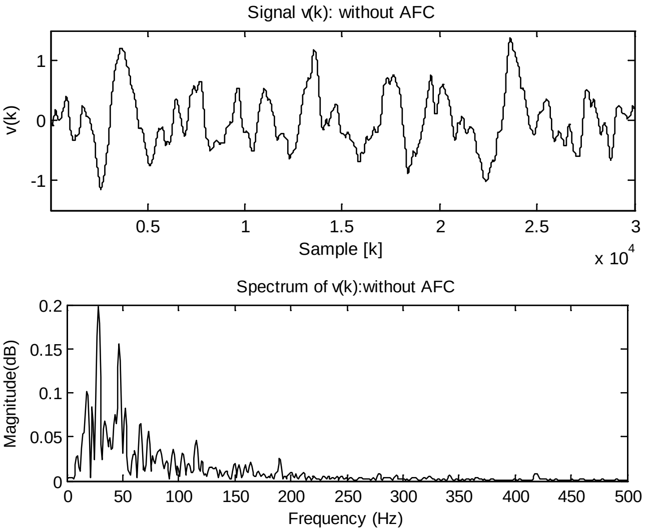

Fig. 7 A graph of magnitude response of the filter.

When the AFC is enabled, results from the computer simulation indicate that AFC noise reduction works well over the dominant low frequency ranges (10-200 Hz), especially at ω_a = 28 Hz as illustrated in Fig. 8. A comparison between signal v(k) before and after implementing high learning rate AFC; when a heavy solid line represents signal v(k) with high learning rate AFC; and a light dash line represents a previous result of signal v(k) without high learning rate AFC. In this computer simulation, there is no output constraint since the limiter has not been implemented. When the limiter is implemented, the integrator windup reduces the gain of the AFC and causes more ripples in the error signal v(k) as shown in Fig. 9.

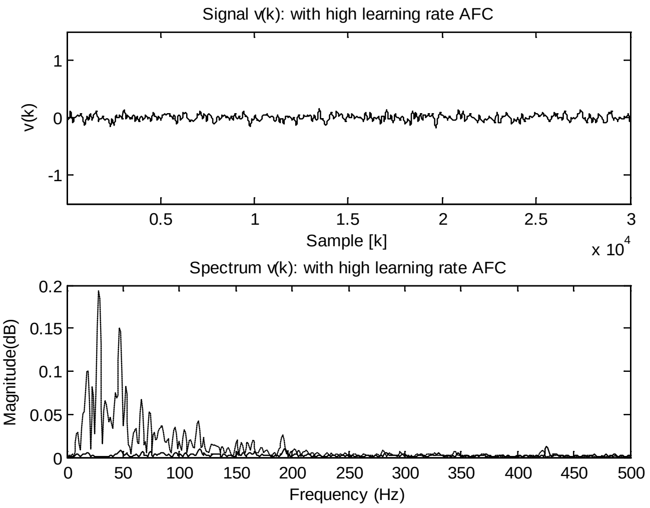

Fig. 8 Signal v(k) with AFC.

Fig. 9 shows the computer simulation results on signal *v*(k) from the AFC ANC system with and without an anti-windup scheme. It is found that noise reduction works more effectively when anti-windup is utilized. As a result, the ripple in the error signal is significantly reduced.

In the consideration of the effect of wind on the primary path and the secondary path, the computer simulation is run when the transfer function is altered at k = 15000. The computer simulation results indicate that changes in primary path has less impact on signal *v*(k) than changes in secondary path. It should be noted that changes in secondary path results in changes in delay time. Fig. 10 shows that the oscillation of signal *v*(k) increases when the parameter k is greater than 15000. However, a double increase in a delay time is not practical in a real situation. To make the system more robust, decreasing learning rate can be an option, but it might reduce the efficiency of noise reduction. In addition, a replacement of the lead compensator in the system can help improve the stability of the current ANC system.

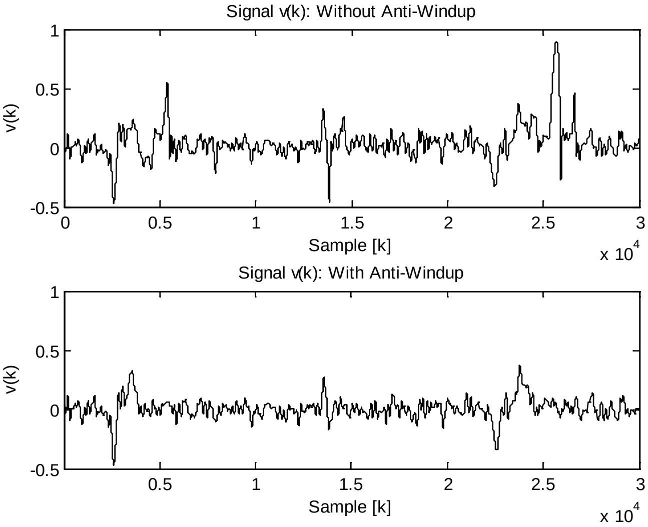

Fig. 9 Results from computer simulation with and without an anti-windup scheme.

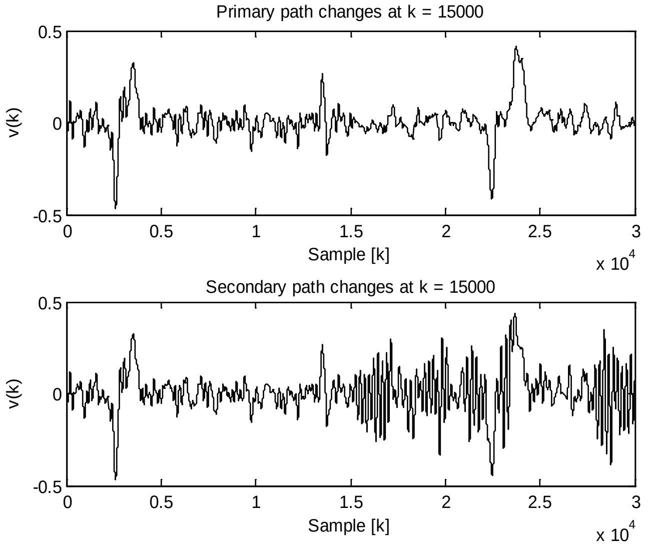

Fig. 10 Changes in primary path and secondary path affecting signal v(k).

IV. CONCLUSIONS

Findings from the current study indicate that the AFC ANC system is an effective method for low frequency noise reduction. It is implied that the AFC ANC system can be used for noise reduction at the cooling tower in the electric power plant. In fact, an increase in learning rate results in a wider effective frequency range for AFC in reducing the low frequency narrow band noise. The AFC ANC system works well without secondary path model. In the computer simulation, changes in primary path and secondary path have no effect on the AFC ANC system. However, changes in delay time in secondary path influence directly on the stability of the AFC ANC system. It is also found that the use of anti-windup schemes in AFC ANC system can reduce the effect of the constraint output on the overall efficiency of the AFC ANC system.

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