Research Article

Low Frequency Noise Reduction with Active Noise Control in Laboratory Settings

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Abstract
Noise problem becomes a major concern for public health throughout the world. This research is conducted to investigate how to reduce low-frequency noise in laboratory settings using Active Noise Control (ANC) technique. Experiments are performed under two conditions: 1) in a close room (6.7 m wide, 11 m long, and 2.87 m high), and 2) in an open field (8.2 m wide and 18 m long). Low-frequency noise at 200 Hz is generated by the 1,000 W speaker (as noise source), and the 1,200 W speaker is used as noise cancelling speaker. Error microphone and spectrum analyzer are installed for measuring noises. Findings indicate that noise reductions of 14.38 dB and 10.73 dB can be made in a close room and in an open field, respectively. Applications and limitations for this research are also discussed.

Keywords: Noise, Laboratory, Open field, Active Noise Control (ANC)

1 Introduction

Noise has become a serious environmental problem in many countries around the world. Exposure to noise should be controlled and is now a large public concern. The extent of the ambient noise problem is becoming more and more critical since the community population has changed and increased significantly. 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 (for example, high blood pressure [1], cardiovascular disease [2], [3], physiological health issues, mental stress, sleep disturbance [1], [2], [4]–[7]) and results in a significant increase in medical expenses for public and private

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organizations [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 capital city of Thailand 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 and indicates that low frequency noise (20–200 Hz) generated from cooling towers is the dominant noise source in the electric power plant [12].

The major objective of the current research 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 with an emphasis on Active Noise Control (ANC).

2 Methods

Long-term exposer to noise becomes more and more critical for public health concerns among residents due to a continuing increase in the use of large industrial equipment (i.e., turbines, engines, transformers, compressors, etc.) in large industrial plants. 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.

The traditional approach for noise control is the use of passive techniques (i.e., barriers, enclosures, etc.) to reduce noise. However, the major disadvantage of using passive approach is the higher cost. Additionally, passive noise control does not work well with the low frequency noise. Therefore, many studies on active noise control are conducted. But, most studies in the past are performed in the duct [13]. Applications of using active noise control are found in many areas, for example in transformers, natural ventilation windows, and communications chassis [14]. In this study, a new design of ANC system is developed and proposed for noise control in the electric power plant. 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 dB(A) in low frequency ranges [3]. The feedforward ANC system in the case study of electric power plant is given in Figure 1.

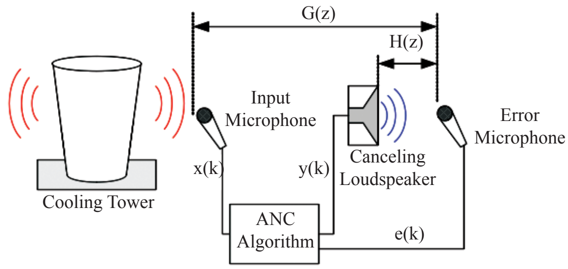

Figure 1: The feedforward ANC system in the electric power plant.

According to the Figure 1, the diagram of feedforward ANC system is given in Figure 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 ($\hat{H}(z)$) compensates delay and attenuation in the H(z) [15].

In fact, the secondary path, $\hat{H}(z)$, 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

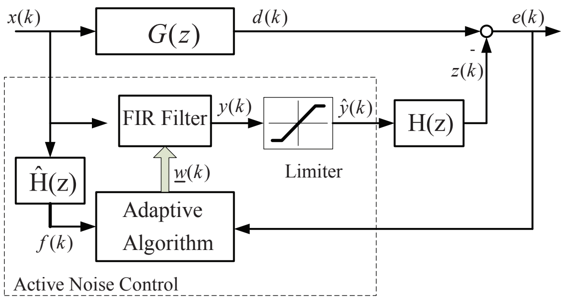

Figure 2: Block diagram of feedforward ANC system.

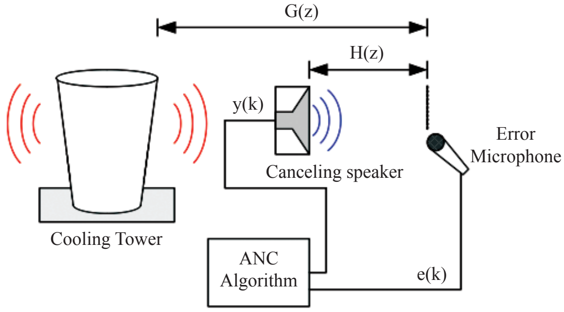

Figure 3: The design model of feedback ANC system in the electric power plant.

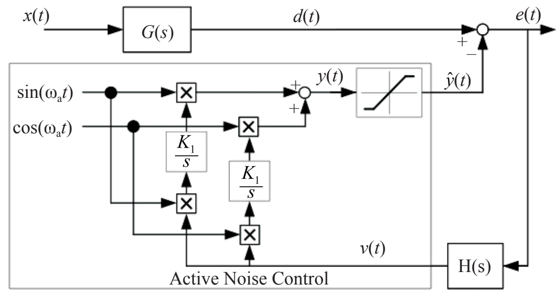

Figure 4: Block diagram of feedback ANC used for the electric power plant.

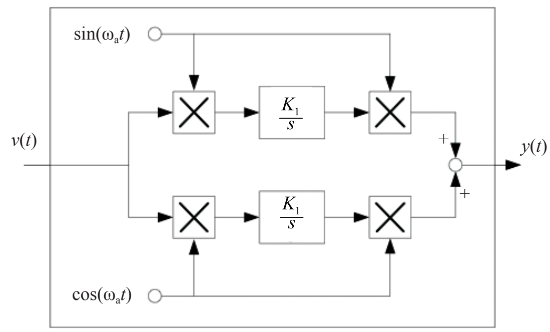

Figure 5: The feedback ANC algorithm in a continuous time.

error, the ANC system without secondary path needs to be considered. In comparison to several algorithms, the feedback ANC model is one of the most effective methods for this project. It is because the feedback ANC system that has been developed to control a certain range of noise frequencies without reference input [16], [17]. The design model of feedback ANC system in the electric power plant is given in Figure 3 and block diagram of feedback ANC system used in this research project is given in Figure 4.

In Figure 4 , the transfer function C(s) represents the input-output model of the feedback ANC 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 [18]. As 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.

$$\frac{Y(s)}{V(s)} = C(s) = K_1 \frac{s}{s^2 + \omega_a^2} \quad (1)$$

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

The idea of feedforward ANC system is developed from Internal Model Principle (IMP). Thus, the feedforward ANC system can deal with a small range of noise frequencies [18], [19]. The algorithm in continuous time is given in Figure 5.

Signal from error microphone v(t) is calculated from sin(ω_at) and cos(ω_at) functions for the magnitude and phase of anti-noise signal y(t). The learning rate in the feedback ANC algorithm is determined by the K_I constant. The speed of noise reduction depends upon learning rate adjustment [20].

3 Exerimental Results

Case 1. An application of feedback ANC system in a close room.

Experiments have conducted in a close room

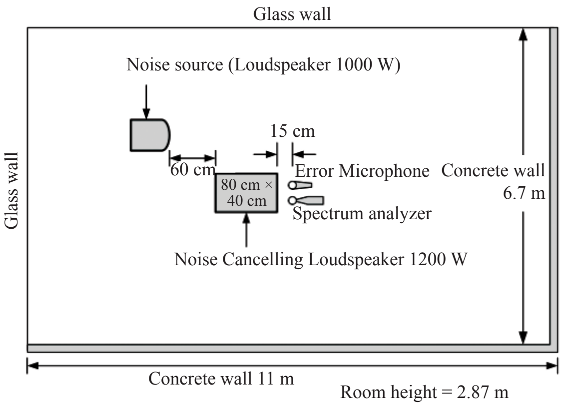

Figure 6: The feedback ANC system layout in a close room.

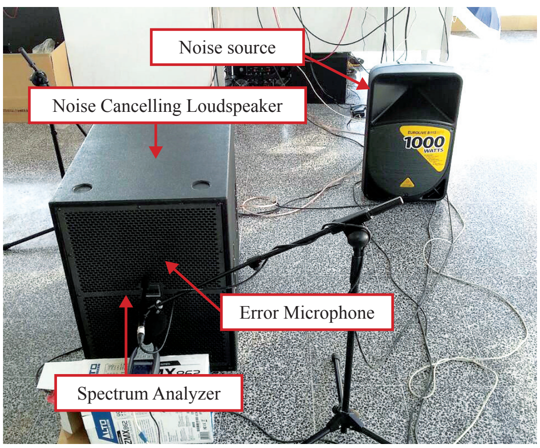

Figure 7: The position of feedback ANC equipment settings in a close room.

(6.7 m wide, 11 m long and 2.87 m height). Noise source is a 200 Hz sinewave. It was generated by 1,000 W loudspeaker. Outdoor Subwoofer 1,200 W is used to generate noise-cancelling wave. Superlux Microphone (model: ECM999) is used as an error microphone. Brüel&Kjær handheld spectrum analyzer (model: 2250) is used for sound frequency analysis. The feedback ANC system layout and its equipment location settings in a close room are given in Figures 6 and 7. Results of noise reduction obtained from a spectrum analyzer is shown in Figure 8.

Experimental results indicate that when the feedback ANC system is off and on, the 200 Hz noise levels in a close room are 81.09 dB and 66.71 dB, respectively. It is implied that a noise reduction of

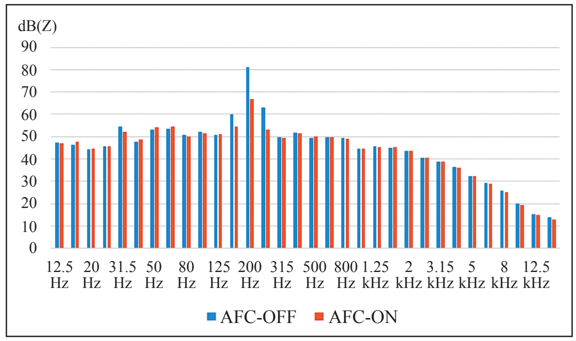

Figure 8: Noise reduction at 200 Hz in a close room.

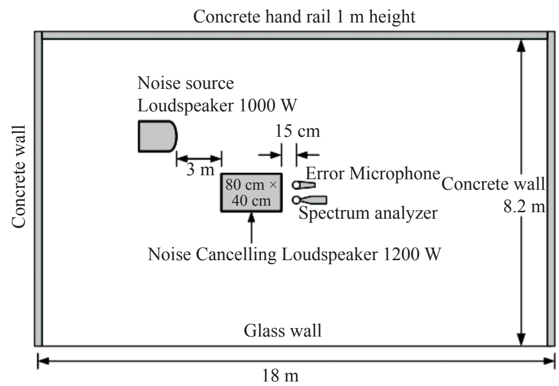

Figure 9: The feedback ANC system layout in an open field.

14.38 dB at 200 Hz can be made with the feedback ANC system.

Case 2. An application of feedback ANC system in an open space.

Experiments are conducted in an open space (8.2 m wide and 18 m long). Noise source is a 200 Hz sinewave. It is generated by a 1,000 W loudspeaker. A 1,200 W outdoor subwoofer is used for generating noise-cancelling wave. A Superlux microphone (model: ECM 999) is used as an error microphone. Brüel&Kjær handheld spectrum analyzer (model: 2250) is used for sound frequency analysis. An ambient environment is simmulated with a maximum wind speed of 17 km/h, a temperature of 28.5°C, a relative humidity of 68% RH. The feedback ANC system layout and its equipment location settings in an open field are given in Figures 9 and 10. Results of noise reduction in an open field obtained from a spectrum analyzer are shown in Figure 11.

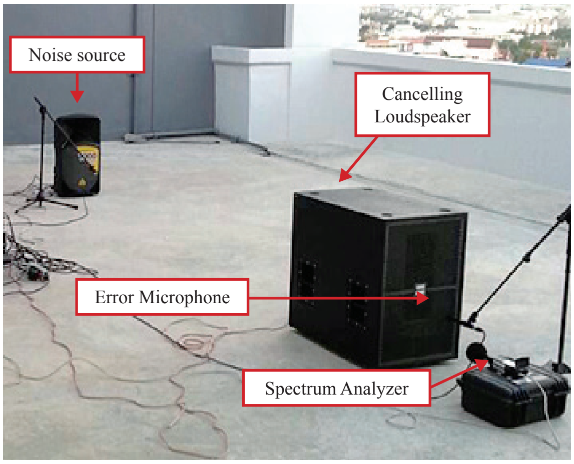

Figure 10: The position of feedback ANC equipment settings in an open field.

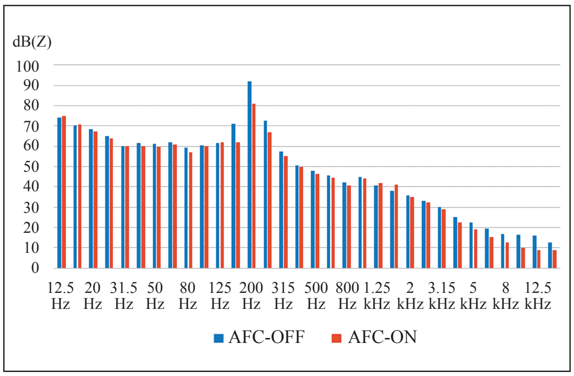

Figure 11: Noise reduction at 200 Hz in an open field.

Experimental results indicate that noise levels at 200 Hz are found at 91.83 dB and 81.10 dB in an open field when the feedback ANC system is off and on, respectively. It is meant that a decrease of 10.73 dB noise level at 200 Hz can be performed using the feedforward ANC system. The comparison of noise reduction using feedback ANC system in a close room and an open field is made and given in Table 1.

Table 1: Noise reduction at 200 Hz in a close room and an open field

Experimental Condition	Noise Level (dB)		Noise Reduction (dB)
	ANC is off	ANC is on	
Close Room	81.09	66.71	14.38
Open Field	91.83	81.10	10.73

4 Conclusions and Discussions

Findings from the current study indicate that the feedback ANC system is an effective method for low-frequency noise reduction. It is implied that the feedback ANC system can be used for noise reduction at the cooling tower in the case study of an electric power plant. In fact, an increase in learning rate results in a wider effective frequency range for feedback ANC system in reducing the low frequency narrow band noise. The feedback ANC system works well without secondary path model. In the current experimental study, it is found that the feedback ANC system in a close room performs better resulting in the higher noise reduction as compared to that in an open field. In addition, the feedback ANC system in an open field is more stable than feed forward ANC system in an open field. It is because the feedforward ANC system does not work well when there is a wind factor involved. It is also found that the location of microphone and loudspeaker is very critical to the stability of the noise reduction system performance.

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References

[1] R. Rylander, "Physiological aspects of noise-induced stress and annoyance," *Journal of Sound and Vibration*, vol. 277, pp. 471–478, Oct. 2004.

[2] P. Tassi, O. Rohmer, S. Schimchowitsch, A. Eschenlauer, A. Bonnefond, F. Margiocchi, F. Poisson, and A. Muzet, "Living alongside railway tracks: Long-term effects of nocturnal noise on sleep and cardiovascular reactivity as a function of age," *Environment International*, vol. 36, pp. 683–689, Oct. 2010.

[3] W. Babisch, G. Pershagen, J. Selander, D.

Houthuijs, O. Breugelmans, E. Cadum, F. Vigna-Taglianti, K. Katsouyanni, A. S. Haralabidis, K. Dimakopoulou, P. Sourtzi, S. Floud, and A. L. Hansell, "Noise annoyance-- a modifier of the association between noise level and cardiovascular health?," *Science of The Total Environment*, vol. 452–453, pp. 50–57, May 2013.

[4] M. Basner, C. Glatz, B. Griefahn, T. Penzel, and A. Samel, "Aircraft noise: Effects on macro- and microstructure of sleep," *Sleep Medicine*, vol. 9, pp. 382–387, May 2008.

[5] K. P. Waye, A. Clow, S. Edwards, F. Hucklebridge, and R. Rylander, "Effects of nighttime low frequency noise on the cortisol response to awakening and subjective sleep quality," *Life Sciences*, vol. 72, pp. 863–875, Oct. 2003.

[6] G. M. Aasvang, B. Engdahl, and K. Rothschild, "Annoyance and self-reported sleep disturbances due to structurally radiated noise from railway tunnels," *Applied Acoustics*, vol. 68, pp. 970–981, Sep. 2007.

[7] R. H. Bakker, E. Pedersen, G. P. van den Berg, R. E. Stewart, W. Lok, and J. Bouma, "Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress," *Science of The Total Environment*, vol. 425, pp. 42–51, May 2012.

[8] A. Koffeman and A. Kerkers, "Cost optimal reduction of noise in large industrial areas a method to select measures," in *Proceedings the NOISE-CON Conference on Noise Control Engineering*, 2000, pp. 3–5.

[9] D. Johnson, "Field studies: Industrial exposure," *The Journal of the Acoustical Society of America*, vol. 90, pp. 170–174, 1991.

[10] P. H. T. Zannin, A. Calixto, F. B. Diniz, and J. A. C. Ferreira, "A survey of urban noise annoyance in a large Brazilian city: The importance of a subjective analysis in conjunction with an objective analysis," *Environmental Impact Assessment Review*, vol. 23, pp. 245–255, Mar. 2003.

[11] M. Pierrette, C. M.-Favre, J. Morel, L. Rioux, M. Vallet, S. Viollon, and A. Moch, "Noise annoyance from industrial and road traffic combined noises: A survey and a total annoyance model comparison," *Journal of Environmental Psychology*, vol. 32, pp. 178–186, Jun. 2012.

[12] S. Junsupasen and N. Yodpijit, "A survey of workplace noise in an electric power plant," in *Proceedings Asia Pacific Industrial Engineering and Management Systems Conference (APIEMS)*, 2012, pp. 1569–1574.

[13] J.-Y. Lin and C.-W. Liao, "Combined feedback design of active noise control and face velocity control based on a novel secondary-path model of speaker-duct systems," *JSME International Journal Series C Mechanical Systems, Machine Elements and Manufacturing*, vol. 49, no. 1, pp. 180–188, 2006.

[14] X. Qiu, J. Lu, and J. Pan, "A new era for applications of active noise control," in *Proceedings of the 43rd International Congress on Noise Control Engineering: Improving the World Through Noise Control*, 2014, pp. 1–10, 2014.

[15] S. M. Kuo and D. R. Morgan, "Active noise control: A tutorial review," in *Proceedings of the IEEE*, 1999, vol. 87, no. 6, pp. 943–973.

[16] S. Weerasooriya, J. L. Zhang, and T. S. Low, "Efficient implementation of adaptive feed forward runout cancellation in a disk drive," *IEEE Transactions on Magnetics*, vol. 32, pp. 3920–3922, 1996.

[17] C. Kempf, W. Messner, M. Tomizuka, and R. Horowitz, "Comparison of four discrete-time repetitive control algorithms," *IEEE Control Systems*, vol. 13, pp. 48–54, 1993.

[18] W. Messner and M. Bodson, "Design of adaptive feedforward controllers using internal model equivalence," in *Proceedings American Control Conference*, 1994, vol. 2, pp. 1619–1623.

[19] M. Bodson, A. Sacks, and P. Khosla, "Harmonic generation in adaptive feedforward cancellation schemes," *IEEE Transactions on Automatic Control*, vol. 39, pp. 1939–1944, 1994.

[20] K. Y.-Hoon, K. Chang-Ik, and M. Tomizuka, "Adaptive and optimal rejection of non-repeatable disturbance in hard disk drives," in *Proceedings of the 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 2005, pp. 1–6.