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A Single channel open-window Active Noise Control system

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Abstract
Recently, several window systems with active noise controller have been suggested and proved to reduce the transmitted exterior noise through an open-window. However, most of the previous works have adopted multichannel scheme which possible cause the interference between channels, and the performance of the systems has been evaluated only in terms of the sound pressure level or the power spectrum. This paper presents an experimental work on the single channel duct type open-window ANC (Active Noise Control) and its performance evaluation in terms of the speech intelligibility. The results of scale-model experiments show that the single channel active window can reduce the noise level and improve intelligibility in the room while the window is open.

Keywords: Active Noise Control, Active windows, Room acoustics, STI, Speech intelligibility

INTRODUCTION

Noise pollution is one of the major environmental problems in the urban area. The control of the urban noise has becoming more important since the long term exposure to the noise has effects on health and living quality. The external noises such as the traffic noise or the living noise can be effectively reduced by closing windows. However, there are many situations when this solution is less effective e.g. in summer times, in tropical countries, or when the dwellers want openness and natural ventilation.

This problem might be solved using active noise control (ANC) that is an effective technique for suppressing low frequency noise [1]–[3]. There have been various studies to develop windows that could achieve a noise reduction and natural ventilation simultaneously [4]. Huang et al. investigated the active window system that was constructed by staggering the opening sashes of a spaced double glazing window to allow ventilation and natural light [5]. Hu et al. used a transparent thin film speaker in a home window that could provide both an invisible audio playback and an active noise cancellation device [6]. Kwon & Park proposed an active window system to reduce the exterior noise entering a room through an open window [7]. Pàmies et al. presented an experimental work on active control of sound transmission through a restricted opening bottom hinged window and its application to aircraft fly-over incident noise [8].

However, in spite of the promising results, many practical issues arise when the active windows have applied to real applications, i.e. the computational complexity of the algorithms and the interference between loudspeakers. These problems are mainly caused by the use of the multi-channel structures. In this paper, we present a single channel duct type active window system for reducing the noise transmitted to the room. The system is consist of a short length duct that configured to cancel the noise from the outside to the room using a single input single output feedforward algorithm. This structure has many advantages. The control complexity is reduced to the simple active control problem in a duct that is relatively well established and the interferences does not arise because of the single channel control loudspeaker.

Meanwhile, most of the previous studies, the performance of the active windows has been evaluated in terms of the sound pressure level or the power spectrum. However, the hearing perception of human depends not only on the sound level but also on the other factors - spectrum of the noise, masking, and room acoustics, hence more practical measures are necessary to assess the performance of the active window. Therefore, the speech intelligibility and the room acoustic parameters are considered to assess the performance of the active window systems in this paper. This study is necessary for ANC windows to be applied to real room.

The experimental study was conducted using a duct type active window system and a scaled model room. The intelligibility parameters and sound pressure level were evaluated for the road noise. The results show that the duct type single channel active window can improve the intelligibility as well as reduce the noise level in the rooms.

THE DUCT TYPE ACTIVE WINDOW SYSTEMS

Several issues arise when applying the ANC technology to the open windows. Some of the issues are the complexity of the controller, the interference between loudspeakers, the performance of the noise reduction, and the practical design architecture.

The single channel duct type ANC systems might alleviate such practical problems [9]–[11]. A schematic diagram of the ANC system installed in a room is shown in Fig. 1. The system is a duct shape structure with the ANC that is designed to be able to suppress the noise pass through in it. In the ANC applications, the ducts are one of the successfully applied systems as shown in many studies [12], [13]. The ANC is equipped with the microphones, loudspeakers, and DSPs. The DSP controller calculates 180 degrees out of phase signal, and the loudspeaker plays it. This makes the destructive interference between the incident noise and the control sound. Therefore, the sound energy of the exterior noise passing through the duct type window can be decreased. If the walls are well insulated than the main pass of the exterior noise into the room is the duct type open window, then the ANC reduces the noise energy in the room.

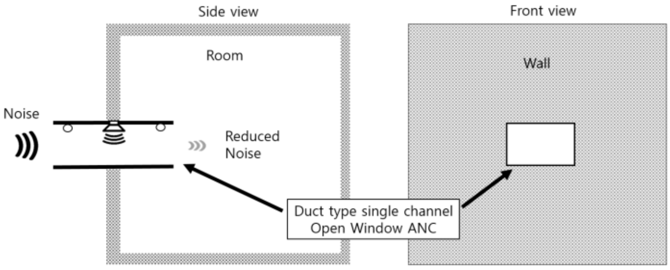


Figure 1. The Single Channel Duct Type ANC Window

The noise reduction ability of the duct type ANC window depends on its length. The longer length duct gives the better noise suppression but may arise aesthetic problems if they are installed in the house or buildings. The minimum length depends on the DSP processing time. The distance between the reference microphone and the secondary source should be long enough so that the system is causal. The propagation time of the sound between the reference microphone and the secondary speaker must be greater than the processing time, i.e.,

$$t_{\mathrm{ANC}} < t_d = d/c$$

where t_{ANC} is a processing time of ANC, t_d is propagation time, d is the distance from the reference microphone and error microphone, and c is the speed of sound.

Since the proposed system is a duct based shape and has single channel structure, it gives several advantages than the other multi-channel active windows systems.

- The system has no causality problem since the noise travels relatively long path in the duct.
- The simple single input single output algorithm can be adopted instead of the complex multichannel algorithm.
- It provides direct view and natural ventilation.

PERFORMANCE EVALUATION

The performance of the active windows has been evaluated in terms of the attenuation achieved inside the dwelling's room. However, it is well known that the hearing perception of human depends not only on the sound level but also on the other factors such as the spectrum of the noise, masking, and room acoustics. Hence, other practical measures are necessary to assess the performance of the active window. We investigate the feasibility of the room acoustic parameters and speech intelligibility for the performance measure of open-window ANC.

A. Room acoustic parameters

A number of room acoustics measures have been developed to describe the various quality of room acoustics characteristics since the 1950s. Many of room acoustics parameters are defined in ISO 3382. The standard is intended to evaluate conditions at audience seats in halls for musical performances [14]. Although these parameters are well defined and widely used in the architectural acoustics, they are not suitable for measuring the performance of the ANC windows. These parameters are measured using only room impulse response without considering noise in the room, since the purpose of these parameters is to evaluate the room itself but not to assess the exterior noises.

B. Speech Intelligibility

The intelligible speech means hearing the consonants and vowels correctly to identify the words and sentence structure. Several criteria have developed and used to measure the speech intelligibility. In room acoustics, STI (Speech Transmission Index), %Alcons (Percentage Articulation Loss of Consonants), and C50 are one of the most frequently used parameters for the intelligibility measure [15]. Among them, the C50 is based on the room impulse response and the %Alcons can be calculated from STI by a simple formula. Hence the STI is the most appropriate measure to access the open-window ANC.

The STI is an objective speech intelligibility measure that considers many parameters which are important for intelligibility such as speech level, background noise level, reflections, reverberation, and psychoacoustic masking. The basic principle of STI measurement consists of emitting synthesized human voice-like test signals instead of a real human voice and evaluates it as it would be perceived by the listener's ear. The intelligibility is calculated based on the contribution of the 7 octave bands within the frequency range of speech signals.

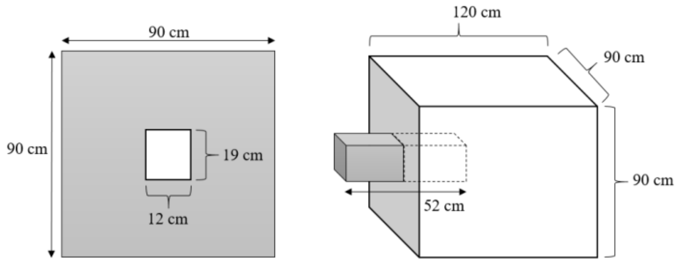
The speech intelligibility measurement acquires this signal then calculates MTIk (modulation transfer index) that represents the contribution of the noise to each octave band k. Then the STI value is obtained by a weighted summation of the MTIk for all 7 octave bands and the corresponding redundancy correction. The final STI is a single number between 0 (unintelligible) and 1 (excellent intelligibility).

EXPERIMENTS AND RESULTS

A. Experimental setup

Figure 2 shows the scale model of the room with the single channel open-window ANC. The dimension of the room was 0.9 m x 1.2 m x 0.9 m. The walls were made of 3 cm thick PVC (Polyvinyl chloride) boards, and the inner walls were covered with 2.5 cm thick sound absorbing materials to suppress excessive reverberation and the standing waves. The size of the window area was 0.12 m x 0.19 m.

The ANC controller used for the open window was Demo S-Fan 90 by Silentium [16]. It was a square-shaped duct with dimension 12 cm(W) ×19 cm(H) ×52 cm(L), and the ANC controller (S-Cube) was installed in it. The system has been originally developed for the demonstration of the ANC controller capability but was suitable for the experiment of open-window ANC. It consisted of a reference microphone, an error microphone, two loudspeakers, and an adaptive controller. Two PC-based software modules (Monitor and S-ANC Tool) were supported for control and interface. The Monitor program was the user interface for the ANC controller configuration and data acquisition. The S-ANC Tool was for analyzing the data acquired during the calibration process and simulating the ANC.



(a)

(b)

Figure 2. The Model Room and the ANC Window (a) A Schematic Diagram (b) Photos

Figure 3 shows the block diagram of the overall experiment setup. The recorded exterior noise was played using loudspeaker (Yamaha MSP5) that was located in front of the ANC window at 1 m distance. A precise measurement microphone (Earthworks M30S) was installed inside the model room to pick up the interior noise, and the EASERA software was used for the acoustic data analysis.

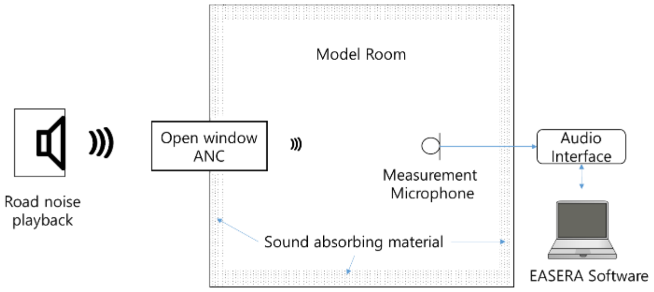


Figure 3. Experimental Setup

The open-window ANC was configured using the software modules at the starting stage of the experiment. The spectrum of the original noise and controlled noise after configuration is shown in Figure 4. The noise was reduced at the l00 Hz-2000 Hz range, and the maximum reduction is 35 dB at 1000 Hz. Note that this result represents the optimal configuration in the duct only, hence the noise reduction effect can be different when it is used as the open-window ANC.

B. Sound Pressure Level

The noise reduction ability of open-window ANC was tested with pink noise and the road noise. The loudspeaker played the noises, and the microphone in the model room measured the sound pressure level when ANC was ON and OFF. Table 1 shows the results. The noise levels were reduced 8 dB ~ 9 dB when the ANC was activated.

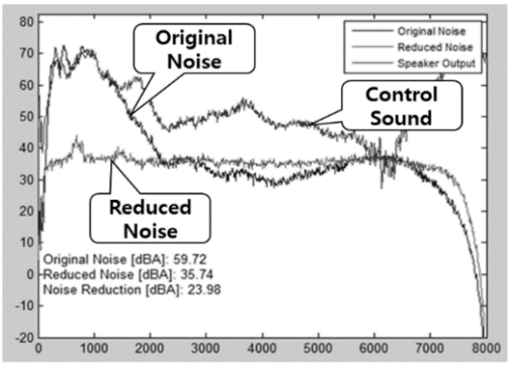


Figure 4. The Noise Spectrum with and without ANC

Table 1. Sound Pressure Level in the Model Room

	ANC Off	ANC On	Difference
Pink Noise	78.4 dB	69.2 dB	-9.2 dB
Road Noise	57.4 dB	49.4 dB	-8.0 dB

The frequency content of road noise is depicted Figure 5. The frequency range from 250 Hz to 4000 Hz has relatively high energy, and the peak level is at 1000 Hz band. Therefore, it is important for ANC window to reduce these frequency ranges.

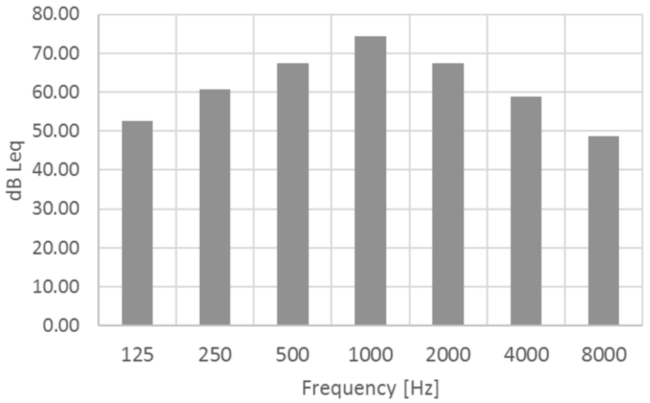


Figure 5. The Spectrum of the Road Noise

Figure 6 shows the magnitude spectrum of the road noise in the room when the ANC was ON and OFF. The noise level was suppressed approximately 5 dB ~ 15 dB between 80 Hz to 1500 Hz frequency range where the energy of the road noise was high. This result showed that the duct type single channel open-window ANC could suppress the transmitted road noise effectively.

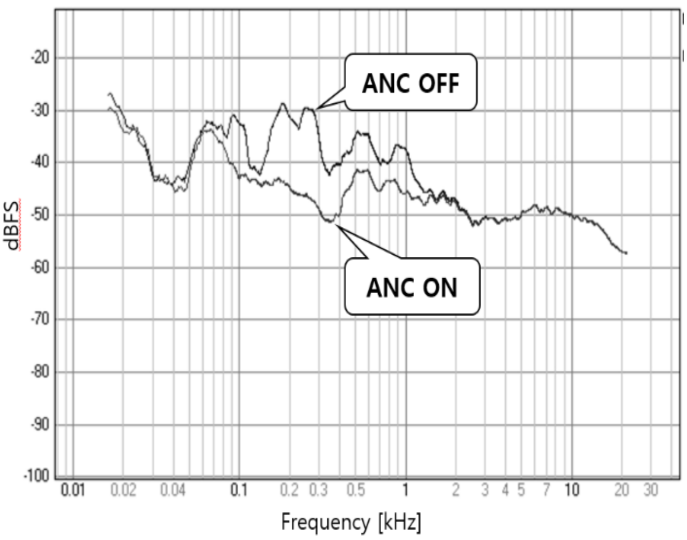


Figure 6. Amplitude Spectrum of the Noise in the Room

C. Intelligibility

Although the noise level was reduced by ANC window, the intelligibility should be evaluated for considering human perception. Figure 7 shows the setup for the STI measure. The loudspeaker in the model room generated the STI test signal while the outside one played the road noise.

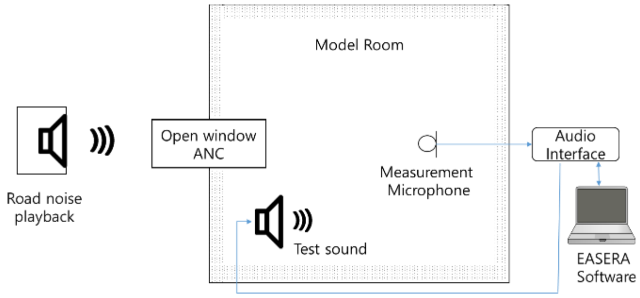


Figure 7. Experimental Setup for the Intelligibility Measurement

Table 2 lists the measurement values of the intelligibility parameters when ANC was activated and not. The STI was improved 0.125, and other intelligibility measures show better results when the ANC was ON.

Table 2. Intelligibility in the Room

	ANC Off	ANC On	Difference
STI	0.557	0.682	0.125
AlCons [%]	8.351	4.229	-4.122
STI (Male)	0.587	0.756	0.169
STI (Female)	0.649	0.792	0.143
RaSTI	0.445	0.672	0.227
Equiv. STIPa (Male)	0.594	0.755	0.161
Equiv. STIPa (Female)	0.655	0.795	0.140

The intelligibility values in Table 2 was for the frequency band from 125 Hz to 8000 Hz. But the ANC can suppress the noise effectively at lower frequency band. Fig. 8 shows the MTI (Modulation Transfer Index) values at each octave band. The changes were concentrated on the 500 Hz and 1000 Hz octave bands, and there were no changes at higher bands. Therefore, the overall intelligibility was improved because of the low frequency band.

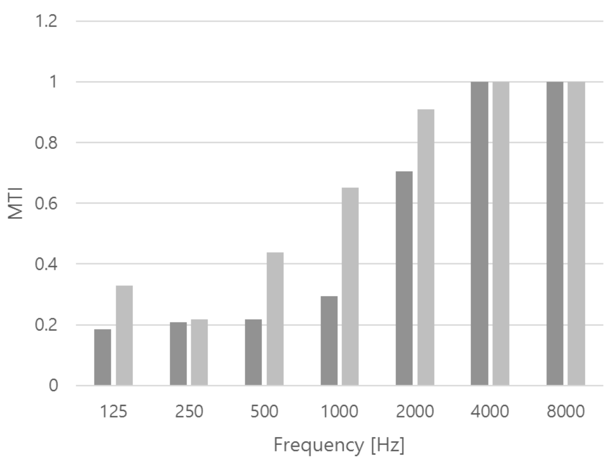


Figure 8. MTI when ANC Off (left) and ANC On (right)

CONCLUSION

In this paper, we presented the structure of the duct type single channel open-window ANCs and the performance evaluation in terms of intelligibility. Since the system has single channel and duct shape, it has several advantages than the other active windows systems i.e., the simple structure, simple control algorithm, and no interference between channels.

The performance of the ANC window has been evaluated in terms of the speech intelligibility parameters as well as the sound pressure level. The hearing perception of human depends not only on the sound level but also on the other factors i.e. spectrum of the noise, masking, and room acoustics. Hence, the intelligibility measure is more suitable to assess the subjective quality of the active windows. Several STI measures have been tested in the scale-model room experiments. The results show that the single channel duct type active noise control windows can improve the intelligibility as well as reduce the noise level in the room.

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REFERENCES

[1] S. M. Kuo and D. R. Morgan, "Active noise control: a tutorial review," Proc. IEEE, vol. 87, no. 6, pp. 943–973, 1999.

[2] S. M. Kuo, K. Kuo, and Woon Seng Gan, "Active noise control: Open problems and challenges," 2010 Int. Conf. Green Circuits Syst., pp. 164–169, 2010.

[3] N. George and G. Panda, "Advances in active noise control: A survey, with emphasis on recent nonlinear techniques," Signal Processing, vol. 93, no. 2, pp. 363–377, Feb. 2013.

[4] B. Lam and W.-S. Gan, "Active Acoustic Windows: Towards a Quieter Home," IEEE Potentials, vol. 35, no. 1, pp. 11–18, 2016.

[5] H. Huang, X. Qiu, and J. Kang, "Active noise attenuation in ventilation windows.," J. Acoust. Soc. Am., vol. 130, no. 1, pp. 176–188, Jul. 2011.

[6] S. Hu, R. Rajamani, and X. Yu, "Invisible speakers in home windows for simultaneous auxiliary audio playback and active noise cancellation," Mechatronics, vol. 22, no. 8, pp. 1031–1042, Dec. 2012.

[7] B. Kwon and Y. Park, "Interior noise control with an active window system," Appl. Acoust., vol. 74, no. 5, pp. 647–652, May 2013.

[8] T. Pàmies, J. Romeu, M. Genescà, and R. Arcos, "Active control of aircraft fly-over sound transmission through an open window," Appl. Acoust., vol. 84, pp. 116–121, 2014.

[9] W. Oh, "An Experimental Study on the Simple Active Noise Control Windows," in 3rd International conference on Innovative Engineering Technologies (ICIET'2016), 2016, pp. 87–90.

[10] W. Oh, "Performance Evaluation of Active Windows Using Speech Intelligibility," in International Conference on Engineering Technologies and Big Data Analytics (ETBDA'2016), 2016, pp. 66–68.

[11] W. Oh, "Noise reduction in rooms using a single channel active noise controller," in Engineering & Technology, Computer , Basic & Applied Sciences, 2016.

[12] L. J. Gelin, "Active Noise Control : A Tutorial for HVAC Designers," ASHRAE J., vol. 39, 8, no. August, pp. 43–49, 1997.

[13] D. Muthusamy and W. Ahmad, "Active Noise Control in Ventilation Duct A Prototype for Remote Laboratory," Blekinge Institute of Technology, 2012.

[14] ISO, "ISO 3382-1. Acoustics - Measurement of room acoustic parameters - Part 1: Performance spaces." 2009.

[15] G. Ballou, Handbook for sound engineers, 4th ed. Focal Press, 2008.

[16] Silentium LTD., "Silentium's Demo S-Fan 90." [Online]. Available: http://www.silentium.com/products/demo-s-fan-90/.