Overview of the application of active noise control technology in the indoor acoustic environment

Junyan Dong 1,2, Yupi Fu1*, Bomin Zheng1, Kechao Li1 and Jichen Qu1

1 School of Architecture and Design, Changchun Institute of Technology, Changchun, Jilin Province, 130000, China
2 School of Architecture and Design, The Tourism College of Changchun University, Changchun, Jilin Province, 130000, China
*Corresponding author’s e-mail: fuyupi@qq.com

Abstract. Passive noise reduction technology is not enough to improve the acoustic comfort of the indoor acoustic environment. This paper discusses the application prospects of active noise control technology in the indoor acoustic environment, studies the principle and development status of active noise control technology, describes the determinants of the effect about the active noise control and the application prospects in the indoor acoustic environment, and points out the current problems to be solved in the research and future research directions.

1. Introduction
The indoor sound environment is an essential part of the building environment. It is closely related to people’s daily lives. The active noise control technology is a method to eliminate noise by adding sound waves opposite to external noise. With the development of science and technology, the requirements of indoor sound environmental have gradually increased. Relative to passive noise reduction technology, active noise control technology has a flexible layout, a more extensive range of applications, more accessible to installation, and manufacturing advantages without changing the material and structure. It has a wide range of applications in the indoor sound environment.

Existing research on active noise control technology mainly focused on earphone noise reduction, industrial products (like automobiles, home appliances, etc.), such as active noise systems established in aircraft and automobile cockpits,[1] highway tunnel noise control.[2] The research of the indoor acoustic that uses the active noise control technology is less, mainly focused on the study of active sound-proof windows,[3] active noise control screens[4] as well as the special structure-borne sound wall and so on. [5]

2. Overview of the development of room acoustics
Room acoustics is also called architectural acoustics. In 1900, W.C. Sabine proposed the famous Sabine formula, which marked the birth of architectural acoustics. [6] In 1936, L. Cremer submitted the room response, which was used to study the effect of sound-absorbing materials on the reverberation time. In 1954, Schroeder proposed Schroeder frequency, which laid the foundation for the widespread application of impulse response and transfer function in building acoustics; [7] With the development of computer technology, building acoustics could begin to be simulated in the 1980s, through computer simulations to simulate sound waves spread and distribution. From the 1990s to the present, architectural
acoustics has gradually become audible, which has further promoted the modernization of architectural acoustics.

The indoor environment serves indoor users. As the focus of indoor acoustics research, it is a necessary task to ensure that the indoor acoustic environment is in a comfortable range. As people’s living standards continue to increase, the need to improve the comfort of indoor acoustic environments continues to grow. In terms of noise sources such as out-of-window, household appliance operating noise, and neighbour’s activity, only relying on passive noise reduction technology, there are still a large number of low-frequency noises that exceed the control. Therefore, the development of an open three-dimensional sound field of active noise control technology and apply it to indoor noise reduction to improve the acoustic environment is a viable option for interior noise control.

3. Noise hazards and necessary measures for noise reduction technology

3.1. The dangers of noise
Noise is a high volume and unpleasant voice. Continued exposure to noise not only causes hearing loss, depending on the duration and intensity of the noise, but also increases the likelihood of hypertension, sleep disorders, and ischemic heart disease. [8, 9] To protect people’s physical and mental health, the US Environmental Protection Agency (EPA) proposed health and tranquil noise standards in 1975, and the European Environment Agency (EEA) designated the Environmental Noise Directive (END) in 2000. China’s current standard proposes the corresponding standard for indoor noise of a house with GB 50118-2010 Code for Design of Sound Insulation of Civil Buildings.

The way that outdoor noise enters indoors could summarise into three forms: direct noise, reflected noise and the noise incoming through the envelope structure. [10] Direct noise refers to the waves passing through structural gaps, doors and windows’ opening. Reflected noise refers to the part of the noise that transmits into the room after being reflected by structures such as balcony canopies; envelope structures include walls, glass, door panels, and structural columns. The third case is that when the noise passes through the envelope structure, the transmission coefficient of walls and structural columns with high areal density is small, so the amount of noise transmitted by it is little. The area density of glasses and doors are small, and the noise projection coefficient is large; thus, a large amount of noise coming into the indoor that need extra attention in the processing environment.

3.2. Noise reduction measures overview
Noise reduction technology in acoustics mainly reduces noise from the sound source, during the propagation process, and at the human ear. The noise reduction at the human ear used primarily in the field of earphone noise reduction, and this article will not expand. Noise reduction at the sound source in the field of building acoustics, it is mainly focused on the noise control of household appliances, [11] and selecting materials with higher sound absorption performance to reduce indoor noise from the sound source. [12] The reduction technology of the noise in the transmission process is the main application of the indoor acoustic noise currently, from the noise reduction measures that can divide into two categories: passive and active noise control. Passive noise reduction refers to taking actions from the layout, structure, and internal design of buildings to reduce the amount of outdoor noise entering the room, and it has a good isolation effect against high-frequency noise. Active noise control refers to the use of this principle to set up additional sound sources. After receiving noise waves, the speaker releases sound waves opposite to the noise to offset the wave of noise, mainly aimed at low-frequency noise.

The control effect of passive noise reduction and active noise control on the noise of different frequencies makes them appear to complement each other. In practice, the application of passive noise reduction technology in indoor acoustic environments has become mature, but problems such as long installation cycles, inability to solve low-frequency noise problems, and difficulties in subsequent maintenance have become increasingly apparent. The industrial manufacturing and tunnels, noise treatment and other fields have already started the application of active noise control technology research. Its flexible layout, low-frequency noise isolation and better highlight the advantages of small size and
easy to control and to make up for the lack of passive noise reduction. ANC has broad application prospects in the acoustic environment.

4. Introduction and application of active noise control technology

4.1. Development of Active noise control Technology

The sound waves transmitted in the form of longitudinal waves in the gas medium. When two columns of waves propagate in the same medium and overlap, the vibration displacement of the media particles in the overlap range is equal to the vector sum of the displacements caused by the two columns of waves. As shown in Fig. 1. [13]

![Figure 1. Sonic a schematic superimposition.](image)

Active noise control technology uses this acoustic wave characteristic to receive noise signals through microphone equipment. After electrical signal processing, the speakers’ output sound waves with the opposite phase to the noise to achieve the effect of noise reduction. Active noise control, as early as 1933 years, was introduced by Paul Lueg. The specific operation principle is shown in Figure 2. [14]

![Figure 2. ANC technology principle.](image)

However, the noise waveform is not regular, also limited by the technical level. The delay from the output of the controller to the secondary sound source is too long, and the result is not accurate enough. Therefore, the active noise control technology had failed to widely used. Until 1980 years, DSP technology development greatly improved signal processing speed and accuracy and laid a solid foundation for the development of active noise control technology. [15, 16]

The goal of active noise control technology is to use an adaptive filter to invert unwanted noise to constrain the noise to a fixed range. The most common solution is to use the FIR filter in combination with the LMS algorithm. The process is shown in Figure 3. The specific expression is as follows. [17]

\[
y(n) = w^T X(n) \]  
\[
e(n) = d(n) - y(n)
\]
\[ w(n + 1) = w(n) + \mu e(n) x(n) \]  \hspace{1cm} (3)

In this expression, \( x(n) \) is the input signal matrix, \( w(n) \) is the adjustment weight matrix, \( d(n) \) is the target (ideal) output signal matrix, \( y(n) \) is the actual output signal matrix, and \( e(n) \) is the error signal matrix, the third formula is the weight adjustment formula, \( \mu \) is the convergence factor (the value is random, and the reciprocal of the maximum eigenvalue of the correlation matrix with \( 0 < \mu < x(n) \)).

Figure 3. LMS noise reduction process diagram. [17]

Through the Matlab simulation, the complex noise reduction effect of the ANC system environment in practical applications, as used controller filter length of about 44 ms and a step size of 0.0001 for these signal statistics, the result shown in Figure 4.

Figure 4. ANC noise reduction effect simulation

As can be seen from the figure, by comparing the difference between the residual error signal and the original signal in the frequency domain, it can be seen that most periodic signals have been attenuated in a large area. Besides, the noise reduction performance of ANC is not consistent at different frequencies, and it is sufficient for noise below 2kHz, while the high-frequency noise wavelength band is sensitive to phase deviation and needs to be supplemented by passive noise reduction measures.
4.2. Measures of active noise control technology

Active noise control technology has a wide range of applications in indoor environments. As a powerful complement to passive noise reduction, current application research is also mainly aimed at the doors and windows’ openings where passive noise reduction technology is weak. Kwon B designed an active window system, using the characteristics of active noise control technology, combined with the flexible requirements of the window opening. [3] Zhang Hongzhi based on active noise control technology active noise control surgery screens designed for the same consideration. [4] And Ke Xuan designed a special structure sound wall. Through the modification of the wall structure, the principle of acoustic interference used to achieve the purpose of noise reduction, which has great reference value for other applications of active noise control technology. [5]

5. Conclusion

The application of active noise control technology is much more in other fields, and the application research for an indoor environment is still insufficient. In view of the lack of passive noise reduction technology, active noise control technology is an excellent complement to the creation of a superb indoor acoustic environment in terms of flexibility, non-destructive structural integrity, and low-frequency noise processing. In summary, the application of active noise control technology in the indoor acoustic environment has broad prospects. Although ANC technology has not been adequately applied to actual projects, its theory needs to be further developed, but its advantages indicate that this technology industry has bright prospects. Compared with other environments, the noise source of the indoor acoustic environment is more complicated. In the actual application process, there are still many problems that need to be solved urgently. We need to improve the research process further to create a better indoor acoustic environment.

Acknowledgments

This work was financially supported by Science and Technology Project Foundation of Jilin Provincial Development and Reform Commission (No. 2019C059-4), Science and Technology Project Foundation of Jilin Provincial Department of Education (No. JJKH20191242KJ) and Jilin Provincial Social Science Foundation.

References

[1] HAN, X., (1999) Active noise control in the cabin. Audio Engineering, 5-9.
[2] WEI, Q., ZHANG, X., ZANG, C. and NI, Y., (2017) Study on active noise control sound field in highway tunnel. China Journal of Highway and Transport, 30: 77-82.
[3] Kwon, B. and Park, Y., (2013) Interior noise control with an active window system. Applied Acoustics, 74: 647-652.
[4] ZHANG, H., Jing, N. and Liyuan, G., (2016) The device design to reduce entrance noise. New Technology & New Products of China, 151.
[5] KE, X., NIU, X. and ZHAO, G., (2010) Study on theoretical feasibility of sound wave interference to eliminate noise by using sound wall with special construction. Journal of Wuhan University of Science and Engineering, 23: 12-15.
[6] Sabine, W. C. and Egan, M. D., (1994) Collected papers on acoustics.
[7] Vorländer, M., (2007) Auralization: fundamentals of acoustics, modelling, simulation, algorithms and acoustic virtual reality. Springer Science & Business Media.
[8] ZHOU, X., (1999) Noise control and application examples. Ocean Press.
[9] Passchier-Vermeer, W. and Passchier, W. F., (2000) Noise exposure and public health. Environmental health perspectives, 108: 123-131.
[10] HUANG, B., (1998) Research on noise reduction measures for housing. Guangxi Physics 46-48.
[11] QIAO, W., (1985) Home appliances and room acoustics. Science and Technology of Household Electric Appliance, 21.
[12] Fatima, S. and Mohanty, A., (2012) Noise Control of Home Appliances—The Green Way. Noise & Vibration Worldwide, 43: 26-34.
[13] Halliday, D., Resnick, R. and Walker, J., (2013) Fundamentals of physics. John Wiley & Sons.
[14] Paul, L., (1936) Process of silencing sound oscillations.
[15] Burgess, J. C., (1981) Active adaptive sound control in a duct: A computer simulation. The Journal of the Acoustical Society of America, 70: 715-726.
[16] Elliott, S. J. and Nelson, P. A., (1993) Active noise control. IEEE signal processing magazine, 10: 12-35.
[17] Kajikawa, Y., Gan, W.-S. and Kuo, S. M., (2012) Recent advances on active noise control: open issues and innovative applications. APSIPA Transactions on Signal and Information Processing, 1.