An experimental study on the active noise control using a parametric array loudspeaker

Jiaxin Zhong[1]
Tong Xiao[2]
Benjamin Halkon[3]
Ray Kirby[4]
Xiaojun Qiu[5]
Centre for Audio, Acoustics and Vibration, Faculty of Engineering and Information Technology, University of Technology Sydney
Tech Lab, 32-34 Lord St, Botany, Sydney, New South Wales 2019, Australia

ABSTRACT

An active noise control (ANC) system using a parametric array loudspeaker (PAL) was designed to cancel broadband noise at a person's ear, where a custom-made low-mass membrane pick-up from a retroreflective film and a laser Doppler vibrometer was used to form a remote sensing apparatus to determine the acoustic information with minimum obstructions to the person. The experiment results show that such an ANC system can achieve similar overall noise reductions from 1 kHz to 6 kHz at the ear as a similar one albeit using a traditional omni-directional loudspeaker. The noise reductions at nine points around the person were used to evaluate the effects of the ANC system in the other areas, and the results show the side effect of the ANC system with the PAL is much smaller than that with the traditional loudspeaker due to the sharp radiation directivity of the PAL. It is also shown that when the PAL was placed away from the person, the ANC performance and the side effect to the other areas remained similar due to its low geometrical spreading attenuation, but the side effect caused by a traditional loudspeaker to the other areas increased with its distance to the person.

1. INTRODUCTION

An active noise control (ANC) system can be designed to cancel the unwanted noise at a person's ears. Recent studies have investigated the error sensing strategies, where various remote error sensing techniques have been used to estimate the sound pressures at the person's ears accurately [1,2]. However, the secondary sources have received little attention to date.

When a secondary source is used to control the noise at a single location, the size of the created quiet zone is found to be about one tenth of the wavelength of the controlled sound in a diffuse sound

[1] Jiaxin.Zhong@student.uts.edu.au
[2] Tong.Xiao@student.uts.edu.au
[3] Benjamin.Halkon@uts.edu.au
[4] Ray.Kirby@uts.edu.au
[5] Xiaojun.Qiu@uts.edu.au

field [3,4]. However, the sound pressures in the other areas might increase due to the sound generated by the omni-directional secondary sources [5,6]. Placing a secondary source close to the control point can mitigate the increase of total energy in the other areas [7,8], but it brings obstructions to the person. Some studies have demonstrated the capabilities and potentials of using directional loudspeakers to cope with this problem [6,9]. For example, a directional source consisting of two closely located loudspeakers with pre-adjusted phase difference have been used to reduce the noise in the shadow zone behind a barrier [10].

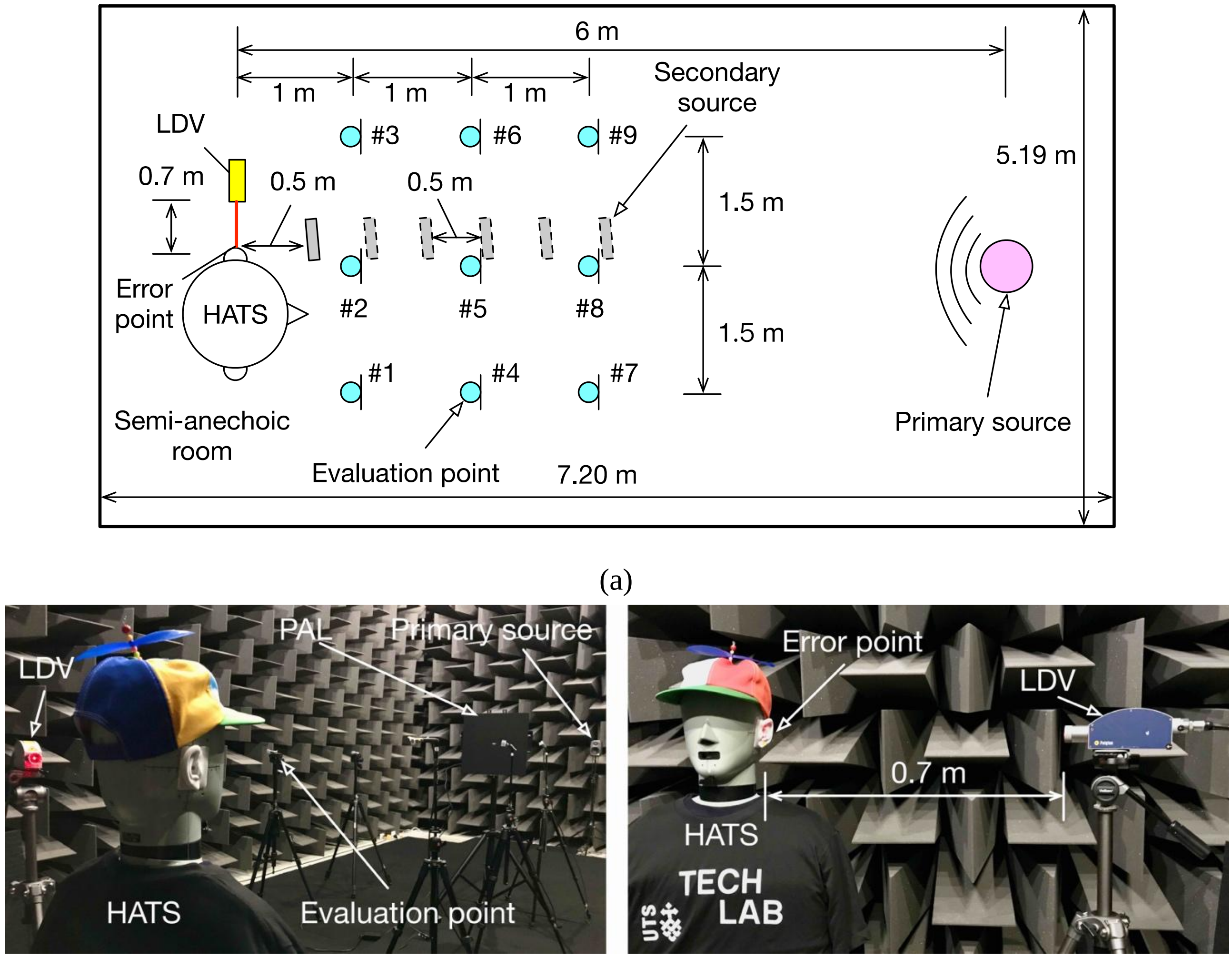
Parametric array loudspeakers (PALs), where the highly directional audio sounds are generated due to the nonlinear interactions of ultrasonic carrier waves in air, have shaper radiation directivity than existing traditional loudspeakers [11]. The advantages of using PALs in ANC systems have been demonstrated in a single-channel system where a 1.5 kHz sound wave at the target point was reduced without affecting sound fields in the other areas [6]. A two-channel ANC system using PALs have been used to reduce the factory noise from 500 Hz to 2.5 kHz [12]. However, the feasibility of using them to reduce the noise with a broader bandwidth remains to be investigated.

In a recent study, a remote acoustic sensing apparatus has been proposed, which placed a custom-made membrane pick-up at the point of interest, and the membrane vibration measured by a laser Doppler vibrometer (LDV) was used to determine the acoustic information at the point from a remote location [13]. The membrane pick-up was placed in the person's ear and the estimated signal from the LDV was used as the error signal in the ANC system. It has been demonstrated the upper limit frequency of effective control can be significantly improved up to 6 kHz [14]. This paper investigates the feasibility of applying this technique to broaden the effective frequency range of ANC experimentally with a PAL as the secondary source.

2. EXPERIMENT SETUP

The experiments were conducted in a semi-anechoic room with dimensions of 7.20 m × 5.19 m × 6.77 m (height). The schematic diagram and the photos of the experiment setup are shown in Figure 1. A broadband primary noise (1 kHz to 6 kHz) was generated by a traditional loudspeaker (Genelec 8010A) at 6 m away from a head and torso simulator (HATS, Brüel & Kjær Type 4128). The custom-made membrane was placed in the left synthetic ear of the HATS, and the radius and thickness of the membrane were 10.5 mm and 0.1 mm, respectively. The LDV (Polytec NLV-2500-5) was placed at a stand-off distance of 0.7 m away from the membrane in the left ear. All the equipment was at the same height during the experiments. The error signal was obtained by measuring the vibration of the membrane and was then fed into a commercial ANC controller (Antysound TigerANC WIFI-Q).

A PAL (Holosonics Audio Spotlight AS-16i with the surface size of 40 cm × 40 cm) was used as the secondary source, and the performance of the ANC system using it was compared with that using a traditional omni-directional loudspeaker (Genlec 8010A). Six groups of experiments were carried out, where the secondary source was placed in front of the error point at the distance from 0.5 m to 3 m with an interval of 0.5 m. To investigate the effects of the secondary source on the sound fields in the other areas, 9 evaluation microphones (Antysound Anty M1212) were placed in front of the HATS as shown in Figures 1(a) and (b). The acoustic signals at all the microphones and the HATS were recorded with a Brüel & Kjær PULSE system with a sampling rate of 12.8 kHz. The fast Fourier transform (FFT) analyzer in PULSE Labshop was used to obtain the FFT spectral.



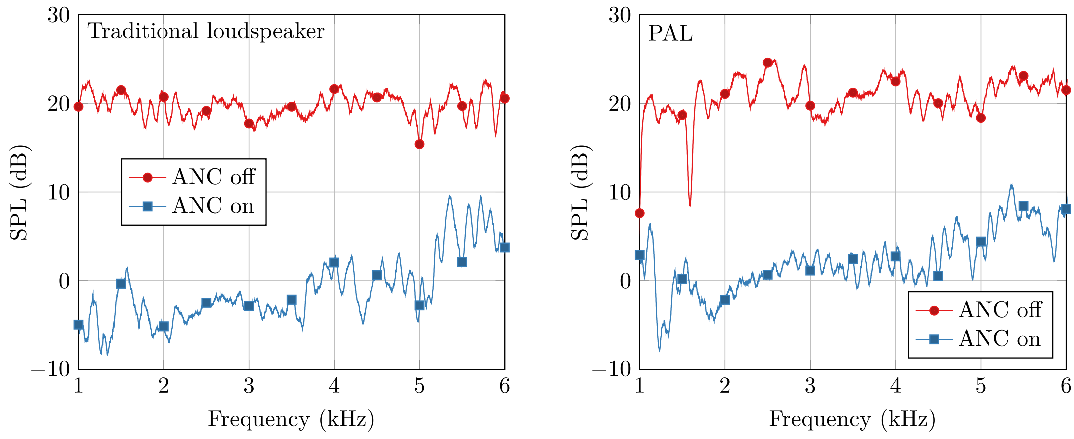
(a)

(b) (c)

Figure 1: (a) Schematic diagram of the experiment setup; (b) A photo of the experiment setup in the semi-anechoic room; and (c) A photo of the LDV error sensing system.

3. RESULTS AND DISCUSSIONS

Figure 2 shows the sound pressure levels (SPLs) measured by the left ear simulator of the HATS with and without ANC when the distance between the secondary source and the error point was 1 m. The overall noise reductions from 1 kHz to 6 kHz measured by the HATS were 18.7 dB and 17.8 dB when the traditional loudspeaker and the PAL were used as the secondary source, respectively. It is clear that both types of loudspeakers can reduce the noise at the ear effectively. There are two troughs near 1 kHz and 1.6 kHz on the curve of the primary noise without ANC in Figure 2(b), which might be caused by the scattering effects of the square PAL used in experiments.



(a) (b)

Figure 2:The SPLs measured by the left ear simulator of the HATS with and without ANC, where the secondary source was (a) a traditional loudspeaker and (b) a PAL, at a distance of 1 m from the error sensing point.

To investigate the effects of the secondary source on the sound fields in the other areas, the SPLs at two typical evaluation points #2 (closest to the secondary source) and #7 (farthest away from the secondary source) with and without ANC are presented in Figure 3, where the distance between the secondary source and the error point was again 1 m. Both types of loudspeakers had little effect for the SPLs at point #7 because it was away from the secondary source as shown in Figure 1(a). However, at point #2 which was close to the traditional loudspeaker, the SPLs changed significantly with ANC on due to the omni-directional secondary source, and the overall noise reduction from 1 kHz to 6 kHz of the ANC system was −4.9 dB indicating that the overall sound energy at this point increased with ANC. The overall noise reduction of the ANC system using the PAL at point #2 was only −0.2 dB due to its sharp directivity. Therefore, using a PAL has little effect on the sound fields in the other areas for an ANC system.

Figure 4 shows the overall noise reductions from 1 kHz to 6 kHz measured by the left ear simulator of the HATS and at the 9 evaluation points with ANC on when the distance between the secondary source and the error point, which is denoted by d_{se}, was varied from 0.5 m to 3 m. It can be seen in Figure 4(a) that the noise reductions using the PAL were similar to those when using the traditional loudspeaker, and are generally between 18 dB and 20 dB. Figure 4(b) demonstrates that the noise reduction levels at all evaluation points were generally increased as the distance between the traditional loudspeaker and the error point increased. Figure 4(c) indicates that the sound pressures at evaluation points were almost unchanged with the PAL except at points #2 and #5. The noise reduction levels at these two points were negative, indicating that the sound pressure increased with ANC on. The reason is that the two points were close to the radiation axis of the PAL as shown in Figure 1(a), and the SPL variation around them was large with and without ANC. The audio sound waves generated by the PAL decay slowly by distance, so the amplitude of the generated secondary sounds changes a little when the distance between the PAL and the error point increased. Therefore, the sound pressure in the other areas was less affected by the ANC system when the PAL was used at far away from the ear.

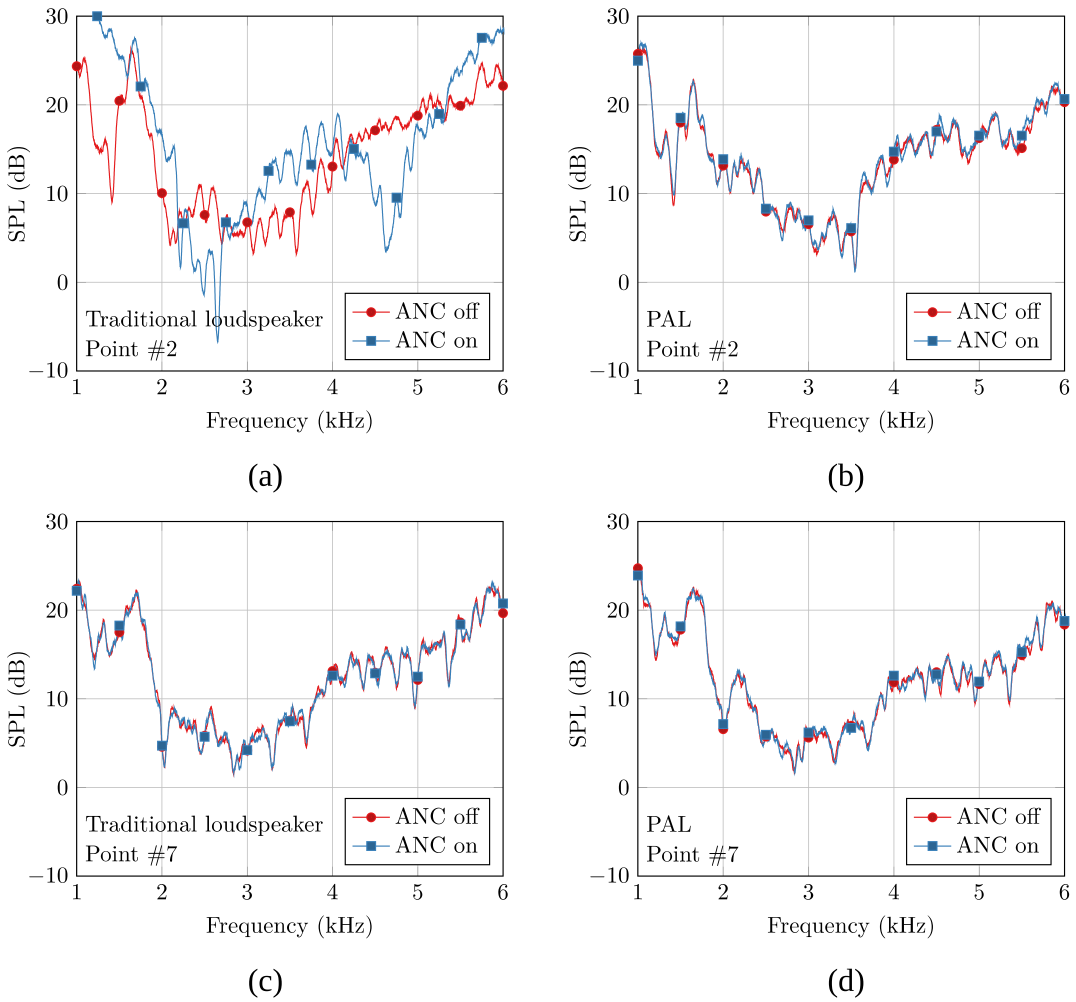


Figure 3: The SPLs at point #2 when the secondary source was (a) a traditional loudspeaker and (b) a PAL; and at point #7 when the secondary source was (c) a traditional loudspeaker and (d) a PAL. The distance between the secondary source and the error point was 1 m.

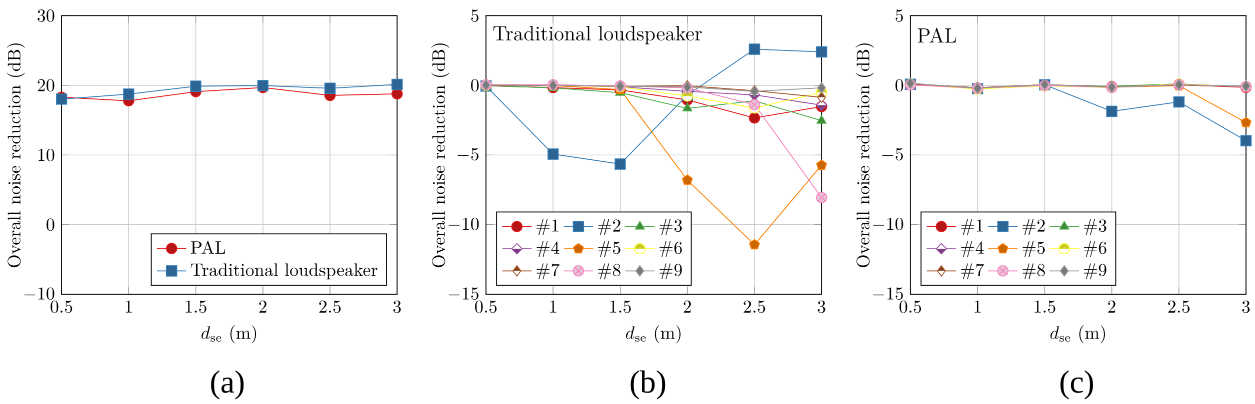


Figure 4:Overall noise reductions from 1 kHz to 6 kHz (a) at the left ear of the HATS, and at the evaluation points, where the secondary source was (b) a traditional loudspeaker and (c) a PAL.

4. CONCLUSIONS

In this paper, an active noise control (ANC) system using a parametric array loudspeaker (PAL) as the secondary source was studied experimentally, with the error signal detected remotely by a laser Doppler vibrometer (LDV). The performance of the ANC system was compared with a similar ANC system albeit using a traditional loudspeaker. The results demonstrate that the overall noise reductions from 1 kHz to 6 kHz at the person's ear were similar with both types of loudspeakers. The sound pressure levels in the other areas were almost unchanged when the PAL was placed away from the ear in the ANC system, while the overall sound pressure levels became higher with the traditional loudspeaker being used at a great distance from the ear. The PAL and the LDV system can be compactly placed away from the person without deteriorating the broadband noise reduction performance. Future work includes developing an accurate prediction model considering the scattering effects of the human head and the improving noise reduction performance of the ANC system using the PAL.

5. ACKNOWLEDGEMENTS

This research is supported under the Australian Research Council's Linkage Project funding scheme (No. LP160100616).

6. REFERENCES

[1] D. Moreau, B. Cazzolato, A. Zander, and C. Petersen, "A review of virtual sensing algorithms for active noise control," Algorithms **1**(2), 69-99 (2008).

[2] S. J. Elliott, W. Jung, and J. Cheer, "Head tracking extends local active control of broadband sound to higher frequencies," Sci. Rep. **8**(1), 1-7 (2018).

[3] S. J. Elliott, P. Joseph, A. Bullmore, and P. A. Nelson, "Active cancellation at a point in a pure tone diffuse sound field," J. Sound Vib. **120**(1), 183-189 (1988).

[4] J. Guo and J. Pan, "Effects of reflective ground on the actively created quiet zones," J. Acoust. Soc. Am. **103**(2), 944-952 (1998).

[5] J. Guo, J. Pan, and C. Bao, "Actively created quiet zones by multiple control sources in free space," J. Acoust. Soc. Am. **101**(3), 1492-1501 (1997).

[6] N. Tanaka and M. Tanaka, "Active noise control using a steerable parametric array loudspeaker," J. Acoust. Soc. Am. **127**(6), 3526-3537 (2010).

[7] P. Joseph, S. J. Elliott, and P. A. Nelson, "Near field zones of quiet," J. Sound Vib. **172**(5), 605-627 (1994).

[8] A. David and S. J. Elliott, "Numerical studies of actively generated quiet zones," Appl. Acoust. **41**(1), 63-79 (1994).

[9] Q. Hu and S. K. Tang, "Active cancellation of sound generated by finite length coherent line sources using piston-like secondary source arrays," J. Acoust. Soc. Am. **145**(6), 3647-3655 (2019).

[10] W. Chen, W. Rao, H. Min, and X. Qiu, "An active noise barrier with unidirectional secondary sources," Appl. Acoust. **72**(12), 969-974 (2011).

[11] W. S. Gan, J. Yang, and T. Kamakura, “A review of parametric acoustic array in air,” Appl. Acoust. **73**(12), 1211-1219 (2012).

[12] K. Tanaka, C. Shi, and Y. Kajikawa, “Binaural active noise control using parametric array loudspeakers,” Appl. Acoust. **116**, 170-176 (2017).

[13] T. Xiao, X. Qiu, S. Zhao, and B. Halkon, “A remote acoustic sensing apparatus based on a laser Doppler vibrometer,” Sensors (under review), (2020).

[14] T. Xiao, X. Qiu, and B. Halkon, “Ultra-broadband active noise cancellation at the ears via optical microphones,” arXiv:1909.03377v2, (2020).