JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Active Noise Control: Open Problems and Challenges

Ms. Aishwarya Jayawant Dalvi
Student Researcher
Mulund College of Commerce
Mulund West, Mumbai.

Dr. Vishal Borude
Assistant Professor
Mulund College of Commerce,
Mulund West, Mumbai.

Abstract—*This paper explores advanced active noise control (ANC) techniques, emphasizing the challenges of real-world implementation and identifying key open problems from a signal processing perspective. We propose innovative strategies to enhance ANC performance, including virtual sensing, residual noise masking, and active sound quality control. Additionally, we address challenges in practical applications, such as mitigating high-frequency and impulse-like noises, as well as managing noise from moving sources. Finally, we highlight ANC applications in consumer electronics and healthcare devices, showcasing potential features to support the development of cost-effective ANC solutions.*

Keywords: *Active Noise Control (ANC), Residual Noise Masking, Healthcare Device Applications.*

INTRODUCTION:

Active noise control (ANC) systems operate by generating secondary noise waves that are equal in amplitude but opposite in phase to the unwanted noise, effectively canceling both through the principle of superposition. These systems excel in reducing low-frequency noises where traditional passive methods are either costly or inefficient.

Adaptive filtering techniques are commonly employed in ANC systems to dynamically respond to changes in noise characteristics and environmental conditions. Among these, the finite impulse response (FIR) filter combined with the filtered-X least-mean-square (FXLMS) algorithm is widely used due to its robust performance. The advent of commercially available digital signal processors has significantly streamlined real-time implementation of ANC algorithms, driving progress in their development and practical use.

This paper provides a concise overview of foundational ANC algorithms while exploring key challenges and open research questions from a signal processing standpoint. Additionally, it introduces advanced techniques such as virtual sensing, residual noise masking, and active sound quality management to further enhance ANC performance for practical applications. Furthermore, potential add-on features are discussed to increase the functionality and cost-effectiveness of ANC systems, making them more suitable for diverse real-world applications.

ANC SYSTEMS AND OPEN PROBLEMS:

A fundamental single-channel ANC system utilizing the FXLMS algorithm is depicted in Fig. 1 [2]. In this setup, a reference sensor captures the reference signal x(n), which is then processed by the adaptive filter W(z) to produce the canceling signal y(n). This canceling signal is emitted through a secondary loudspeaker to counteract the primary noise. An error sensor monitors the system's performance by detecting the residual noise e(n) Adaptive algorithms are crucial for ANC systems to account for the effects of the secondary path S(z) [2].

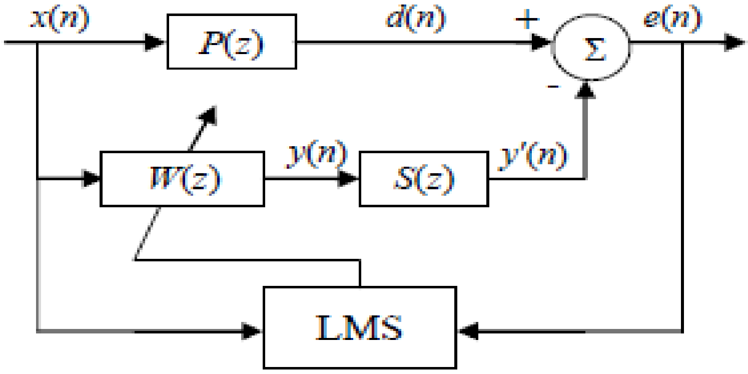

Fig. 1 Basic single-channel ANC system using the FXLMS algorithm

In this section, we use basic ANC algorithms to present some open problems for further research from adaptive signal processing viewpoints.

A. Broadband Feedforward Systems

Broadband feedforward ANC systems use the FXLMS algorithm to iteratively update filter coefficients for noise cancellation, tolerating phase errors in secondary-path modeling. FIR filters are common, but advanced filters and techniques like Kalman algorithms improve convergence. Challenges include developing robust on-line modeling for dynamic environments and mitigating acoustic feedback, which distorts reference signals.

B. Narrowband Feedforward Systems

Narrowband ANC systems generate reference signals internally to cancel periodic noise, using higher-order adaptive filters in various configurations. Key challenges include addressing frequency mismatches, optimizing filter designs for multi-frequency noise, and improving the management of single error signals for multiple filters.

C. Adaptive Feedback ANC

Adaptive feedback ANC systems estimate reference signals from outputs and errors, relying on accurate secondary-path models for effective noise cancellation. Research focuses on identifying suitable noise types, mitigating modeling errors, and improving reliability for applications like headsets and industrial environments.

CHALLENGES IN IMPROVING ANC PERFORMANCE

Fig. 2. Experimental setup of the snore ANC system

In this section, we illustrate several challenges to enhancing ANC system performance for practical applications using the example of a snore ANC system installed on a traditional headboard [17]. The setup for the bed partner's snore cancellation, shown in Fig. 2, includes two secondary loudspeakers and two error microphones mounted on the headboard. A human torso model, known as KEMAR (Knowles Electronics Mannequin for Acoustics Research), simulates the bed partner. Microphones placed inside the ear cavities of the KEMAR are used to assess performance as perceived by the human ears.

Spectral plots of the signals picked up by the error microphones and the microphones inside the KEMAR's ears were captured using an HP dynamic signal analyzer. These plots display the noise spectra before (ANC OFF) and after (ANC ON) activating the active snore cancellation.

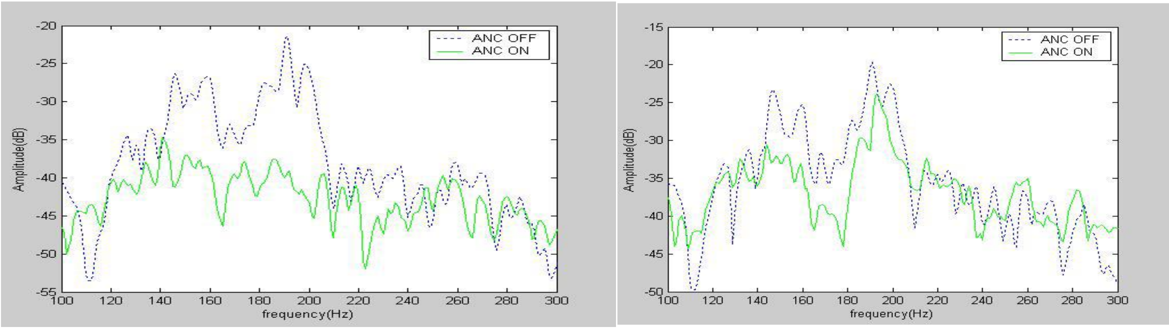

Fig. 3 and 4 .Spectra of signals at the left error microphone

Virtual Sensing Techniques Placement of Error Microphones

Figures 3 and 4 show snore ANC performance improves when error microphones are near the ears, with noise reduction of 10-20 dB at the error microphones and 5-10 dB at the KEMAR ear. Quiet zones are centered around error microphones, but creating these zones at virtual sensor locations (e.g., bed partner's ears) using headboard sensors remains challenging.

Class 1 - Requiring Preliminary Identification:

These algorithms use system models derived during an off-line training phase where sensors are placed at both physical and virtual locations. Performance depends on accurate models, but environmental changes may require re-training, making this method impractical in some scenarios.

Class 2 - No Off-Line Identification:

Algorithms like stochastic tonal diffuse field sensing bypass off-line training, making them more practical. They allow quiet zones to shift to virtual locations, making them ideal for real-world ANC applications. Further research is needed to refine virtual sensing techniques for dynamic environments.

Residual Noise Masking

ANC systems often leave residual noise due to physical constraints. Masking this noise with calming audio, such as music or nature sounds, improves comfort and aids relaxation. Masking signals can also support ANC processes like:

1. Residual noise masking based on psychoacoustic principles.
2. Off-line secondary-path modeling.
3. On-line modeling using the FXLMS algorithm.

An integrated system combines masking audio with anti-noise to refine error signals and enhance ANC performance. In consumer devices, soothing sounds like rain or streams serve dual purposes of masking and system optimization.

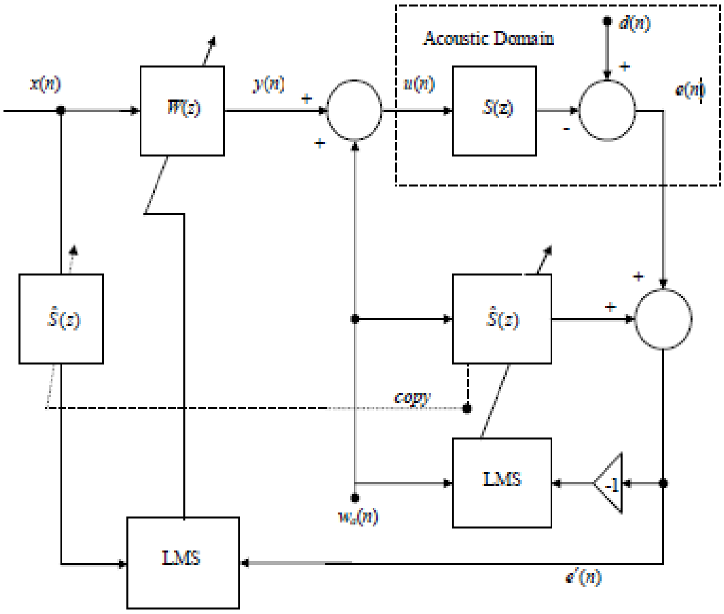

Fig. 5 Integrated audio/ANC system that provides both audio cancellation and on-line secondary-path modelling

To seamlessly mask the residual noise, the audio signal wa(n) must be carefully selected and processed by the psychoacoustic processor, taking into account the characteristics of the residual noise. Additionally, it is crucial to adjust the volume of the audio signal to match the level of the residual noise. This requires further research into psychoacoustic principles and human perception of sound.

Active Sound Quality Control: In certain applications, it is desirable to maintain a low-level residual noise with a specific spectral shape or altered noise signature. Active sound quality control (ASQC) is a valuable extension of ANC, as it modifies the amplitudes of noise components according to predefined values. One particular method for controlling indvidual harmonics of periodic noise is known as narrowband active noise equalization [23]. The narrowband ASQC algorithm can be implemented and analyzed in the frequency domain [24] and extended for broadband noise control [25].

The block diagram for the broadband ASQC system is shown in Fig. 6. In this system, the broadband ASQC algorithm employs a shaping filter C(z) to modify the residual noise spectrum. The filter is designed such that the squared magnitude $|C(z)|^2$ matches the desired shape of the residual noise spectrum.

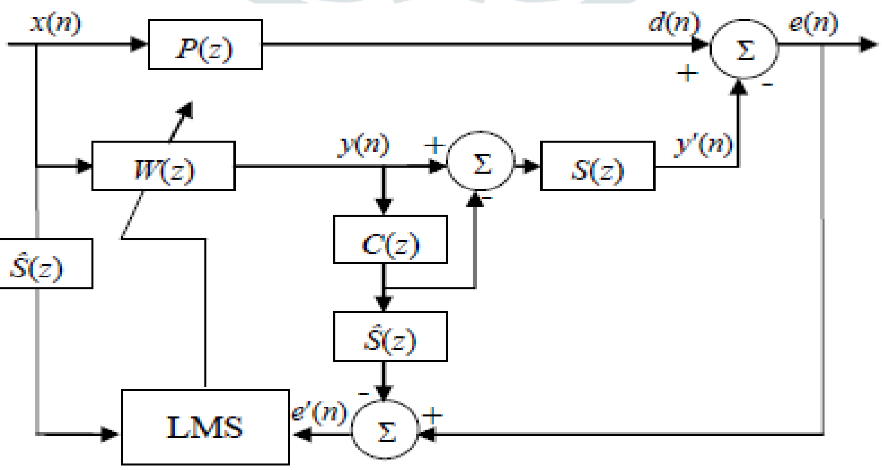

Fig. 6 Block diagram of the broadband ASQC system

Active Sound Quality Control (ASQC)

ASQC faces challenges similar to ANC, including passband disturbances from uncorrelated interference at frequencies with high secondary path gains and slow convergence due to the input autocorrelation matrix's eigenvalue spread. Research is needed to optimize the shaping filter C(z)C(z), study algorithm transients, and understand the impact of secondary-path modeling errors.

Special Noise Types

High-Frequency Noises: ANC systems increasingly address high-frequency noises, such as those from privacy-phone handsets or dental drills (2000–6000 Hz). Current solutions combine active and passive noise control, but advancements in acoustic theory could enable effective ANC for these noises in confined spaces.

Impulse-Like Noises: Impulse-like noises, such as explosions or gunshots, require ANC systems like helmets or headphones to selectively cancel harmful sounds while preserving environmental awareness. Similarly, ANC can address loud industrial noises from machines like stampers, necessitating further development for these specialized applications.

Fig. 6 ANC setup based on the GE Giraffe® incubator

Special Noise Types:

Impulse-Like Noises: Hospital equipment, such as IV pumps and incubators in NICUs, produces impulse-like noises. ANC systems, including nonlinear filtered-X least mean M-estimate algorithms, reduce these noises. Further analysis, experiments, and better algorithms are needed to address impulse-like noise effectively.

Dynamic Noise Control: Traffic noise from moving sources like vehicles and airplanes poses challenges. Limited research shows that ANC performance depends on Doppler effects, time-varying paths, and transfer function changes. Fast-convergence algorithms and further studies are needed for dynamic noise control.

Add-On Functions

ANC adoption can improve by integrating cost-effective additional features using shared hardware:

1. **Infant Incubators**: Reduce NICU noise and add intrauterine sounds to support infant development without extra costs.
2. **Cry Detection**: Use microphones and LPC algorithms to classify infant cries and identify causes like hunger or discomfort.
3. **Snore ANC**: Incorporate audio entertainment and hands-free phone features using headboard hardware with echo cancellation.

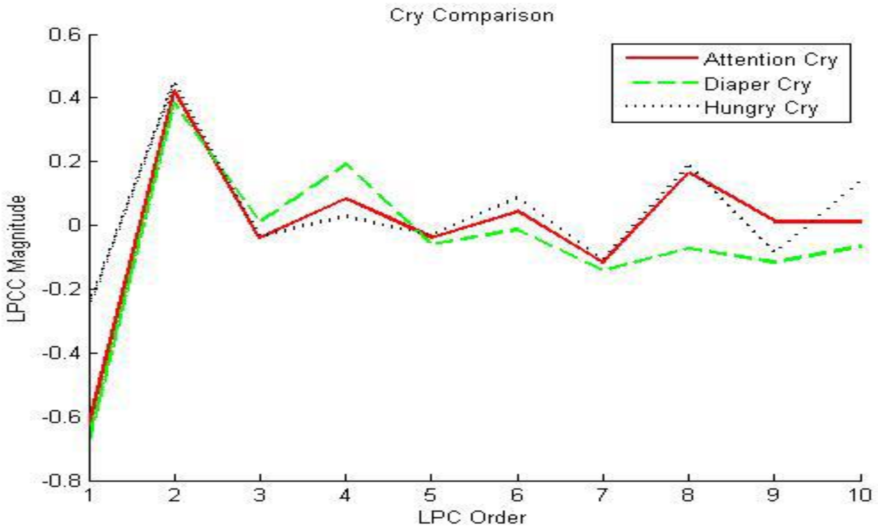

Fig. 7 LPC coefficient sets of attention, diaper and hungry cries

V. CONCLUSIONS

This paper explored the challenges and open issues in active noise control (ANC) systems from a signal processing perspective. It highlighted several key areas for further research and development. Three crucial techniques—virtual sensing, residual noise masking, and active sound quality control—were proposed as methods to enhance the performance of ANC systems. Additionally, we discussed some complex and promising ANC applications, such as addressing high-frequency and impulse-like noises, as well as managing traffic noise from moving sources. Lastly, the paper outlined potential add-on functions that could help make ANC systems more cost-effective and appealing by integrating additional features without increasing overall costs.

REFERENCES

1. P. A. Nelson and S. J. Elliott, *Active Control of Sound*, Academic Press, 1992.
2. S. M. Kuo and D. R. Morgan, *Active Noise Control Systems*, Wiley, 1996.
3. C. R. Fuller, S. J. Elliott, and P. A. Nelson, *Active Control of Vibration*, Academic Press, 1996.
4. C. H. Hansen and S. D. Snyder, *Active Control of Noise and Vibration*, E&FN Spon, 1997.
5. S. J. Elliott, *Signal Processing for Active Control*, Academic Press, 2001.
6. S. M. Kuo and D. R. Morgan, "Active noise control: A tutorial review," *Proc. IEEE*, vol. 87, pp. 943-973, 1999.
7. B. Widrow and S. D. Stearns, *Adaptive Signal Processing*, Prentice-Hall, 1985.
8. D. R. Morgan, "Analysis of multiple correlation cancellation loops," *IEEE Trans. Acoust.*, vol. ASSP-28, pp. 454-467, 1980.
9. S. M. Kuo and W. S. Gan, *Digital Signal Processors: Architectures*, Prentice Hall, 2005.
10. L. J. Eriksson, M. C. Allie, and R. A. Greiner, "Selection of IIR adaptive filter for sound attenuation," *IEEE Trans. Acoust.*, vol. ASSP-35, pp. 433-437, 1987.
11. S. M. Kuo, "Active noise control with online feedback path modeling," *US Patents No. 6,418,227*, 2002.
12. S. J. Elliott and P. Darlington, "Adaptive cancellation of periodic interference," *IEEE Trans. Acoust.*, vol. ASSP-33, pp. 715-717, 1985.
13. B. Widrow et al., "Adaptive noise canceling: principles and applications," *Proc. IEEE*, vol. 63, pp. 1692-1716, 1975.
14. H.-J. Jeon, T.-G. Chang, and S. M. Kuo, "Frequency mismatch in narrowband ANC," *IEEE Trans. Audio*, 2008.
15. S. J. Elliott and T. J. Sutton, "Feedforward and feedback systems performance," *IEEE Trans. Speech Audio Processing*, vol. 4, pp. 214-223, 1996.
16. S. M. Kuo et al., "Active noise control for headphone applications," *IEEE Trans. Control Systems Tech.*, vol. 14, no. 2, 2006.

17. S. M. Kuo et al., “Active snore noise control systems,” *Noise Control Engineering Journal*, vol. 56, no. 1, 2008.
18. G. Bonito, S. J. Elliott, and C. C. Boucher, “Zones of quiet with virtual microphones,” *J. Acoust. Soc. Am.*, vol. 101, pp. 3498-3516, 1997.
19. B. Cazzolato, “Adaptive LMS virtual microphone,” *Proc. Active 2002*, 2002.
20. D. Moreau et al., “Virtual sensing algorithms for ANC,” *Algorithms*, vol. 1, no. 2, 2008.
21. S. Singaraju and S. M. Kuo, “Noise masking with psychoacoustics,” *Proc. Active 2006*, 2006.
22. W. S. Gan and S. M. Kuo, “Integrated audio and ANC headsets,” *IEEE Trans. Consumer Electronics*, vol. 48, no. 2, 2002.
23. S. M. Kuo and M. J. Ji, “Development of an adaptive noise equalizer,” *IEEE Trans. Speech Audio Processing*, vol. 3, 1995.