WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

METHODOLOGIES IN ACTIVE NOISE CONTROL

Harsha Vardhini[1] , Vishnu Vardhan[2] , Deepika[3] , Anitha [4], Appalanaidu[5] , Kalyan Sai[6], Dr. R.Kranthi[7]

[1,2,3,4,5,6]Department of Electronics and Communication Engineering, GMR Institute of Technology, Rajam, 532127, Andhra Pradesh, India
[7]Sr.Assistant Professor, Department of Electronics and Communication Engineering, GMR Institute of Technology, Rajam, 532127, India

A B S T R A C T :

Active Noise Control (ANC) has been a vital technique for reducing acoustic disturbances in electroacoustic and electromechanical systems. This paper provides a comprehensive overview of significant advances in ANC methodologies over the last decade, including linear algorithms such as filteredx least mean square (Fx-LMS) based adaptive filtering techniques, as well as nonlinear approaches such as functional link neural network (FLN) based nonlinear filtering and deep learning enabled ANC strategies. We also highlight recent innovations and applications of ANC in various domains, identifying future research challenges and opportunities in this field, such as the need for more robust and adaptive algorithms, improved noise reduction performance, and improved system stability and reliability

Keywords: Active Noise Control, Fx-LMS,ANC, NLANC, GFANC, Heuristic algorithms,Deep learning anc

1. Introduction

Active Noise Control (ANC) is a technology that eliminates unwanted noise by introducing a sound wave to cancel it out. It operates on the basis of destructive interference, in which two opposing sound waves cancel each other out. The concept of ANC was created in the 1930s, but it was not practicable until the 1970s due to developments in signal processing, control theory, and electronics [1].The working premise of ANC is based on destructive interference, which occurs when two sound waves cancel out. ANC systems typically include a reference microphone, an adaptive controller, a loudspeaker, and an error microphone. The reference microphone detects incident noise, the adaptive controller processes the signal to produce an anti-noise waveform, and the loudspeaker outputs it. The error microphone detects remaining noise, and the controller automatically updates to ensure continual effective noise reduction. The main idea behind ANC is to employ sensors (microphones) to identify undesired sound, process the signal in real time using algorithms such as filtered-x least mean square (Fx-LMS), and then use actuators (loudspeakers) to create an anti-noise wave with the same amplitude but opposite phase.

This anti-noise wave cancels out undesirable noise, resulting in significant fluctuations in noise levels, particularly at low frequencies. Recent ANC technologies have progressed greatly, incorporating artificial intelligence (AI), hybrid system topologies, and novel signal processing methods. Leading ANC systems employ deep learning models to generate the most effective noise cancellation filters for real-time adaption. Hybrid ANC systems [2], which combine feedforward and feedback techniques, are gaining popularity as they improve noise cancellation across a wider frequency range. Some new ANC solutions use psychoacoustic concepts and active noise equalizing methods to shape the resulting noise spectrum for increased human comfort. However, actual environments rarely sustain linearity, and nonlinearities can be caused by parts like speakers and microphones or by sounds that are wide-band, impulsive, or chaotic. To solve this problem, nonlinear ANC (NLANC) methods have been developed, using sophisticated forms like Volterra filters, FLANN, kernel adaptive filters, and heuristic optimization techniques. The latest generation of ANC systems, like GFANC[3][4], use neural networks to automatically create or choose the best control filters depending on the noise characteristics. This gets rid of the need for repeated adaptation and lowers the chance of filter divergence, allowing ANC to quickly and reliably cancel out a wide range of acoustic situations.

1.1. Methodologies in Active Noise Control

Various methods have been created to apply ANC, based on the configuration and nature of the noise that is to be attenuated. The most typical arrangement is the feedforward ANC system, where a reference microphone is located upstream of the source of noise. The system anticipates the noise prior to arrival at the listener and produces an anti-noise signal ahead of time. Feedforward systems are highly common in products like headphones, ducts, and car cabins. Compared with feedback ANC systems, the latter do not need a reference microphone. They use only the error signal to generate adaptively anti-noise. Although the feedback systems have less hardware complexity, they tend to be less stable for wideband noise. The hybrid ANC approach uses both the feedforward and feedback methods together to achieve better performance and stability over a wider range of frequencies. The adaptive algorithm plays a significant role in ANC performance. One of the initial adaptive techniques used in ANC was the LMS (Least Mean Squares) algorithm. Due to not taking into consideration the acoustic delay from the speaker to the error microphone, it was eventually substituted with Filtered-x LMS (FxLMS), which is the one typically used in practical systems. Others include the more recent version of Normalized FxLMS, Recursive Least Squares (RLS), and frequencydomain FxLMS algorithms, which offer faster convergence speed and higher accuracy. In recent years, researchers have investigated deep learning-based ANC systems that employ neural networks to directly learn the intricate relationships between the reference and error signals. These models better handle nonlinearities and time-varying noise compared to conventional linear filters. Other emerging methodologies are model predictive ANC, robust H-infinity control, and hybrid passive–active systems combining sound-absorbing materials with active control to achieve broadband noise attenuation. The various methods classified under ANC are:

1.2. Linear ANC Technologies:

This section explores linear ANC techniques developed over the past few decades The standard LMS algorithm can become unstable when a secondary path is introduced, prompting the development of the F-xLMS algorithm, which addresses noise and stability concerns. Additionally, a linear feedback ANC approach has been proposed to mitigate acoustic noise in functional magnetic resonance imaging (fMRI) applications. The linear ANC systems that have addressed non-Gaussian noise, showcasing the various methods developed over the years. Researchers have suggested novel strategies to address the problem of attenuating non-Gaussian impulsive noise, such as a recursive noise mitigation process and an online estimation technique [5],[6]. The need for sophisticated ANC systems is highlighted by the growing prevalence of industrial and medical equipment, which has increased acoustic noise concerns. Strong similarity metric correntropy has been successfully used in signal processing and machine learning, resulting in the creation of a stable adaptive filtering method and the GMCC [7]. Building on this, the maximal correntropy Kalman filter (MCKF) [8] was proposed to increase performance in noisy situations by strengthening the resilience of conventional Kalman filters against nonGaussian impulsive noises. In order to minimize computing complexity and guarantee consistent estimation error, researchers have also developed an ideal approach for ANC systems [9]. This strategy uses a recursive algorithm [10] that adaptively changes the weighting factor. An other noteworthy advancement is a new technique called MF-xAPLMCC [12] that offers improved performance by combining informationtheoretic learning with affine-projection-based data reuse. The proposed F-xRNLMAT [13] algorithms offer enhanced resilience and speed of convergence in order to overcome stability issues. With the introduction of the F-xEHCAF method more recently, the AF-xEHCAF algorithm—which uses an affine combination technique—achieves faster convergence and smaller residual error in non-Gaussian situations..

1.3. Nonlinear ANC Technologies

Although linear filters work effectively under perfect circumstances, they have trouble with nonlinearities in practical settings. In [14], a feedback ANC system that combines variable step-size learning and an adaptive neural controller yields faster convergence and better noise reduction. Improved FLN (IFLANN) and SIFLANN filters [15] include a corrective filter prior to trigonometric function expansion in order to enhance performance. Kernel adaptive filters are used by the KFxLMS method [16] to manage Gaussian white noise and numerous narrowband signals. Sparse modeling [17] reduces complexity while capturing the features of nonlinear secondary routes. Non-stationary primary noise is addressed using a novel method [18] that combines an adaptive CN filter with CEMD. The SAF-VGMCC [19] employs spline interpolation and correntropy-based methods to achieve faster convergence in dynamic situations. Traditional adaptive filters, like the classic filtered-s LMS (FsLMS) algorithm [1], fail to control nonlinearities and impulsive noise in real-world situations, resulting in limited noise reduction, instability, and slower convergence. This is especially difficult in nonlinear active noise control (ANC) systems, where non-Gaussian or extremely impulsive noise is common. To overcome these restrictions, a robust FsLMS algorithm [20] has been presented for FLANN-based nonlinear adaptive controllers, offering increased performance and stability in ANC systems. Researchers have presented a variety of nonlinear robust ANC algorithms to meet noise reduction difficulties in complicated situations. The VFxlogCLMP algorithm [21] can eliminate parameter selection and threshold estimation in white Gaussian noise settings. Algorithms like FsqLMS [22] and RFsSAF-qMCC [23] enable faster convergence in impulsive noise circumstances.

1.4. Heuristic Methods of ANC

Recent research has investigated numerous heuristic strategies for improving single-channel ANC technology. The fireworks algorithm (FWA) [24] can handle both linear and nonlinear optimization scenarios, resulting in increased performance in ANC applications. Other heuristic approaches have been studied, including the particle swarm optimization (PSO) algorithm [25], which addresses the local minima problem, and the flower pollination algorithm (FPA) [26]. Researchers studied the hybrid grasshopper optimization using the sequential quadratic programming method (GOA) [27].

Additionally, the cuckoo search (CS) algorithm [28] has been applied for single-tone and real noise reduction in indoor environments, while a genetic algorithm (GA) [29] has been used to address low-frequency noise, achieving superior performance despite spatial constraints.

1.5. Deep Learning ANC Technologies:

Current research in ANC targets systems to be more intelligent, adaptive, and efficient. With the advancement in deep learning, ANC frameworks have been introduced that apply convolutional recurrent networks (CRN) and long short-term memory (LSTM) models for processing complex, non-stationary noise environments [3],[4]. These data-based systems are capable of handling nonlinearities and acoustic condition variations better than conventional algorithms. Rencently a novel fixed filter using extended Kalman filter was used in [30] (

2. APPLICATIONS OF ACTIVE NOISE CONTROL

ANC is commonly applied in numerous areas because of its effectiveness and versatility. In manufacturing, it decreases fan noise, factory vibration, and pipeline noise, enhancing comfort and noise standard compliance. In transportation, it reduces motor, road, and tire noise in vehicles, engine and propeller noise in aircraft, and ship and submarine vibrations for quieter and more stealthy operation. ANC is a main feature in consumer electronics for headphones, laptops, phones, and home appliances, providing a quieter life. In structures, Active Structural Acoustic Control (ASAC) minimizes vibration on walls and panels, while smart structures utilize sensors and speakers for noise control dynamics. In medical ANC reduces MRI machine noise and improves hearing aid functionality, neonatal care units reduce the incubator noises and illustrate their increasing influence in enhancing comfort and sound quality throughout everyday life

3. CHALLENGES IN ANC IMPLEMENTATION

In spite of its achievement, ANC is also subject to a number of challenges that keep it under research. Among these challenges is secondary path variability, where the speakerto-microphone acoustic path changes because of movement or environmental changes. Nonlinearities in loudspeaker and microphone can also decrease the performance of the system. Computational expense is another aspect, especially for multi-channel systems that need real-time processing. Additionally, latency, i.e., the time lag between noise picking up and generation of anti-noise, has to be reduced to avoid instability. Making robustness in dynamic and uncertain environments is still the most critical goal of research in contemporary ANC development.

4. FUTURE SCOPE

The future of ANC is in bringing artificial intelligence, advanced control theory, and smart hardware together. AI-based ANC will enable systems to adapt and learn in new settings autonomously, and spatial sound control will make it possible to have individualized quiet spaces in public areas. IoT and smart home integration will make living spaces quieter, with devices controlling sound in real time. Hybrid passive–active systems will also become prevalent, merging power efficiency, adaptability, and wide frequency control. As research advances, ANC will further augment its function in healthcare, transportation, consumer electronics, and industrial noise control.

5. CONCLUSION

The reviewed papers showcase important progress in machine learning and signal processing. They are used in consumer audio equipment, image categorization,and hearing protection systems. An effective method for enhancing nonlinear transformations in deep networks is the Smish activation function. By using smart noise categorization, the selective fixed-filter ANC approach overcomes the main drawbacks of conventional adaptive algorithms. With an emphasis on dependable implementation, the feedback FxLMS hybrid ANC system offers workable solutions for low-frequency noise settings. For the next generation of wearable audio systems, further research will include integrating novel activation functions with ANC designs, modifying CNN-based noise classification for multi-channel spatial audio, and developing unified frameworks that link hardware optimization and software algorithms

REFERENCES

[1] Lu Lua.;Kai-Li Yinb.;Rodrigo C. de Lamarec.;Zongsheng Zheng d, Yi Yue.;Xiaomin Yanga.;Badong Chenf.;"A survey on active noise control in the past decade—Part I: Linear systems"

[2] Chen, T.-Y.; Yang, J.-H.; Lai,C.-L.; Wei, C.-T. Low-Frequency Active Noise Control System Based onFeedback FXLMS. Electronics 2025, 14,1442. https://doi.org/10.3390/electronics14071442

[3] Dongyuan Shi.; Bhan Lam.;Kenneth Ooi.; Xiaoyi Shen.;Woon-Seng Gan.;"Selective Fixed-filter Active Noise Control Based on Convolutional Neural Network"

[4] Zhengding Luo.;Dongyuan Shi.;Xiaoyi Shen.;Junwei Ji.;Woon-Seng Gan.;"DEEP GENERATIVE FIXEDFILTER ACTIVE NOISE CONTROL"

[5] Marco Bergamasco, Fabio Della Rossa, Luigi Piroddi, Active noise control with on-line estimation of nonGaussian noise characteristics, Journal of Sound and Vibration,Volume 331, Issue 1,2012,Pages 27-40,ISSN 0022-460X, https://doi.org/10.1016/j.jsv.2011.08.025

[6] Kajikawa Y, Gan W-S, Kuo SM. Recent advances on active noise control: open issues and innovative applications. APSIPA Transactions on Signal and Information Processing. 2012;1:e3. doi:10.1017/ATSIP.2012.4

[7] B. Chen, L. Xing, H. Zhao, N. Zheng and J. C. Prı´ncipe, ”Generalized Correntropy for Robust Adaptive Filtering,” in IEEE Transactions on Signal Processing, vol. 64, no. 13, pp. 3376-3387, July1, 2016, doi: 10.1109/TSP.2016.2539127.

[8] Badong Chen, Xi Liu, Haiquan Zhao, Jose C. Principe, Maximum correntropy Kalman filter, Automatica, Volume 76, 2017, Pages 70-77, ISSN 0005-1098, https://doi.org/10.1016/j.automatica.2016.10.004.

[9] M. S. Aslam, P. Shi and C. C. Lim, ”Robust Active Noise Control Design by Optimal Weighted Least Squares Approach,” in IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 66, no. 10, pp. 3955- 3967, Oct. 2019, doi: 10.1109/TCSI.2019.2910290.

[10] Y. Zhu, H. Zhao, X. Zeng and B. Chen, ”Robust Generalized Maximum Correntropy Criterion Algorithms for Active Noise Control,” in IEEE/ACM Transactions on Audio, Speech, and Language Processing, vol. 28, pp. 1282-1292, 2020, doi: 10.1109/TASLP.2020.2982030

[11] Y. -R. Chien, C. -H. Yu and H. -W. Tsao, ”Affine-Projection-Like Maximum Correntropy Criteria Algorithm for Robust Active Noise Control,” in IEEE/ACM Transactions on Audio, Speech, and Language Processing, vol. 30, pp. 2255-2266, 2022, doi: 10.1109/TASLP.2022.3190720.

[12] A. Mirza, F. Afzal, A. Zeb, A. Wakeel, W. S. Qureshi and A. Akgul, ”New FxLMAT-Based Algorithms for Active Control of Impulsive Noise,” in IEEE Access, vol. 11, pp. 81279-81288, 2023, doi: 10.1109/ACCESS.2023.3293647.

[13] Krishna Kumar, M.L.N.S. Karthik, Nithin V. George, A robust active noise control system based on an exponential hyperbolic cosine norm, Signal Processing, Volume 221, 2024, 109469, ISSN 0165-1684, https://doi.org/10.1016/j.sigpro.2024.109469.

[14] Nguyen Le Thai, Xing Wu, Jing Na, Yu Guo, N.T. Trung Tin, Phan Xuan Le, Adaptive variable step-size neural controller for nonlinear feedback active noise control systems, Applied Acoustics, Volume 116, 2017, Pages 337-347, ISSN 0003-682X, https://doi.org/10.1016/j.apacoust.2016.09.022.

[15] Lei Luo, Zonglong Bai, Wenzhao Zhu, Jinwei Sun, Improved functional link artificial neural network filters for nonlinear active noise control, Applied Acoustics, Volume 135, 2018, Pages 111-123, ISSN 0003-682X, https://doi.org/10.1016/j.apacoust.2018.01.021.

[16] Liu, Y., Sun, C. and Jiang, S. Kernel Filtered-x LMS Algorithm for Active Noise Control System with Nonlinear Primary Path. Circuits Syst Signal Process 37, 5576–5594 (2018). https://doi.org/10.1007/s00034-018- 0832-6

[17] X. Guo, Y. Li, J. Jiang, C. Dong, S. Du and L. Tan, ”Sparse Modeling of Nonlinear Secondary Path for Nonlinear Active Noise Control,” in IEEE Transactions on Instrumentation and Measurement, vol. 67, no. 3, pp. 482-496, March 2018, doi: 10.1109/TIM.2017.2781992.

[18] Bin Chen, Shuyue Yu, Yang Yu, Rongrong Guo, Nonlinear active noise control system based on correlated EMD and Chebyshev filter, Mechanical Systems and Signal Processing, Volume 130, 2019, Pages 74-86, ISSN 0888-3270, https://doi.org/10.1016/j.ymssp.2019.04.059.

[19] Gao, Y., Zhao, H., Zhu, Y. et al. Spline Adaptive Filtering Algorithm-based Generalized Maximum Correntropy and its Application to Nonlinear Active Noise Control. Circuits Syst Signal Process 42, 6636–6659 (2023). https://doi.org/10.1007/s00034-023-02411-5

[20] Nithin V. George, Ganapati Panda, A robust filtered-s LMS algorithm for nonlinear active noise control, Applied Acoustics, Volume 73, Issue 8, 2012, Pages 836-841,ISSN 0003-682X, https://doi.org/10.1016/j.apacoust.2012.02.005.

[21] Lu Lu, Haiquan Zhao, Adaptive Volterra filter with continuous lp-norm using a logarithmic cost for nonlinear active noise control, Journal of Sound and Vibration, Volume 364, 2016, Pages 14-29, ISSN 0022-460X, https://doi.org/10.1016/j.jsv.2015.11.029.

[22] Kaili Yin, Haiquan Zhao, Lu Lu, Functional link artificial neural network filter based on the q-gradient for nonlinear active noise control, Journal of Sound and Vibration, Volume 435, 2018, Pages 205-217, ISSN 0022- 460X, https://doi.org/10.1016/j.jsv.2018.08.015.

[23] K. L. Yin, Y. F. Pu and L. Lu, ”Robust Q-Gradient Subband Adaptive Filter for Nonlinear Active Noise Control,” in IEEE/ACM Transactions on Audio, Speech, and Language Processing, vol. 29, pp. 2741-2752, 2021, doi: 10.1109/TASLP.2021.3102193.

[24] Wasim Ullah Khan, Zhongfu Ye, Faisal Altaf, Naveed Ishtiaq Chaudhary, Muhammad Asif Zahoor Raja, A novel application of fireworks heuristic paradigms for reliable treatment of nonlinear active noise control, Applied Acoustics, Volume 146, 2019, Pages 246-260, ISSN 0003-682X,https://doi.org/10.1016/j.apacoust.2018.11.024.

[25] Raja, M.A.Z., Aslam, M.S., Chaudhary, N.I. et al. Design of hybrid nature-inspired heuristics with application to active noise control systems. Neural Comput and Applic 31, 2563–2591 (2019). https://doi.org/10.1007/s00521-017-3214-2

[26] Khan WU, He Y, Raja MA, Chaudhary NI, Khan ZA, Shah SM. Flower pollination heuristics for nonlinear active noise control systems. CMC-Comput. Mater. Contin. 2021 Jan 1;67:815-34.

[27] Wasim Ullah Khan, Muhammad Asif, Zahoor Raja, Yigang He, Naveed Ishtiaq Chaudhary, A novel application of integrated grasshopper optimization heuristics for attenuation of noise interferences, Ain Shams Engineering Journal,Volume 13, Issue 2, 2022, 101536,ISSN 2090-4479, https://doi.org/10.1016/j.asej.2021.06.022.

[28] Tao W, Ma Y, Xiao S, Cheng Q, Wang Y, Chen Z. An Active Indoor Noise Control System Based on CS Algorithm. Applied Sciences. 2022; 12(18):9253. https://doi.org/10.3390/app12189253

[29] Giouvanakis M, Sevastiadis C, Papanikolaou G. Active Low-Frequency Noise Control Implementing Genetic Algorithm on Mode Coupling of a Compound Source. Applied Sciences. 2023; 13(11):6740. https://doi.org/10.3390/app13116740

[30] Fareedha, Vasundhara, A. Kar and M. G. Christensen, "Next-Generation ANC: Integrating Dynamic Fixed-Filter Strategies With Extended Kalman Filtering for Enhanced Noise Suppression," ICASSP 2025 - 2025 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Hyderabad, India, 2025, pp. 1-5, doi: 10.1109/ICASSP49660.2025.10888794.