Active Noise Control using Deep Learning Methods

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ABSTRACT

Active Noise Control (ANC) is an effective technique for attenuating low-frequency noise, where conventional passive noise control methods are often ineffective or impractical. Traditional ANC systems primarily rely on linear adaptive algorithms such as the Filtered-x Least Mean Square (FxLMS) algorithm. However, their performance deteriorates in the presence of nonlinearities and dynamic acoustic environments commonly encountered in practical applications.

This thesis investigates the application of deep learning techniques to overcome the limitations of conventional ANC systems. Initially, a novel Stacked Autoencoder (SAE)-based ANC framework is proposed for single-channel ANC systems. The proposed model is trained to estimate the optimal anti-noise signal required for noise cancellation. To enhance practical applicability, a transfer learning strategy is introduced in which the model is pre-trained using simulated data and subsequently fine-tuned using experimentally acquired data from a real ANC setup. The proposed approach demonstrates superior noise reduction performance compared to conventional adaptive filtering techniques.

To extend noise cancellation over larger spatial regions, the proposed methodology is further developed for Multi-Channel Active Noise Control (MC-ANC) systems. A Multi-Channel Stacked Autoencoder (MC-SAE) architecture is designed to address the challenges of multiple reference and error sensors, acoustic coupling, and cross-talk effects. Experimental results validate the effectiveness of the proposed framework in achieving enhanced noise attenuation across an extended quiet zone.

Recognizing the limited adaptability of offline-trained deep learning models, hybrid ANC frameworks are subsequently developed by integrating adaptive LMS filtering with the pre-trained SAE and MC-SAE models. The resulting Adaptive-SAE and Adaptive-MC-SAE systems combine the nonlinear modeling capability of deep learning with the real-time adaptability of adaptive filtering, enabling robust performance under varying acoustic conditions.

Finally, the practical feasibility of the proposed hybrid framework is demonstrated through real-time implementation on the NVIDIA Jetson Nano embedded platform. Key challenges related to computational complexity, latency, and real-time synchronization are addressed, confirming the suitability of the proposed approach for deployment in practical ANC applications.

The contributions of this thesis establish that the integration of deep learning and adaptive signal processing provides an effective solution for nonlinear and dynamic ANC problems. The proposed architectures offer significant improvements in noise reduction performance, adaptability, scalability, and real-time deployment capability, thereby advancing the state-of-the-art in Active Noise Control systems.

Keywords: Active Noise Control, Deep Learning, Stacked Autoencoder, Multi-Channel Active Noise Control, Adaptive Filtering, Transfer Learning, Nonlinear ANC, Hybrid ANC Framework, Real-Time Implementation, Embedded Systems.