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Recent Applications and Challenges on Active Noise Control

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***Abstract*—Acoustic noise problems become more and more serious with increasing use of industrial and medical equipment, appliances, and consumer electronics. Active noise control (ANC) has been studied to solve such acoustic noise problems. ANC is a technique based on the principle of superposition, i.e., an antinoise with the same amplitude and opposite phase is generated and combined with an unwanted noise, thus resulting in the cancellation of both noises. However, ANC is still not widely used owing to the effectiveness of control algorithms, and to the physical and economical constraints of practical applications. In this paper, we briefly introduce some fundamental ANC structures, and focus on recent advances on signal processing algorithms, implementation techniques, challenges for innovative applications, and open issues for further research and development of ANC systems.**

I. Introduction

Acoustic noise problems have become serious with the increased use of industrial equipment, such as engines, fans, blowers, transformers, and compressors. Traditional acoustic noise reduction techniques are based on passive noise control, such as earplugs, ear-protectors, sound insulation walls, mufflers, and sound-absorbing materials. These passive techniques are effective for reducing noise over a wide frequency range. However, they require relatively large and costly materials, and are ineffective at low frequencies. Therefore, the active noise control [1]–[4] proposed in the early 20th century, has gained intensive development in the last two decades to reduce low-frequency noise.

The first patent on ANC was granted to Paul Leug, in 1936 [5]. Leug appended a drawing to his patent, describing how two sinusoidal sound waves can cancel each other. ANC is an electro-acoustical technique based on the principle of superposition, that is, an anti-noise with the same amplitude but opposite phase is generated by secondary source(s) to cancel unwanted (primary) noise acoustically, thus resulting in reduced residual noise. The ANC system is very efficient for attenuating low-frequency noise in environments where the passive noise control techniques are expensive, bulky, and ineffective.

In practical applications, the characteristics of the noise source and acoustic environment are changing, and thus the frequency content, amplitude, and phase of the primary noise are also changing. The noise reduction performance is mainly dependent on the accuracy of the amplitude and phase of the anti-noise generated by a signal processing algorithm. To deal with these time-varying issues, most ANC systems utilize adaptive filters to track these variations and unknown plants. The most commonly used adaptive filters are realized using a finite impulse response (FIR) filter with the least-mean-square (LMS) algorithm.

The control structure of ANC is generally classified into two classes: feedforward control and feedback control. In the feedforward control case, a reference noise is assumed to be available for the adaptive filter. Feedforward ANC systems can be categorized as either a broadband or a narrowband depending on the type of primary noise that can be reduced. In the broadband feedforward control case, a reference noise is detected by a reference sensor (e.g.,microphone), and thus noise correlating with the reference noise can be reduced. On the other hand, in the narrowband feedforward control case, a reference signal is internally generated using information available from a reference sensor (e.g., accelerometer) that is not affected by a control field. The feedforward ANC scheme utilizes a secondary loudspeaker (e.g., actuator) to generate anti-noise and an error sensor (e.g., microphone) to pick up residual noise, which serves as the error signal for updating the adaptive filter. The single-channel feedforward ANC scheme, which consists of two sensors (reference and error) and an actuator, is widely used for industrial applications such as reducing duct noise.

The feedback ANC system uses only an error sensor and a secondary source, not using an "upstream" reference sensor. Analog feedback control based on a simple negative feedback is widely used in headphone applications. Unfortunately, the controllable bandwidth is limited by the throughput of the overall control system; thus, it is difficult to reduce broadband noise. Digital feedback control generally utilizes internal model control (IMC) [6], which minimizes residual noise using predicted primary noise as the reference signal. Hence, the IMC-based feedback ANC system can reduce only predictable noise (including sinusoidal, narrowband, and color noises). The bandwidth that can be controlled by the feedback ANC system is limited because of the large delay due to the analog-to-digital converter (ADC) and digital-to-analog converter (DAC).

Today, successful real-world ANC application is still lim-

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