Volume 5, Issue 4, April 2015 ISSN: 2277 128X

International Journal of Advanced Research in Computer Science and Software Engineering

Research Paper

Available online at: www.ijarcsse.com

Acoustic Noise Reduction Using ANC Technique: A Review

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Abstract: Acoustic noise problems have become serious with the increased use of industrial equipment. The increased noise pollution and ineffectiveness of passive control techniques leads to innovation of active control techniques. Active noise control (ANC) is an electro-acoustical technique based on principle of superposition in which an anti noise with same amplitude but opposite phase is generated by secondary source to cancel unwanted noise acoustically. The secondary sources which generate anti-noise for destructive interference are interconnected through an electronic system using an adaptive algorithm called FXLMS. The filtered-X least mean square(FXLMS) algorithm is adapted to update coefficients of filters efficiently independent of fact that filter is either linear or non linear. In this paper, we briefly introduce some fundamental ANC algorithms and theoretical analysis, challenges for innovative application and development of ANC systems.

Keywords: Active noise control, digital signal processing, path modelling, filters, algorithm

I. INTRODUCTION

Noise pollution becomes a serious issue with the increased use of industrial equipment. It is especially eminent in vehicular systems, manufacturing plants, electrical apparatus, medical machinery system and human activities. Our machinery systems also have another type of noise called mechanical vibration which present in almost all transportation systems and home appliances. The medical research has shown that listening to high level noise for a long duration put the human life at the risk of high blood pressure, hearing loss, headache, fatigue, stress, anxiety and loss of concentration which results in reduced productivity [1, 2].

Acoustic noise subjugation techniques are of two types: passive noise control and active noise control. Passive noise control techniques require relatively large and costly materials which are effective for reducing noise over a wide frequency range but remain ineffective at low frequencies. Basically passive noise control techniques include earphones, ear protectors, sound insulation walls, wrapper and sound absorbing materials. To reduce noise problems at low frequencies, an effective technique is proposed called as active noise control (ANC) techniques which have gained intensive development in last two decades [3].

ANC is an electro-acoustical mechanical art based on the concept of superposition in which an anti-noise with the same amplitude but opposite phase is generated by secondary source(s) to cancel unwanted noise acoustically, thus resulting in diminution of primary noise. The ANC systems are competent for attenuating low frequency noise in environment where the passive noise control techniques are expensive, bulky and ineffective. Generally, the characteristics of noise sources and acoustic environment are changing resulting in change of amplitude, phase and frequency of primary noise. The performance of noise subjugation is dependent on accuracy of the amplitude and phase of anti-noise generated by signal processing algorithm. Adaptive filters are used in ANC systems to deal with these time varying issues. Most commonly used algorithm to track this variation is least mean square (LMS) algorithm [4].

The ANC structure is generally classified into two categories: feed forward control and feedback control. In the feed forward control model category, a reference noise is pretended to be available for the adaptive filter. Depending on the reduction of primary noise, Feed forward ANC systems can be categorized as either a broadband or a narrowband. In the broadband feed forward control structure, a reference noise is to be discovered by a reference sensor and thus noise correlating with the reference noise can be reduced. On the other hand, in the narrowband feed forward control model case, a reference signal is evolved internally using necessary data available from a reference sensor that is not affected by a control field. The feed forward ANC scheme utilizes a secondary loudspeaker to evolve anti-noise and an error sensor to pick up residual noise, which serves as the error signal to update the adaptive filter coefficients weights [5]. The feedback ANC technique utilizes only an error sensor and a secondary source. It does not use a reference sensor. A feedback control system utilize a simple negative feedback that is widely used in headphone applications [6,7]. The bandwidth of feedback ANC systems is limited because of the large delay due to the analog-to-digital convertor (ADC) and digital-to- analog convertor (DAC).

ANC application is still bounded depending on the efficiency of signal processing algorithms, physical implementation restraints, and economical consideration. This paper is organized as follows. In section II, the basic structural concept and algorithms of ANC will be represented. In section III, the basic principles of secondary path modelling will be introduced. In section IV, various applications and their challenging issues in ANC application will be discussed.

II. CONCEPT OF ANC

In this section, we briefly present basic ANC concepts, algorithm, analysis and recent work with help of broadband feed forward ANC and adaptive feedback ANC systems.

A. Broadband feed forward ANC:

The single channel broadband feed forward ANC system is shown in Fig.1 [2], where digital, analog, acoustic regions are clearly depicted. Noise coming from source of sound is quickly caught by reference sensor and then digital reference signal is generated with help of preamplifier, a reconstructive filter, and an ADC. The control filter W (z) processes the reference signal and generate sampled time anti noise signal y (n) that drives the secondary source as shown in Fig.1. Residual noise is monitored by error sensor and sampled by preamplifier, reconstructive filter and ADC. The coefficients of adaptive filter W (z) are changed automatically according to LMS algorithm to minimize the error signal e (n).

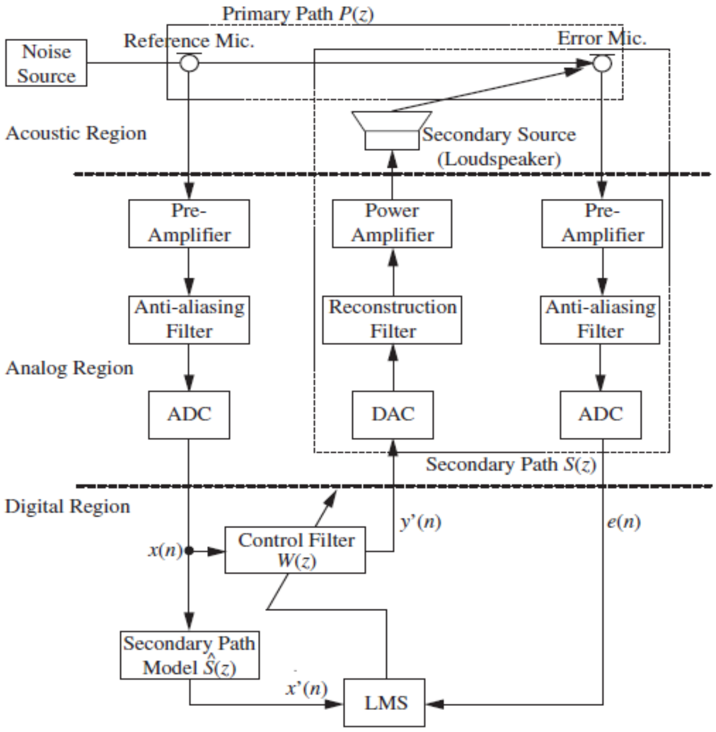

Fig.1. Block diagram of broadband feed forward ANC

The efficient solution of adaptive filter W (z) is given by following transfer function in steady state:

$$W(z) = \frac{P(z)}{S(z)} \qquad (1)$$

The performance of ANC system is mostly depend on transfer function of secondary path S (z)[2].

B. Adaptive feedback ANC

A block diagram of single channel adaptive feedback ANC system is shown in Fig.2 [19]. This mechanical art is also named as internal model control (IMC)[8,9] because it regenerates reference signal using only error signal and adaptive filter output filtered by secondary path model. This method can achieve fast convergence and high noise reduction because of no requirement of filtering of reference signal with secondary path model. It can easily cancel out affirmed noise.

The primary noise d (n) is generated by filtering the original noise with primary path P (z) as shown in Fig.2. If $\hat{S}(z) \approx S(z)$, then judgement of the primary noise shows $\hat{d}(n) \approx d(n)$ because current estimate of d(n) is used as reference signal for the next loop.

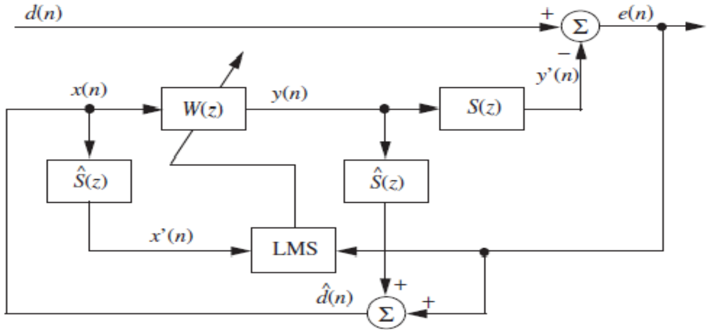

Fig.2. block diagram of adaptive feedback ANC

C. The FXLMS algorithm

As shown in Fig.3, the secondary path transfer function S (z) is present just after the controller W (z), this will route to instability of LMS algorithm. The reason behind this instability is incorrect alignment between error signal and reference signal because of presence of S (z). Therefore to update the weights of LMS correctly, a secondary path opinion Ŝ (z) is placed to filter the reference signal x (n) which is called FXLMS algorithm [10]. The block diagram of ANC system using FXLMS algorithm is shown in Fig.3.

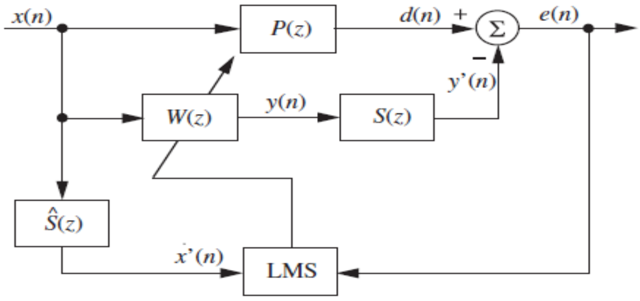

Fig.3 sampled time block diagram of feed forward ANC

Let L be the filter length, w (n) and x (n) are coefficient and signal of W (z), then secondary signal y (n) is calculated by [20]:

$$y(n) = w^t(n)x(n) \qquad (2)$$

And coefficient vector update by FXLMS algorithm is given by:

$$w(n+1) = w(n) + \mu e(n)x'(n) \qquad (3)$$

Here μ is convergence factor/step size and also

$$x'(n) = \hat{s}(n) * x(n) \qquad (4)$$

Where x' (n) is filtered reference and $\hat{s}(n)$ is impulse response of the secondary path estimation filter. Online modelling of secondary path is significant in time varying environment; that's why, Updating of secondary path model is important in ANC which will explain in detail in section III. The maximum convergence factor of FXLMS algorithm in case of white reference signal was derived by Elliot and Nelson [11] as

$$\mu_{max} = \frac{2}{(L+\Delta)P_x'} \qquad (5)$$

where P_x' is power of filtered reference signal $x'(n)$ and Δ is number of samples corresponding to overall delay in secondary path. Maximum step size is inversely proportion to delay, i.e., step size reduces with longer delay resulting in slow convergence speed of algorithm. The analysis depicts that FXLMS algorithm remain stable if secondary path model phase error remains within limit of ±90º but with a condition of small values of step size[12,15].

III. SECONDARY PATH MODELLING

Secondary path model can be estimated by two methods: offline modelling and online path modelling. Offline secondary path modelling is significant only where no primary noise exist. Therefore, offline modelling of secondary path using adaptive system identification with LMS algorithm and white noise as excitation signal can be used to estimate S(z) during initial training stage before the operation of noise control. Practically, primary noise always exist that leads to significant time varying secondary path and to achieve efficient performance and stability of algorithm, online modelling is required. Online secondary path modelling technique using additive random noise[16] is shown in Fig.4[20].

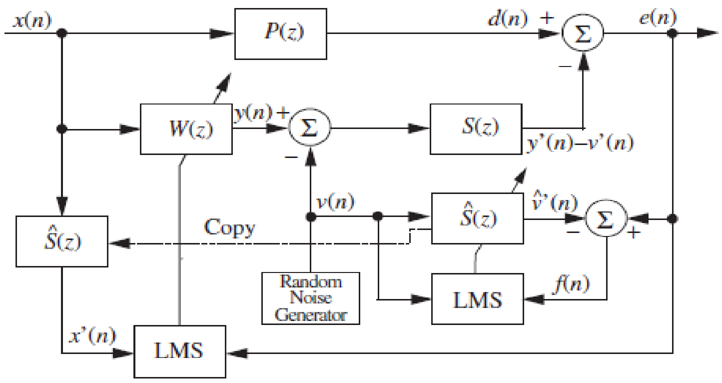

Fig.4 block diagram for online secondary path modelling

v(n) and x(n) represents zero mean white noise and primary noise respectively which are uncorrelated with each other. White noise is internally generated and added to secondary signal y (n) as shown is Fig.4, a adaptive filter Ŝ¬(z) is added in parallel with secondary path for online estimation. So error signal consists of two types of noise: one is u (n), residual noise without using v (n) and second is filtered v(n). u (n) becomes interference for secondary path modelling filter Ŝ(z) and additive random noise v(n) becomes interference for ANC filter W(z). Both noise are uncorrelated with each other but presence of u (n) degrade the convergence of adaptive filter. As shown in Fig. 4, where a random noise v(n) is added to the adaptive filter output y(n), and the mixed signal y(n) is output to the secondary loudspeaker to cancel the primary noise d(n). Thus, the signal e (n) picked up by the error microphone contains both the residual noise and the desired noise component. To estimate the noise component picked up by the error microphone, v(n) is filtered by the adaptive secondary-path estimation filter Ŝ(z). The estimated audio component v(n) is subtracted from e(n) to obtain the true error signal e(n) if Ŝ(z) = S(z). This noise-free error signal is then used to update the adaptive filter W (z). Therefore, the adaptive filter Ŝ (z) performs the online cancelling of the additive noise component using the LMS algorithm. Therefore, the performance of the FXLMS algorithm will not degrade with the additional noise signal, and the ANC system will not cancel the desired audio component because the additive noise component is not fed back to the LMS algorithm.

In general, there are two different techniques for online secondary-path modelling: the additive random noise technique which we discussed above and the overall modelling technique. Overall modelling techniques cover disadvantages of previous one, but we limited this paper to online secondary path modelling.

IV. APPLICATION OF ANC

ANC systems are most required systems in this era of noise pollution. Drastic increase in noise pollution is harmful for not only human beings but also to animals, birds and our environment. Some recent applications of ANC system includes motorcycle helmet ANC, snore ANC. MRI ANC. Some of these application and challenges in these applications are briefly described in this section.

A. Motorcycle helmet ANC systems

Here we limit our discussion to noise pollution. There are four types of noise present in Motorcycle: engine, wind, tire and road noise. The low frequency engine noise generated by motorcycle can vary depending on speed of motorcycle and type of motorcycle. It can be in range from 80–90 dB at speed of 30mph to 116 dB at speed of 120mph. It also depends on the road conditions [18]. Listening to high-volume noise will result in hearing loss, and even distract the attention of the rider and make it worse to hear or communicate any emergency signal on the road, which may put our life on stake. A motorcycle helmet's liner can act as a passive barrier and serves fair noise attenuation. So, ANC with passive noise control from the helmet liner can accurately and effectively control broadband noise. While communicating in a noisy environment, there is also a need to remove near-end noise sensed by the reference microphone before sending it to the far end.

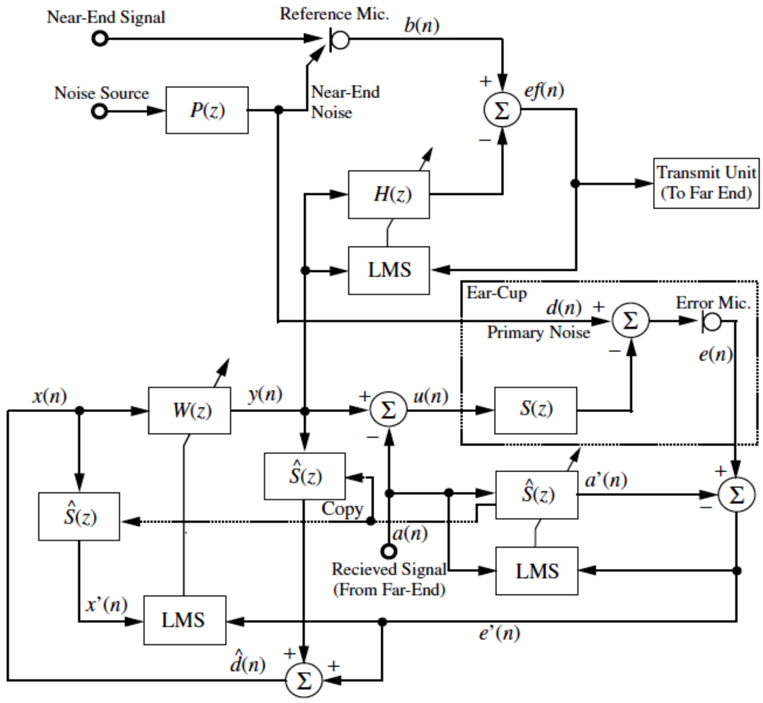

Fig.5. block diagram of ANC system to cancel out near end noise for speech communication

H(z). Operation and functionality of online secondary path modelling using additive noise will remain same. A simple adaptive noise-cancelling filter H (z) using the LMS algorithm can be added to the audio integrated ANC system, as shown in Fig.5[20]. The reference microphone is used to pick up the near-end speech from the speaker, but also to sense near-end noise. Correlated noise derived controller W (z) can be used as the reference input H(z). Operation and functionality of online secondary path modelling using additive noise will remain same as we explained in previous section.

B. Duct Acoustic Noise

The noise control in ducts or pipe used in heating, ventilation, and air conditioning are done by using single-channel broad-band feed forward ANC systems. ANC system components are located outside the duct without hindering the air flow; there is no unpropitious effect on the fan speed. Installation of ANC system is easy, and does not require major changes to the existing system. These ANC systems use an adaptive IIR filter with the filtered-U recursive LMS algorithm generally.

C. ANC Headsets

Hearing protectors are used to protect ears from injurious noise. The feed forward ANC method has been evolved [17] to cancel repetitive background noise at the ears of a person while keeping the ability to hear other ambient sounds. The synchronization signals can be obtained by either optical or electrical means (e.g., wire or radio). The synchronization system can be common to a number of ANC headsets, such as in the case of a vehicle carrying multiple passengers.

D. Snore ANC systems

Snoring is a prominent problem in modern society. The annoying spasmodic nature of snoring disturbs the sleep of the snorer's bed partner, causing stress, social nuisance. Passive are either ineffective for low frequency noise and it is uncomfortable to wear passive devices during sleep.

Single-channel ANC system structures using adaptive IIR filters and FIR filters have been developed and tested to evaluate their performance for cancelling snore noise. Online secondary path modelling using additive noise which we explained in previous section is used to control snoring noise control. The snoring audio can be used as a training signal (instead of annoying white noise) for offline secondary path modelling, and can continue to function in the online secondary-path modelling shown in Fig. 4, where a random noise generator is replaced with an audio player.

E. MRI ANC Systems

ANC has a vast application in medical equipments. As medical apparatus like X-ray machine, MRI equipment which is used to scan human body parts also generates very high noise which can be dangerous for patients. So ANC systems are very helpful in this field.

Two approaches to control noise in MRI: passive control and ANC. Passive approaches include earphones or sound absorbing things, which is only effective for high-frequency noise. Passive noise control devices prevent verbal communication among patients and medical staff during operation. Also, MRI noise has a high sound pressure level (SPL) at low frequencies, so ANC system offers an effective technique for noise control. There are two types of system techniques used in MRI ANC systems: headset based ANC system and head- mounted based ANC system. Head-mounted ANC system distinguishes from the headset-based ANC systems by one property that it does not cover the user's ears, so that the user can verbally have conversation with other people while reducing unwanted noise. Hence, this ANC system is utilized for medical staff working in the MRI room.

The feed forward ANC system requires at least two microphones (reference and error) and sufficient distance between the two microphones to ensure causality, thus increasing the size of the system. Moreover, the reference noise picked up by reference microphone must highly synchronize with the noise picked up by the error microphone. The ANC structure consists of two microphones arranged near the opening of the patient's external auditory canal and two loudspeakers located close to the user's ears, The head-mounted ANC system utilizes optical microphones and piezoelectric loudspeakers to realize noise reduction in a high magnetic field and compensate the low SPL of the piezoelectric loudspeakers because the loudspeakers are close to the patient's ears. This ANC system uses the IMC-based feedback system, which can reduce affirmative noise, is independent of the direction of arrival of noise, and is small in physical size as compared with the feed forward ANC system because the reference sensor is not needed. A challenging problem for MRI ANC is that the MRI noise contains periodical and impulse-like noise. Periodic components can be minimized by feedback ANC. The second challenge is that MRI machine generates intense magnetic fields. Therefore, it is necessary for transducers in the ANC system to satisfy some conditions like the transducer must work normally in an intense magnetic field and must not affect the MR image.

So these are some application of ANC systems are briefly explained above.

V. CONCLUSION

ANC systems are essential requirement of our environment in this technical era where technology is developing on a faster rate. With growing use of industrial and medical equipments, appliances, the problem of noise is becoming serious. So ANC play a prominent role in this technical era. ANC cancels the unwanted noise by generating anti noise of equal amplitude and opposite phase through the secondary sources. This paper gives a brief review of concept ANC techniques, its application, challenges and their solutions. In future, we intend to develop the ANC system for more efficient, accurate and effective noise reduction.

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