

# SUBOPTIMAL MULTICHANNEL ADAPTIVE ANC SYSTEM

Krzysztof Czyż, Jarosław Figwer

Institute Automatic Control, Silesian University of Technology Akademicka 16, 44-100 Gliwice, Poland krzysztof.czyz@polsl.pl jaroslaw.figwer@polsl.pl

#### Abstract

The paper presents a new approach to real-world implementation of multichannel adaptive active noise control (ANC) systems. In the proposed approach the multichannel adaptive ANC system is decomposed into a constellation of single channel autonomous adaptive active noise controllers. They exchange models of electro-acoustic cross-interaction paths by broadcasting them over the local Ethernet network. These models are used to estimate signals used by each of single channel autonomous adaptive controllers in the constellation to compensate their mutual cross-interactions. The presented idea enables to implement the multichannel adaptive ANC system as the constellation of single channel autonomous adaptive active noise controllers that can be easily tuned to specific application needs.

## 1. INTRODUCTION

In classical approach, multichannel adaptive active noise control (ANC) systems are designed as full controllers taking into account all diagonal and off-diagonal (cross-interaction) paths to eliminate the inter-channel cross-interactions [4], [7], [8]. The main drawback of this approach is the necessity of implementation of complicated, computationally complex controllers.

Alternate approach is to decompose the multichannel adaptive ANC system into a constellation of single channel autonomous adaptive active noise controllers [9]. Each of them is used to create single local zone of quiet surrounding one error microphone. In this case the inter-channel cross-interactions can appear and they have to be compensated. The most obvious idea to compensate these interactions is to exchange the error and reference signals between all single channel autonomous adaptive active noise controllers over the local Ethernet network, but due to the Ethernet network limitations, i.e. lack of determinism or considerable latency efficient implementation of such idea is almost an impossible task. The alternative approach to overcome this problem is to exchange models of cross-interaction paths that have been identified before multichannel ANC system activation. These models are applied to estimate signals

<sup>&</sup>lt;sup>1</sup>The partial financial support of this research by The Polish Ministry of Higher Education and Science (grant 3 T11A 012 29) is gratefully acknowledged.



Figure 1. A general scheme of the exemplary k-th single channel autonomous adaptive active noise controller with cross-interactions compensation.

used by each of the single channel autonomous adaptive active noise controllers in the constellation to minimise its influence on other controllers. It results in a suboptimal multichannel adaptive ANC system that is very flexible and can be easily reconfigured to specific application needs.

#### 2. MULTICHANNEL ANC SYSTEM

The first multichannel adaptive ANC systems were designed as controllers taking into account only diagonal channels [9]. Such controllers can be decomposed into a constellation consisting of single channel autonomous adaptive active noise controllers creating local zones of quiet surrounding single error microphones. The single channel autonomous adaptive active noise controllers are implemented mainly as feedforward control systems using reference and error microphones to adjust controller parameters and monitor ANC system performance. In real-world, ANC system implementations are based on the filtered-x LMS (Fx-LMS) [3],[7] algorithm.

The Fx-LMS algorithm employs as an adaptive controller the FIR filter  $W_k(z^{-1})$ . Its parameters are tuned on the basis of error signal  $e_k(i)$  and reference signal  $x_k(i)$  filtered through the secondary path model  $\hat{S}_k(z^{-1})$ . The goal of the adaptation algorithm is to calculate the coefficients of digital filter  $W_k(z^{-1})$  that minimise the mean square value of error signal  $e_k(i)$ . The structure of ANC system implies that there is a necessity to identify secondary path model  $\hat{S}_k(z^{-1})$  before activating the ANC system.

The main drawback of the feedforward ANC system is the fact that values  $x_k(i)$  of the reference signal can be often difficult to obtain in multichannel adaptive ANC systems creating distributed zones of quiet. To solve this problem ANC system of internal model control (IMC) structure may be applied. In this system a model of the secondary path, represented in Figure 1 by the transfer function  $\hat{S}_k(z^{-1})$  is used to estimate the unavailable reference signal  $x_k(i)$  [5],[8].

Implementation of the multichannel diagonal adaptive active noise controller as the constellation of single channel autonomous adaptive active noise controllers is not complicated but its performance suffers due to the fact that single channel autonomous adaptive active noise controllers tend to 'fight' each others. This problem can be solved by employing full controllers taking into account all diagonal and off-diagonal (cross-interaction) paths [4]. The drawback of this approach is high cost due to necessity of employing complicated, computationally complex controllers [8]. Additionally, it is difficult to decompose such multichannel adaptive active noise controller into a constellation of single channel autonomous adaptive active noise controllers. In such decomposition an interchange of all error signals and the corresponding secondary and cross-interaction path models between all single channel autonomous adaptive active noise controllers is necessary. Furthermore, this idea is inefficient when medium used to communicate introduces random delays along with the potential for transmission failure, making it entirely unsuitable for real-time applications requiring determinism.

In the proposed approach, the multichannel adaptive ANC system is decomposed into a constellation of single channel autonomous adaptive active noise controllers in such a way that they compensate their mutual influence (Figure 1). In this approach each of single channel autonomous adaptive active noise controllers should have modificated goal of adaptation algorithm, in which a cost function taking into account the mean square value of error signal  $e_k(i)$ and also the influence of control signal  $u_k(i)$  on zones of quiet created by the remaining single channel autonomous adaptive active noise controllers is minimised. For example it can achieved by adding to the error signal  $e_k(i)$  the corresponding control signal  $u_k(i)$  filtered through the cross-interaction paths models  $\hat{S}_{jk}(z^{-1})$  (Figure 1). This operation can be compared to adding extra virtual error microphones for the each of single channel autonomous adaptive active noise controllers. To archive better system performance the level of cross-channel compensation can be controlled by extra weighting in the minimised cost function (i.e. parameter  $\alpha_{jk}$  in the equation (1)). Models of secondary and cross-interaction paths can be identified off-line before the ANC system activation or on-line during ANC system operation [6].

#### 3. ACTIVE NOISE CONTROLLER

The presented above approach to multichannel adaptive ANC system implementation resulted in a set of single channel autonomous adaptive active noise controllers. They were implemented on portable active noise control platform (PANC) designed at the Institute of Automatic Control, Silesian University of Technology, Gliwice, Poland [1], [2]. The PANC is a dedicated highefficient, miniature, programmable DSP platform that is destined for generation of spatial local zones of quiet in enclosures. The platform consists of two modules: analogue frontend and signal processing board (Figure 2).

The analogue frontend board contains analogue input channels for reference and error microphones and analogue output channels for control loudspeakers. The analogue-to-digital (A/D) converters are 16 bit differential successive approximation converters with maximum 100 kHz sampling frequency. The digital-to-analogue (D/A) converters are 12-bit converters with maximum 100 kHz sampling frequency.

The signal processing board is based on high-performance Renesas SH4 RISC processor with internal clock speed rated at 240 MHz. Additionally, the core board includes 64 MBytes of SDRAM memory, 4 MBytes of on-board programmable flash memory containing board



Figure 2. The PANC - the portable multichannel active noise control platform core module.

firmware and 100 Mb/s Fast Ethernet controller.

The switched Ethernet with full duplex links was chosen as a communication medium between controllers. Such solution minimise random delays and probability of transmission failure and is the preferred solution for real-time ANC system applications.

On the basis of user datagram protocol (UDP) broadcasts dedicated network communication protocol was developed. It provides all necessary synchronization mechanisms between single channel autonomous adaptive active noise controllers enabling to control state of all controllers. Because all messages are send as broadcasts there is no need to know IP addresses of system nodes (controllers), they only have to be in the same subnetwork. This ensures that new single channel autonomous adaptive active noise controllers can be activated without any maintenance activity (i.e. system configuration, model identification, etc.). The developed protocol ensure also all necessary synchronization required during identification of electro-acoustic paths transfer functions  $\hat{S}_{jk}(z^{-1})$ . When the synchronization packet is received by single channel autonomous controller it starts to register responses of secondary and cross-interaction paths. Then corresponding models are estimated and broadcasted to all single channel autonomous adaptive active noise controllers working in the constellation. Each of the single channel autonomous adaptive active noise controllers has its own unique excitation signal known by all controllers. When excitation signals are orthogonal, identification can be performed in each of single channel autonomous adaptive ANC controllers at the same time [6].

#### 4. EXAMPLE

In Figure 3 an exemplary configuration of the suboptimal multichannel ANC system is presented. This system consists of three single channel autonomous adaptive active noise controllers. They exchange over the Ethernet network models of cross-interaction paths. The exemplary magnitudes of the secondary and cross-interaction paths for the suboptimal multichannel ANC system are shown in Figure 4. The magnitudes are characterized by large differences for close frequencies. This implies that it is difficult to attenuate some frequencies using sin-



Figure 3. Suboptimal multichannel adaptive ANC system consisting of three single channel autonomous adaptive active noise controllers communicating over the Ethernet network – exemplary noise attenuation map (in dBs).

gle channel autonomous adaptive ANC system. Furthermore, strong cross-interactions between single channel autonomous adaptive active noise controllers can be noticed. During suboptimal multichannel ANC system operation the following cost function is minimalised for k-th single channel adaptive active noise controller:

$$J_k = E\{e_k^2(i) + \sum_{j=1, j \neq k}^N (\alpha_{jk} S_{jk}(z^{-1}) u_k(i))^2\},\tag{1}$$

In Figure 3 an exemplary noise attenuation map obtained during the suboptimal multichannel ANC system operation is presented. It can be noticed that local zones of quiet surrounding each of error microphones  $(M_k)$  are created.



Figure 4. Frequency response magnitudes for exemplary suboptimal multichannel adaptive ANC system consisting of three single channel autonomous adaptive active noise controllers, (a) secondary paths, (b,c,d) secondary and cross-interaction path.

## 5. CONCLUSIONS

In the paper a new approach to real-world implementation of multichannel adaptive ANC systems creating distributed local zones of quiet in the enclosures was presented. In the proposed approach the multichannel adaptive ANC system is decomposed into a constellation of single channel autonomous adaptive active noise controllers that compensate their mutual crossinteractions. The resulted multichannel adaptive ANC system is suboptimal one but very flexible. It can be easily reconfigured to specific application needs.

## REFERENCES

- [1] K. Czyż, "A Portable Active Noise Control System", *Preprints of IFAC Workshop on Programmable Devices and Systems*, PDS'04, pp.372-376, Kraków, 2004.
- [2] K. Czyż, "Active Noise Control Systems with Nonuniform Signal Sampling", *Jacek Skalmierski Computer Studio*, Gliwice, 2007.

- [3] S. J. Elliott, "Signal Processing for Active Control", Academic Press, 2001.
- [4] S. J. Elliott, C. C. Boucher, "Interaction Between Multiple Feedforward Active Control Systems", *IEEE Transactions on Speech and Audio Processing*, 2(4), pp. 521-530, 1994.
- [5] S. J. Elliott, T. J. Sutton, "Performance of Feedforward and Feedback Systems for Active Noise Control", *IEEE Transactions on Speech and Audio Processing*, 4(3), pp. 214-223, 1996
- [6] J. Figwer, "A new method of on-line model identification and update for multichannel active noise control system", *Archives of Control Sciences*, 13, pp. 141-155 2003
- [7] S. M. Kuo, D. R. Morgan, "Active Noise Control Systems. Algorithms and DSP Implementations.", J. Wiley & Sons, N. York, 1996.
- [8] M. I. Michalczyk, "Active Noise Control System Creating Distributed Zones of Quiet.", Proc. of the 12th IEEE Int. Conf. on Methods and Models in Automation and Robotics, 1075-1081, Miêdzyzdroje, 2006.
- [9] D.E. Melton, R.A. Greiner, "Adaptive feedforward multiple-input multiple-output active noise control.", *IEEE International Conference on Acoustics, Speech, and Signal Processing*, ICASSP-92 (2), pp. 229-232, 1992.