UTS UNIVERSITY OF TECHNOLOGY SYDNEY

Computationally efficient adaptive algorithms for active control systems

by Somanath Pradhan

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Doctor of Philosophy

under the supervision of A/Prof. Jinchen Ji
and
Dr. Guoqiang Zhang

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Certificate of Original Authorship

I, Somanath Pradhan declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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3. **Pradhan, S.**, Zhang, G. & Qiu, X. 2020, 'A time domain decentralized algorithm for two channel active noise control', *The Journal of the Acoustical Society of America*, vol. 147, no. 6, pp. 3808-13. https://doi.org/10.1121/10.0001401
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1. **Pradhan**, **S.**, Qiu, X. & Ji, J. 2021, 'Affine combination of the filtered-x LMS/F algorithms for active control', Vibration Engineering for a Sustainable Future, Springer, pp. 313-9.

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In International Journals

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2. Bhattacharjee, S. S., **Pradhan**, **S.**, George, N. V. & Nordholm, S. 2020, 'Multi microphone assisted variable step size delayless multiband-structured subband feedback cancellation for two microphone hearing aids', submitted to *Signal Processing* [under review].

In Conference Proceedings

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Contributor	Statement of Contribution	Thesis Chapters
Somanath Pradhan	Literature review, Conceptualization, Methodology, Validation, Investigation, Manuscript Writing- Original Draft. Overall contribution: 80%	Chapter 2 and 3
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Abbreviations

WHO	world health organization
NIOSH	national institute for occupational safety and health
ANC	active noise control
ADC	analog-to-digital converter
DAC	digital-to-analog converter
FIR	finite impulse response
IIR	infinite impulse response
LMS	least mean square
FxLMS	filtered-x least mean square
NLMS	normalized least mean square
FBPM	feedback path modelling
FBPN	feedback path neutralization
FBPMN	path modelling and neutralization
CS	convergence speed
NR	noise reduction
FxAP	filtered-x affine projection
FAP	fast affine projection
VSS	variable step size
FxLMF	filtered-x least mean fourth
FxGMN	filtered-x generalized mixed norm
FFT	fast Fourier transformation
IFFT	inverse fast Fourier transformation
FBFxLMS	frequency domain block FxLMS
MDF	multidelay adaptive filter
PBFDAF	partitioned block frequency domain adaptive filter
FPBFxLMS	frequency domain partitioned block FxLMS
DANC	decentralized active noise control

FxLMS/F	filtered-x least mean square and fourth
A-FxLMS/F	affine combination of the FxLMS/F
S/P	serial-to-parallel converter
P/S	parallel-to-serial converter
TFPBFxLMS	time-frequency domain delayless partitioned block FxLMS
GA	genetic algorithm
MSE	mean square error
EF	extended filtering
SNR	signal to noise ratio
AR	autoregressive
ANR	averaged noise reduction

Abstract

As the side effect of urbanization, acoustic noise from various sources is the most common health threat in our day-to-day life. Passive noise control methods are constrained by several factors such as frequency content of noise, absorbing material type, thickness and geometry. Alternatively, active noise control method has emerged as a promising solution to control low-frequency noise cost-effectively. In an active noise control system, the acoustic path from the control source to the error microphone affects the control performance. If the reference microphone is placed in close proximity of the control source, an unwanted acoustic feedback signal from the control source will be captured by the reference microphone, which may lead to system instability. Furthermore, the adaptive control algorithms have a high computational complexity, which limits its application with high sampling frequency and the scalability of a control system for generating a larger quiet zone. Various algorithms have been proposed in literature for modelling acoustic paths, low-complexity implementation of single and multiple channel control systems. However, they are still constrained by factors such as computational complexity, noise reduction performance, causality issue and stability issue.

The objectives of this PhD research are to develop low-complexity algorithms for (1) online modelling of acoustic paths without affecting noise reduction performance, (2) achieving improved control performance at transient and steady state, (3) high sampling frequency operation and broadband noise control and (4) multiple channel decentralized algorithm for broadband noise control.

In the first aspect of this thesis, the online modelling of secondary path and feedback path are explored and two active control methods are proposed. One method is for online modelling of secondary path, and the other is for online modelling of feedback path.

Unlike the existing methods in literature, the proposed methods do not require auxiliary noise injection, rather uses the control signal and decorrelation filters to model the acoustic paths. The simulation results demonstrate the improved control performance and low computational complexity of the proposed method compared to the existing methods in literature.

In the second aspect of this thesis, an affine combination of adaptive filters are investigated for active control operation. Unlike the convex combination, the combining parameter in this linear combination is not constrained to lie in a specific interval and plays a vital role in deciding the overall control performance. An adaptation rule is developed for updating the combining parameter. The simulation results demonstrate that the proposed algorithm provides faster convergence and improved steady-state control performance.

In the third aspect of this thesis, a time-frequency domain flexible structure is proposed for active control operation, which has no signal path delay and is well suited for low-cost DSP implementation. The proposed structure divides the long filters into many equal partitions and carry out the control filter update in frequency domain while generating the control signal in both time and frequency domains. The simulation results using the measured acoustic paths in a duct and in a normal room demonstrate that the proposed structure maintains similar performance as that of the time domain algorithm but with much less computational complexity.

In the last aspect of this thesis, a multiple channel decentralized control algorithm is proposed to achieve the similar noise reduction performance as the centralized one. Auxiliary filters are introduced to filter the reference signal for control filter update and a unique design method is proposed to shape the frequency response of the auxiliary

filters. The simulation results using the measured acoustic paths demonstrate the efficacy of the proposed algorithm for broadband noise control.

In summary, online acoustic path modelling methods are proposed using the control signal; an affine combination of adaptive filters are proposed for improved control performance; a time-frequency domain flexible structure is proposed for active control operation for high sampling frequency operation; a decentralized algorithm is proposed to achieve similar noise reduction performance as the centralized one for broadband control.

Keywords: Active control system, online secondary path modelling, online feedback path modelling, computational complexity, decentralized control.