Employing Active Noise Control Problems in Education of Electrical Engineering Students

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Abstract *— The paper presents an active noise control (ANC) inspired dydactic activities for Electrical Engineering students. Being still a challenge ANC seems to be a good example for digital signal processing and advanced adaptive control education on graduate courses, even though, some ANC aspects may be also addressed to undergraduate students. A relatively low cost of ANC laboratory equipment, in comparison to classical automatic control laboratories, makes ANC systems an excellent didactic tool, allowing a practice with implementation of real-world digital signal processing and control systems, as well as impressing demonstrations.*

Index Terms *— laboratory practical works, modelling and simulation techniques, digital systems design, master theses.*

INTRODUCTION

Active noise control (ANC) has been a subject to research in Institute of Automatic Control of Silesian Univesity of Technology, Gliwice, Poland, for almost 20 years [10]. A number of master's theses and five PhD theses have been succesfully defended so far. Since 2001 a course Active Vibration Control for graduate students of Automatic Control and Robotics direction, including lecture, laboratory exercises and students projects, has been led by dr Zbigniew Ogonowski. Also a remote ANC oriented laboratory was created in a LABLINK programme [2, 9]. Due to a multidisciplinary nature the problems of ANC have been also incorporated in a number of other courses. The paper presents an ANC inspired Author's dydactic activities for Electrical Engineering students.

WHAT IS ACTIVE NOISE CONTROL

Active noise control is a technique for unwanted noise suppression. ANC is effective at low frequencies, for which the wavelengths of disturbances are comparable with dimensions of a region controlled. Low-frequency noise is especially tiresome for human being and is practically impossible to cancel this noise using traditional passive walls, because their thickness has to be large. On the other hand large wavelength of the noise allows creation of 3-dimensional zones of quiet of large dimensions using ANC environment.

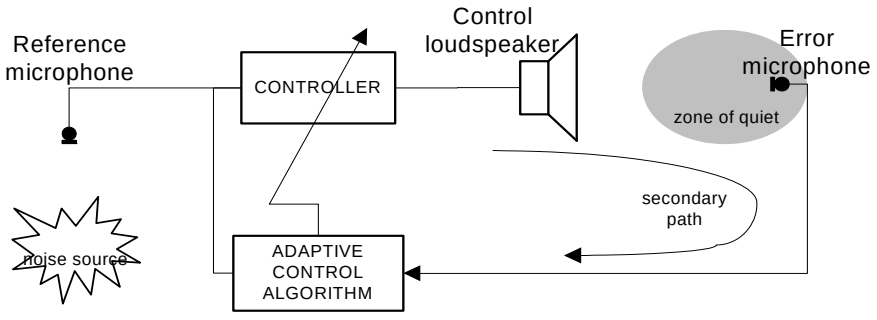

FIGURE 1
IDEA OF ACTIVE NOISE CONTROL

The idea of adaptive feedforward ANC [5] is illustrated in Figure 1 on the example of a single-channel feedforward ANC system. A reference microphone is situated close to a primary noise source (being a loudspeaker driven by a noise generator) and picks up a reference signal, processed further by an adaptive control algorithm. As the result, a control signal is generated to drive a control loudspeaker. By noise (disturbance) attenuation, zones of quiet are created around a sound sensor - an error microphone, which picks up an error signal used further for adaptation purposes. Adaptation

makes ANC system flexible to time-varying properties of the noise and of electro-acoustic plant, controlled by it. The specificity of ANC systems is the existence of a secondary path – an electro-acoustic plant including electronic and acoustic elements – amplifiers, filters, as well as loudspeaker, microphone, and the acoustic space between them (Figure 3). The existence of the secondary path implies that they have to be compensated employing electro-acoustic plant models, necessary for parameterisation of most adaptive ANC algorithms.

In ANC systems an adaptation is necessary, in particular for systems creating spatial zones of quiet in enclosure. An acoustic plant changes due to temperature or humidity conditions, the geometrical configuration of the enclosure may change, there may be persons moving inside, characteristics of the noise may change, etc. A broad range of control algorithms can be used for ANC systems, in particular adaptive control algorithms: LMS-based (least mean squares) control algorithms, as well as RLS-based (recursive least squares) algorithms are applied [5].

Application of advanced and computationally complex algorithms, supported by digital signal processing routines, imply their implementation on a dedicated hardware platforms, preferably digital signal processors (DSP). Then, the implementation aspects have to be coped with – real time programming, code optimisation, handling of numerical errors, etc.

FIGURE 2
ANC LABORATORY

ANC LABORATORY EQUIPMENT

An ANC laboratory is small (Figure 2), however, well equipped. The research conducted in this laboratory concerns: ANC in an acoustic duct, hearing protection and creation of three-dimensional zones of quiet in enclosure, as well as, structural noise control, sound and radar signal processing. Digital signal processing and measurement hardware, allowing implementation of advanced signal processing and control algorithms, include:

- Spectrum Digital boards with floating-point TI TMS320C6713, and fixed-point TI TMS320C6416 DSPs,
- Analog Devices boards with dual-core Blackfin ADI BF561, and ADI BF526 DSPs,
- Logic Zoom developers kits with TI OMAPL138 DSP,
- dSPACE DS1102 with TI TMS320C31 DSP, DS1103, and DS1104 boards with PPC processors,
- NVIDIA graphic cards with CUDA technology,
- real-time spectrum analyser Tektronix RSA3303A,
- arbitrary waveform generator Tektronix AWG430,
- signal generator Rohde&Schwartz SMIQ3,
- National Instruments PCI-6289 multifunction data acquisition board,
- Bruel&Kjaer and Svantek sound level meters.

The students are also free to create and test their own microprocessor systems.

A set of Alcone Acoustic 10HE woofers, as well as Tonsil loudspeakers, Beyerdynamic measurement microphones, Sennheiser wireless microphone kits, and simple electret microphones, analogue filters, and amplifiers constitute the electro-acoustic equipment of the ANC laboratory. Also simple robots (Lego Mindstorms NXT and qfix Crash Bobby) are employed to introduce a predictable movement into the ANC system. Thus, research activities make not only the students struggle with programming problems, but also have fun testing loudspeakers or using simple robots.

LABORATORY EXERCISES

A multidisciplinary approach is necessary for successful implementation of ANC systems creating spatial zones of quiet. At least basic knowledge of problems of digital signal processing, system identification, advanced control techniques, digital signal processors, and measurement techniques, as well as acoustics fundamentals is essential. Most of these topics are taught on Automatic Control and Robotics, and Macrocourse on Automatic Control and Robotics, Electronics and Telecommunication, and Computer Science directions of the Faculty of Automatic Control, Electronics and Computer Science of Silesian University of Technology, and thus, ANC could be an inspiration for students' didactic activities.

System Identification and Digital Signal Processing

Problems of digital systems and signal processing are raised in courses for graduate students: Process Identification, Digital Signal Processing, Applied Digital Signal Processing, and Estimation and Identification, as well as Digital Signal Processing Fundamentals – a course for undergraduate students.

In ANC systems the plant to be controlled is a kind of an electro-acoustic plant, the physical structure of which is shown in Figure 3. The electro-acoustic plant input signal is a control signal driving the control loudspeaker to attenuate disturbance, and the output signal is a processed signal picked up by a microphone. The analytical derivation of the necessary models is impossible, especially in the case of ANC systems creating three-dimensional zones of quiet in enclosures, due to high level of their complexity. Thus the only way of obtaining these models is their identification, possible with a range of techniques taught during the Process Identification course.

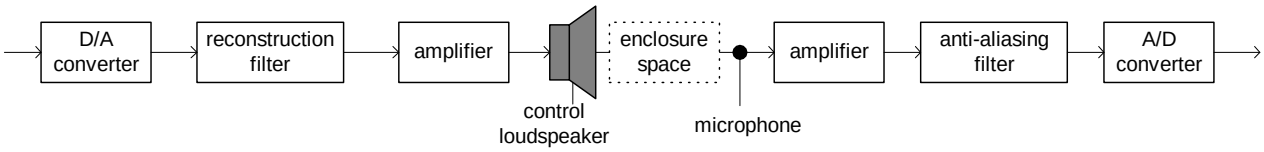

FIGURE 3
BLOCK DIAGRAM OF AN ELECTRO-ACOUSTIC PLANT

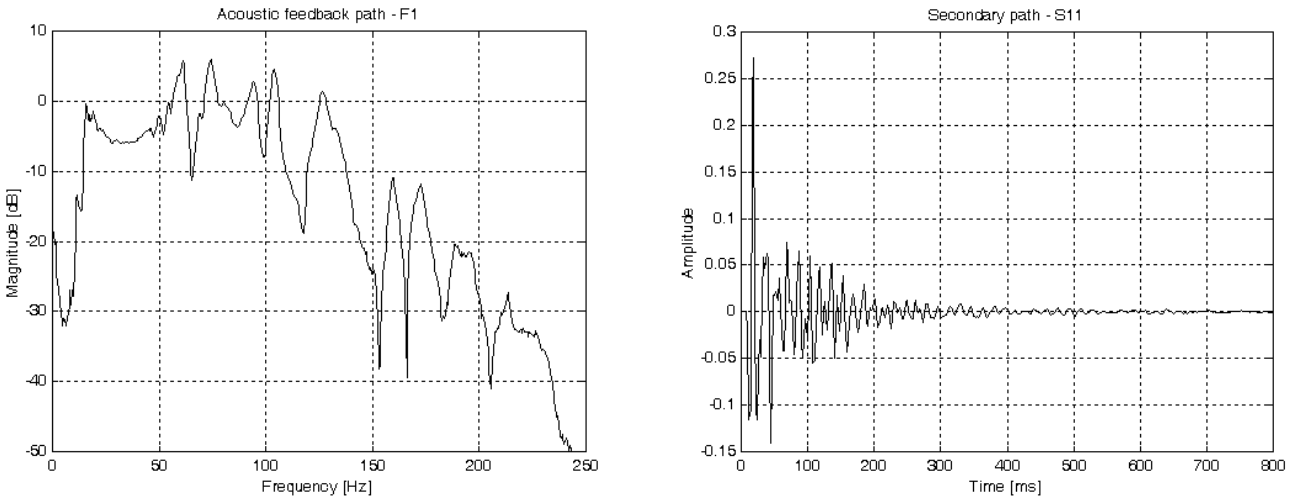

FIGURE 4
A TYPICAL FREQUENCY RESPONSE MAGNIUDE (LEFT) AND IMPULSE RESPONSE (RIGHT) OF AN ELECTRO-ACOUSTIC PLANT IN ENCLOSURE , OBTAIND WITH A SAMPLING FREQUENCY 500 HZ

Analysis of complicated dynamic properties of the plant helps students realise the influence of anti-aliasing and reconstruction analogue filters, loudspeaker dynamic properties, and enclosure acoustics on magnitude of electro-acoustic plant frequency response (Figure 4). In contrary to known to the students simple classical automatic control plants, the electro-acoustic plant properties are a novelty, however, specific to most sound signal processing systems and inspiring to those, who are interested in audio systems. Simplified identification experiments can be conducted at home, to examine home audio systems. A digital audio signal time and frequency domain analysis and processing, one of obligatory topics of digital signal processing courses, may also refer to ANC systems.

In some publications on digital signal processing an implementation of an ANC or acoustic echo cancellation systems are given as examples of laboratory exercises [1, 3, 4]. Due to time limits it seems, however, to be too complex and difficult task for a single, or even a series of a few laboratory exercises, rather being predestined for a project activities, or full laboratories series devoted to the ANC field. Two approaches are possible instead. The first is an implementation of an ANC system, using ready hardware and software modules, and focussing on chosen aspects (e.g. parameterisation of adaptive control algorithm). The second is a complete implementation of a chosen module and its thorough analysis (e.g. identification of an electro-acoustic plant model, spectral analysis of a measured signal, implementation in Matlab environment of an adaptive ANC system with LMS algorithm). Both approaches have been successfully applied.

Hardware and Software

Hardware and software implementation aspects are referred to on the example of ANC systems design on undergraduate course Microprocessor Systems and graduate courses Embedded Systems and Digital Signal Processing. During the undergraduate course students get acquainted with digital signal processing hardware and basics of software implementation. The graduate courses allow the students to implement digital signal processing algorithms on DSP hardware, with the focus on implementation aspects, like code optimisation and fixed-point programming, particularly important when working with complicated and time-consuming algorithms. Very often algorithm implementation on a DSP platform or any microprocessor board occurs to be much more difficult than simulating and understanding of advanced control algorithm. Thus, practical approach is by no means less important than a theoretical background [11].

PROJECTS AND MASTER THESES

A variety of aspects of ANC system design and implementation predestines this field to be a brilliant source of master's theses topics. Even if the students have researcher inclinations, most of them plan their future on the broad work market rather then a research work at the University. Then, ANC problems give talented students the possibility to dig into the depth of advanced control, however, with very important practical aspects of system implementation. Most of the master's theses concerning ANC include work on following stages:

- reading literature, choosing, and understanding an algorithm,
- simulating the algorithm in a non real-time Matlab environment in order to gain practical experience, and modifying the algorithm to obtain a desired system performance,
- rewriting the algorithm in C language on a personal computer, to be portable onto a DSP platform,
- simulating of a written code using a DSP simulator, rewriting time-consuming routines in assembler, if code optimisation is required,
- final implementation of the system on DPS platform, and testing the algorithm in real-world conditions,
- experiment design and comparison of results.

Such real-world professional approach, similar to these given in [3], seems to be applicable only to master's theses or projects, when time limits given by studies curriculum allow students for a thorough handling of the problem. Nevertheless, in some cases a key issue in progress of ANC based master's theses may be an assistance of an experienced supervisor.

Every year about five to ten ANC derived master's theses are run in the Institute of Automatic Control; some of them have been led by the Author:

- Performance of adaptive control algorithms for active noise control system with moving error microphone, 2006,
- Signal weighting methods for FX-LMS algorithm in active noise control, 2006,
- RLS algorithm for active noise control, 2007,
- System creating zone of quiet around moving wireless microphone,
- Distributed system for sound processing,
- Multi-channel active noise control system,
- Inexpensive active noise control system.

Results of the research of two of them have been presented on conferences [6, 7] and published in a journal [8]. Some other master's theses have not concerned directly ANC problems, but also deal with audio signal processing and hardware aspects:

- Mobile sound source tracking system,
- Wireless conference kit,
- Sound control in a listening room, 2009,
- Algorithms for sound source localization, 2008,
- Benchmark of processors for signal processing applications, 2008,
- Tools for real-time communication between TMS320C6713 digital signal processor and personal computer, 2007.

ANC projects, in some cases supporting master's theses, are conducted in the ANC laboratory as a part of the Active Vibration Control graduate course and year after year draw students' interest.

CONCLUSIONS

Active noise control (ANC) can be a source of inspiration for many didactic activities run for Electrical Engineering students. The same reason, why practical applications of ANC are sill rare, allows the students for gaining much from working on ANC aspects. ANC is a complicated task, demanding advanced control techniques, and, consequently, is a challenge for those, who want to learn more. An ANC equipment is of a relatively low-cost, in comparison to classical automatic control laboratory setups, and allows implementation of digital signal processing, and advanced control algorithms, which are applicable on other practical fields, like: communications (speech processing and transmission, line and acoustic echo cancellation, sound compression), entertainment (audio systems, applications to room acoustics control), radar signal processing, etc. Most of the students choose ANC derived master's theses challenged by ANC's difficulty and appealed by its practical aspects. They learn much about real-world real-time digital system implementation, as well as, advanced digital signal processing and control techniques, and research activities. Satisfaction is brought not only by successfull genaration of adaptive 3-dimensional zones of quiet in enclosure, but also by implementation of unconventional algorithms on real-world DSP platform applying the knowledge gained during the studies.

ACKNOWLEDGEMENT

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