NETWORK-BASED LEARNING OF ACTIVE NOISE CONTROL

Zbigniew Ogonowski[1]

Abstract *¾ The paper presents a concept of network-based learning of Active Noise Control (ANC) problems. Arguments motivating remote experimenting are given. It follows from the presentation that basic experiments can be done automatically using "remote design". The most important is a structure of the virtual laboratory of ANC (VL ANC). There are four projects that can be conducted in five stages and on three levels of difficulty. All elements of this structure are briefly described and an example of one unit is presented. The role of remote tutor is discussed with special respect to an evaluation process. Four-experiment course covers all the most important problems of ANC design. Students solve problems concerning identification, modeling, excitation signal design, controller design and digital signal processing. For all projects tutorials and illustrative examples of experiments are provided.*

Index Terms ¾ active noise control, control system design, identification, virtual laboratory and distance learning.

INTRODUCTION

Active Noise Control (ANC) techniques concern the control of low frequency noise which became an important problem of human protection. Traditional passive methods are difficult, expensive and in many cases not applicable [2]. ANC is efficient methodology of noise attenuation. It is the only last decade when ANC left laboratories and became a market product. Thus it is necessary to include ANC subjects into curricula of control systems education. On the other hand still lots of challenging problems of ANC systems remain unsolved. The researchers need well equipped laboratory to carry experiments. There are many arguments motivating *remote* experimenting with ANC systems. Equipment of the laboratory is expensive especially because of sophisticated acoustical measuring and actuating units and also because of using Digital Signal Processing (DSP). Researchers and students have to be properly protected against acoustical noise during experiments. The efficiency of ANC follows from the coupling of modern control theory and hardware implementation. Identification, control, signal processing and microprocessor implementation issues are gathered in every application of ANC systems . From the educational point of view ANC serves as an example of compact set of control problems being well illustrated, interpreted and understood. Tutorials to be study remotely can be clearly divided and considered separately. The same feature concerns researching: all elements of ANC systems can be tested and reconsidered separately. A particular feature of ANC systems is that they can be easily configured in a top-down manner. This allows grading of the teaching and more efficient design of the control structures by the researchers.

The paper presents a compact concept of Virtual Laboratory of ANC Systems. The laboratory is established in Institute of Automatic Control, Silesian University of Technology, Gliwice, Poland. ANC systems team has been working on ANC problems since early nineties. ANC Systems subject has been lectured on Computer Controlled Systems specialization in 5 year of study. The laboratory is used by researchers and students.

CONCEPT OF THE VIRTUAL LABORATORY

A general structure of the ANC virtual laboratory is shown in Fig. 1. Communication is provided by the server. System configuration, control algorithms and data collection are realized in DSP card. Programmable-configured multiplexers realize chosen structure (connections) of the ANC system. Control signals are formed with low-pass filters and amplified with power amplifiers connected directly to loud speakers of the acoustical system. Feed-back signals are measured by microphones, the signals are then preamplified and filtered with programmable anti-aliasing filters. Feed-back signals are also transmitted by programmable multiplexers to reach finally DSP. The structure of ANC system is then defined by three elements: Algorithms (DSP), programmable multiplexers and acoustical part.

There are four projects to be realized in the virtual laboratory:

1. Personal attenuator.
2. Sound duct.
3. Compact size zones of quite.
4. 3-D zones of quite in the enclosure.

Personal attenuator (see Fig. 2) is a headphones with additional built-in microphones and electronic system controlling headphones loudspeaker to attenuate outer noise. Being active personal attenuator increases passive noise reduction of the headphones set. Personal attenuators are probably the first ANC systems being widely sold as a market product (e.g. Senheiser HDC 451, HDC 200). The control system in these units is simply unity-negative feedback. The similar system completed with the feed-forward compensators are investigated in the first project. Personal attenuator is placed on so-called 'artificial head'

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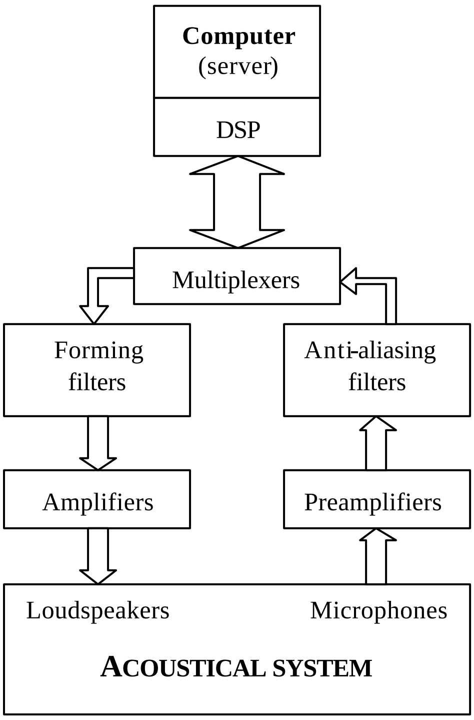

FIGURE. 1
GENERAL STRUCTURE OF THE VL ANC.

(Fig. 2) enabling noise level measuring inside of the headphones. Two microphones: inner and outer measure acoustical signals for feedback and feedforward loops. Additional loudspeaker generates the noise to be attenuated. All signals are transmitted onto DSP card through the signal channels described in the previous section.

FIGURE. 2
PERSONAL ATTENUATOR.

Sound duct (Fig. 3) is the first ANC systems patented by Lueg [1]. Due to unidirectional sound-waves, the sound duct serves as an example of one-dimensional control problem. There are constantly growing number of applications of duct ANC systems (e.g. air conditions systems, ventilation fans).

The project concerns different structures of the ANC systems (loud-speakers and microphones) [1].

Zones of quite of small dimensions are to be created in lorries cabins and similar enclosures (so called compact size zones of quite). Third project concerns zones of quite in a fixed configuration i.e. there is only one place where the zone has to be created (chair bolster as shown in Fig. 4).

The fourth project concerns the most challenging problem of ANC. Three-dimensional zones of quite has to be created in the enclosure with changing configuration of loudspeakers and microphones (protected person changes his position).

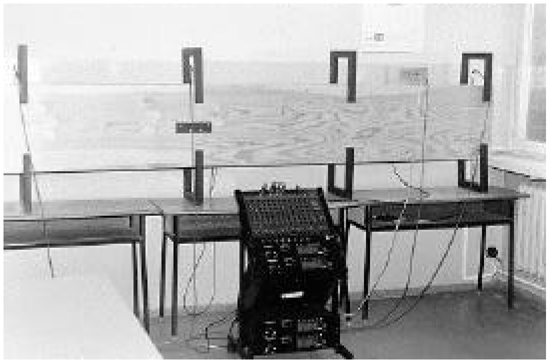

FIGURE. 3
ACOUSTICAL DUCT.

FIGURE. 4
ZONES OF QUITE OF SMALL DIMENSIONS.

This problem needs application of sophisticated control algorithms e.g. on-line adaptation. The enclosure (Fig. 5) used in the virtual laboratory is a room of 24 m^3 o volume. Installed are the following elements: 8 broad-band loudspeakers, 4 low-frequency loudspeakers and 16 error or reference microphones. Spatial configuration of all elements are fixed, but respect cables and connectors enable operation in different structures.

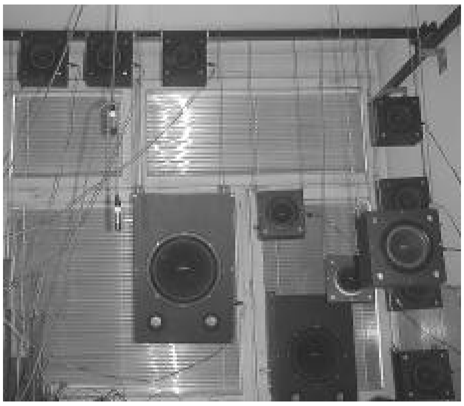

FIGURE. 5
3-D ZONES OF QUITE.

Every project consists of five stages:

1. Theoretical introduction.
2. Configuration.
3. Signals and controllers design.
4. Processing of the experiment results.
5. Discussion.

Theoretical introduction is a text to be red by the user. Text describes the project, elements of its configuration, algorithms, steps to be realized, and gives references to go deeply into the problem.

Configuration defines the structure of ANC system. In every problem a few structures can be realized. The structures are programmed by the user. It depends on the chosen level (see below) how many elements of the structure can be chosen.

The main goal of the ANC system is noise attenuation thus it become necessary to define noise generated in the experiment. There are a bank of noise benchmarks with detailed description offered by the virtual laboratory. However, there is also a possibility to compose (simulate) a noise with parameters chosen by the user. Yet another possibility is to use signal sent by the user (e.g. in the *wave* format). According to the stage (below) user has to choose or design control algorithms to be implemented in the system. After implementation user starts the experiment. Signals obtained from the microphones during the experiment are collected in the files and sent back to the user.

There are two ways of processing the signals obtained from the experiment: the simplest way is preprocessing by the “standard” programs implemented in the system. The very basic processing is for instance: calculation of degree of attenuation, power spectral densities, variances etc. The second way is to make the calculation by the user. The system only suggest what should be calculated to make proper discussion of the results.

Discussion is nothing else but answers the questions stated by the system. The user has an opportunity to compare what he obtained with average results obtained by specialists. There are also some suggestions where can be the reason of poor results or hints how to solve the problem once more.

There are also three levels of difficulty to chosen by the user:

1. Introductory level.
2. Basic problems of ANC.
3. Advanced ANC.

Introductory level gives the basic information abut ANC systems. It is only admissible to follow the tutor and to see what can be done in the system. The main goal of the introductory level is to show the basic configurations of ANC systems in four projects included.

Basic problems of ANC allow to change the structure and parameters of the ANC system to see the difference in noise attenuation efficiency. There are selected configurations to be chosen by the user. Different excitations can be chosen by the user form the bank of input signals. Selected parameters of the (fixed) control algorithms can be changed by the user.

In the advanced level the user is able to configure its own structure. Still there are some limits. The main limitations come from: programmable multiplexers used in the system, number of microphones or loudspeakers installed, capacity of the system memory, calculation speed limits in DPS (on-line process). Third level is reserved rather to the researcher then to the students.

AN EXAMPLE OF THE UNIT

Consider the following example. Project: 3-D zones of quite in the enclosure, stage: signals and controllers design, level: basic problems of ANC.

There are two basic structure to be designed: feedback and feedforward. Below the second is described. General scheme of the system is shown in Fig. 6. Loudspeaker creating primary sound makes a noise to be cancelled around the observer position. Noise level is measured by microphones: error signal in the observer place and reference signal in the detector place. Only the second is used by the controller, the first one is used to evaluate the level of noise cancellation. After being processed by the controller error signal actuates loudspeaker – secondary source of sound. The role of controller is to create excitation to cancel the noise around observer. Here are the stages of the design:

1. Identification.
2. Filter design.
3. Adaptation: simple LMS.
4. Adaptation: FxLMS.
5. Acoustic feedback cancellation.

The user can choose one of 12 benchmarks – acoustic signals used to identify acoustical path of noise and control signal (see Fig. 7).

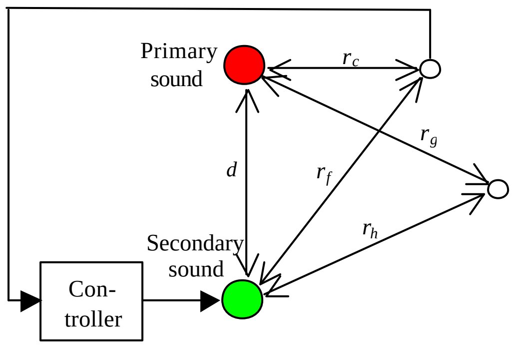

FIGURE. 6
GENERAL SCHEME OF FEEDFORWARD STRUCTURE OF ANC.

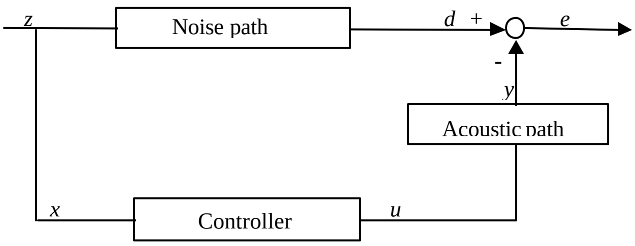

FIGURE. 7
SIMPLIFIED STRUCTURE OF FEEDFORWARD ANC SYSTEM.

After identification (experiment) controller design is simple division of the respect transfer function, however the filter should be of Finite Impulse Response (FIR) type thus the problem of truncation has to be solved. Another difficulty is anticipation issues. Distances: d, r_g, r_f, and r_h are defined with the configuration chosen by the user (8 possibilities). Three of these configuration are design to obtain anticipating filtration problem. The user is warned before the configuration is chosen. After filter is designed another a atenuation experiment is conducted and results are stored to be discussed later.

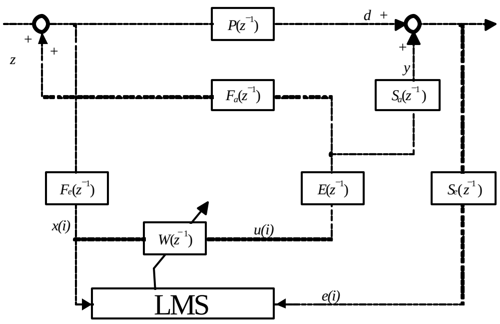

FIGURE. 8
FULL STRUCTURE OF FEEDFORWARD ANC SYSTEM.

Third stage of the design is much different due to the adaptation. Fig. 8 presents full structure of feedforward control system. It is necessary to distinguish acoustical and electrical parts of the system. Assuming linear modeling the following transfer function (in discrete back-shift operator z^{-1}) describes the system. In the acoustical part: $P_a(z^{-1})$ – noise path; $S_a(z^{-1})$ – control path; $F_a(z^{-1})$ – acoustical path. In the electrical part: $S_e(z^{-1})$ and $F_e(z^{-1})$ – microphone, amplifiers, anti-aliasing filters, and analogue-digital converters of control and feedback paths respectively; $E(z^{-1})$ – digital-analogue converters, reconstructing filters, amplifiers, and loudspeaker (secondary source of sound) in common part of feedback and control paths. In the stages 3, 4 and 5 on-line identification of the FIR filter $W(z^{-1})$ is done on the basis of error signal. The third stage is simplest due to simplified assumption: there are no acoustical feedback and transmittance $F_e(z^{-1})$, $E(z^{-1})$, $S_a(z^{-1})$, and $S_e(z^{-1})$ are neglected. Simple LMS [3] algorithm is used to identify filter $W(z^{-1})$ parameters. After the choice of the excitation noise the user repeat attenuation experiments for different order of the filter and different gain of identification algorithm.

The four stage needs additional identification of control path $E(z^{-1})\,S_a(z^{-1})$ in order to filtrate input $x(i)$ signal (i is discrete time) with FxLMS [3]. The identification procedure is the same as in the first stage.

Similar operation has to be done in the fifth stage, however, identification concerns acoustical feedback. The control system structure is changed by adding parallel path as shown in Fig. 9.

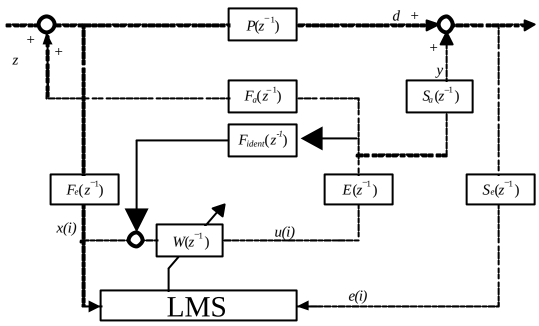

FIGURE. 9
CANCELLATION OF ACOUSTIC FEEDBACK .

Stages 2–5 ends with attenuation experiment. All results are stored and transferred to the user. The control system structures can be then compared especially according to degree of noise attenuation. Stages 3–5 can also be compared according to convergence issues.

Fig. 10 shows power spectral density of the possible excitation – band limited noise. Figs 11–14 presents results of nonparametric identification of control path and feedback path respectively (stages 4 and 5). Blue color represents results obtained from identification data, green color – from validating data. Fig. 15 shows the results of noise attenuation in the observer place for two different values of FxLMS algorithm gain (stage 4).

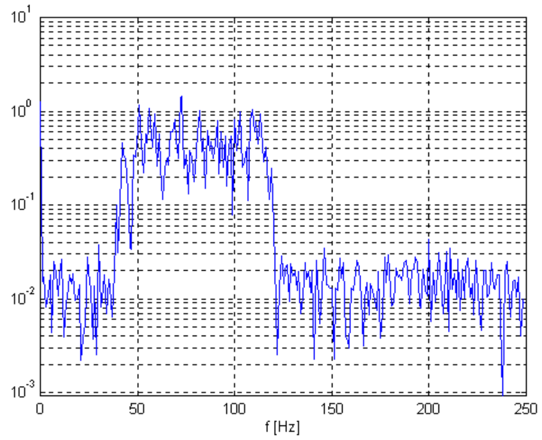

FIGURE. 10
POWER SPECTRAL DENSITY OF THE EXCITATION.

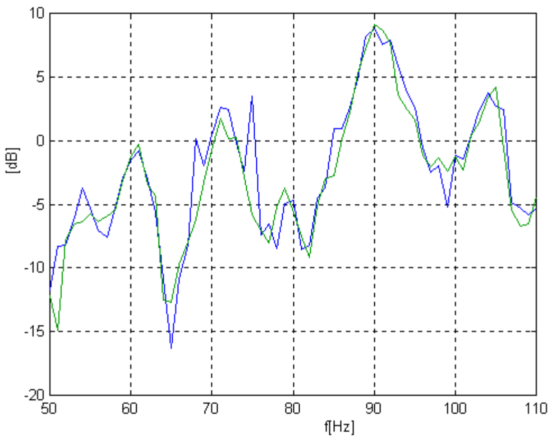

FIGURE. 11
RESULT OF THE IDENTIFICATION – CONTROL PATH, GAIN.

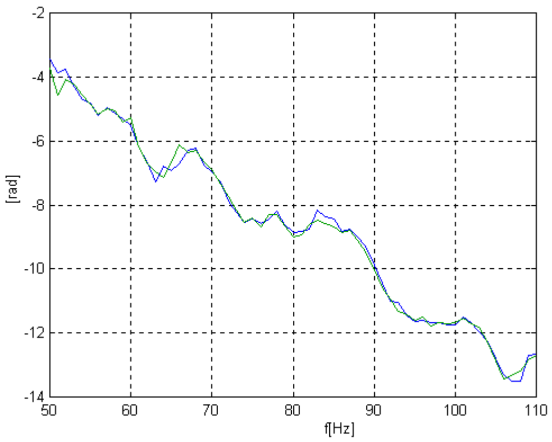

FIGURE. 12
RESULT OF THE IDENTIFICATION – CONTROL PATH, PHASE.

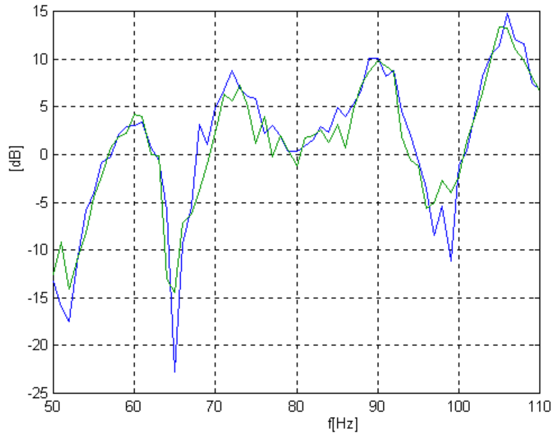

FIGURE. 13
RESULT OF THE IDENTIFICATION – FEEDBACK PATH, GAIN.

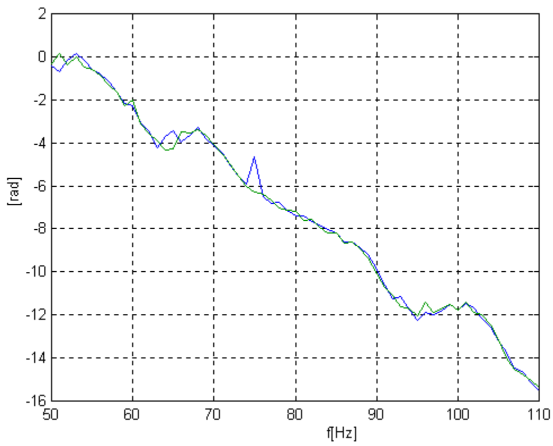

FIGURE. 14
RESULT OF THE IDENTIFICATION – FEEDBACK PATH, PHASE.

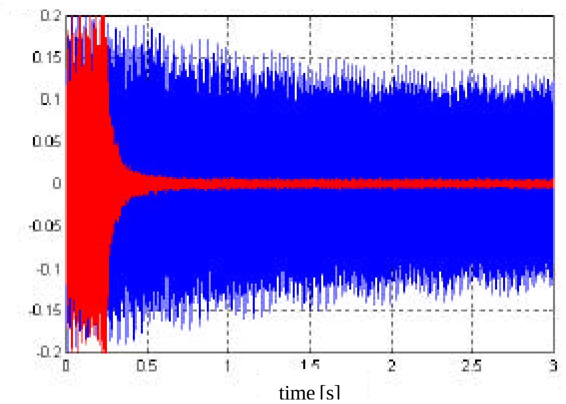

FIGURE. 15
CONVERGENCE OF THE CONTROL SYSTEM.

REMOTE TUTOR

Remote tutor plays important role in the learning process. His knowledge concerning ANC systems should be enough deep to be helpful for the students. Division of the VL ANC into three levels allows to start teaching from basic problems and gradually increasing the demands. The tutor himself has to pass all stages and all p rojects from the start.

Another problem concerns evaluation. Clear structure of the VL ANC allows to create the system of evaluation to be used automatically. This can be a set of test questions when tutorials are concerned. All other four stages (configuration, signals and controllers design, processing of the experiment results, discussion) can hardly be automated. This is the role of remote tutor to evaluate results of experiments. However, again clear structure of the VL ANC makes it easy to elaborate a form of the final report to be evaluated. For presented above example the report may contain (in the case of the first stage):

1. Excitation choice: explanation of the choice and signal analysis (e.g. spectral analysis).
2. Length of the experiment, division of the measurement data into identification data and validation data, stationarity problem.
3. Initial data processing: average value, trends, overloads.
4. Model structure choice and identification method choice – explanation.
5. Identification of the models and comparison: identification and validation data, different model type and different identification method.
6. Discussion of identification indices (variance of the parameters, prediction error, structure indices etc).

Most procedures of model identification and validation are accessible in VL ANC. The only role of remote tutor is the choice of the specific tasks for the students.

CONCLUSIONS

Specific features of ANC systems motivate remote experimenting. All these arguments are detailed in the paper. Probably the most important is the fact that difficult control theory and practice can be gradually studied with virtual ANC laboratory. Starting from very simple structures of ANC systems students can discover more complex problems. This drilling process ends with advanced design especially concerning control algorithm.

What can not be realized in VL ANC is the construction of hardware units. The only fixed elements can be configured into control system using programmable multiplexers. This is the role of researchers to use ANC laboratory to design hardware units. Up to now the main goal of the VL ANC is to provide simply access to complex equipment and software to learn more about sophisticated control systems.

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