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Benchmarking of active noise control

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Streszczenie

W pracy przedstawiono zasady badań wzorcowych układów aktywnego tłumienia hałasu (ATH). Zwrócono uwagę na trudność powtarzalności eksperymentów. Wskazano jednak na trzy elementy układów ATH, dla których można prowadzić badania wzorcowe: struktury układów starowania w ATH, sygnały pobudzające i wskaźniki dla porównania wyników eksperymentów. Szczególną uwagę zwrócono na dobór sygnałów: wykorzystując zarejestrowane sygnały rzeczywiste zaproponowano odpowiedniki generowane sztucznie tak, aby zachować własności dynamiczne, przeprowadzić generację w łatwy sposób oraz zapewnić możliwość parametryzacji sygnałów. Badania zilustrowano odpowiednim przykładem.

Summary

The paper presents motivation for Active Noise Control benchmarking as well as the basic problems of the benchmarking. Emphasise is put on impossibility of experiment repetition. However, there are three elements being benchmarkable: structures of control systems, exciting signals and indices to compare results. Special attention is put on signals in the paper. Basing on real-world benchmark signals artificial exciting signals are proposed. The rules to generate them are: the same dynamical properties then in reality, simplicity of generation and, possibility of parametrization. Illustrative example is presented to describe the role of benchmarking.

Key words: active noise control, benchmarking, control system structures, identification, modelling.

1. Introduction

Idea of benchmarking means a process of finding and using a benchmark in order to improve or compare at least two solutions of the same task. Andersen and Pettersen [3] summarized the benchmarking idea by the following definition "Benchmarking is the practice of being humble enough to admit that someone else is better at something, and being wise enough to learn how to match and even surpass them at it". The word benchmark probably takes its origin in geographical surveying, where the benchmark is a topological point of reference in the terrain - the position of other points is compared with it. Another hypothesis is that it originates from fishing contests where the size of the fish is compared by putting the fish on the bench and measuring its length by making a mark in the bench. In both cases the key word is comparing. The necessity of comparing follows from the number of possibly solutions thus if the specific problems or area of development can be dealt in different ways by different researchers then benchmarking provides a tool for comparing and discussion.

Benchmarking makes a great carrier in business industries as well as in different areas of technology. In the control world benchmarking consists of the following two elements: experi-ment and validation of the results. In other words benchmarking proposes conditions of experi-menting in order to make the experiment repeatable and formulates set of indices to make the validation [1,2].

Active Noise Control (ANC) is a specific field of control development. Limited number of structures and control algorithms applied in ANC makes it necessary to create benchmarking standards. The paper presents the basic problems of ANC benchmarking. Dedicated nature of ANC makes the repetition of the experiment difficult, however a part of the experiment conditions namely excitation signals can be standardized. Rules for creation of such signals as well as examples are presented. Methods of validation are also discussed.

2. Experimenting with ANC

ANC systems are in their nature dedicated. Elements of ANC systems are configured differently in laboratories and even very similar stands can behave significantly different. The most important factor seems geometry. Sizes and shape of the enclosure, furniture, placement of loudspeakers and microphones - all these factors influence much dynamical properties of the system and it is extremely difficult to obtain repeatable spatial distribution of the sound level. Another factors are properties of active elements included in the system: amplifiers, cables, microphones, loudspeakers, filters and so on. All these elements have different characteristics. Clearly, repetition of experiments in different laboratories to obtain the same results is not possible. Dedicated nature of ANC systems means that first of all tuning problem has to be stated and solved. Fixed controllers are synthesized basing on models. It is, of course not possible to use phenomenological models thus identification is necessary. However, well known in ANS systems is necessity of adaptation. Adaptive systems use on-line identification and parameter adjustment and adaptive structures of control systems in ANC are probably the most promising solutions.

It follows from the above resume that benchmarking of ANC systems can be difficult if experiment repetition is concerned. However, still the basic question remains: what elements of ANC experiment are common and can be benchmarked? The answer consists of three: control structures, excitation signals and, indices of attenuation quality.

3. Benchmark structures

Structures can be benchmarked according to standard notions in control theory. There are two basic control structures: feedback and feed-forward. The first can be augmented with disturbances compensation. Feedback control is common in systems creating so called small dimension zones of quiet (e.g. active head set or active headrest system [4]). The feed-forward is usually used to create local zones of quite in the enclosure. This structure can be modified by cancellation of acoustic feedback [5].

Both of the basic structures can be implemented as fixed or adaptive. Different control and identification algorithm can be used in these structures, thus the final structure-benchmark follows form the specific algorithms used. There are also structural modification following from the specific tasks. If, for example, one uses Fx-LMS instead of LMS algorithm in feed-forward structure then additional filtration is necessary and new structure is obtained [5]). Similar modification follows from usage of recursive least square method with orthogonal filtration [6].

Number of different structures is limited. This allows creation of a tableau containing specified control structures to be compared according to signals and indices benchamarks.

4. Benchmark signals

Benchmark signals seem probably the most obvious candidate to be standardized. Laboratory experiments need proper excitation of ANC systems. The problem of noise cancellation is three-dimensional. However, only one loudspeaker creating primary sound is necessary. Thus one-dimensional signal can be used as the primary excitation. Clearly, the problem concerns signal generation rather then usage previously recorded example of real-world signals. This follows from the need of parameterization: performance of the ANC system has to be judged according to specified parameters of the excitation while real-world example of noise is only a sample. On the other hand ANC systems has to cancel real noises, so finally the choice of signal benchmarks has to take into account both: the need for parameterization and coincidence with real-world signals.

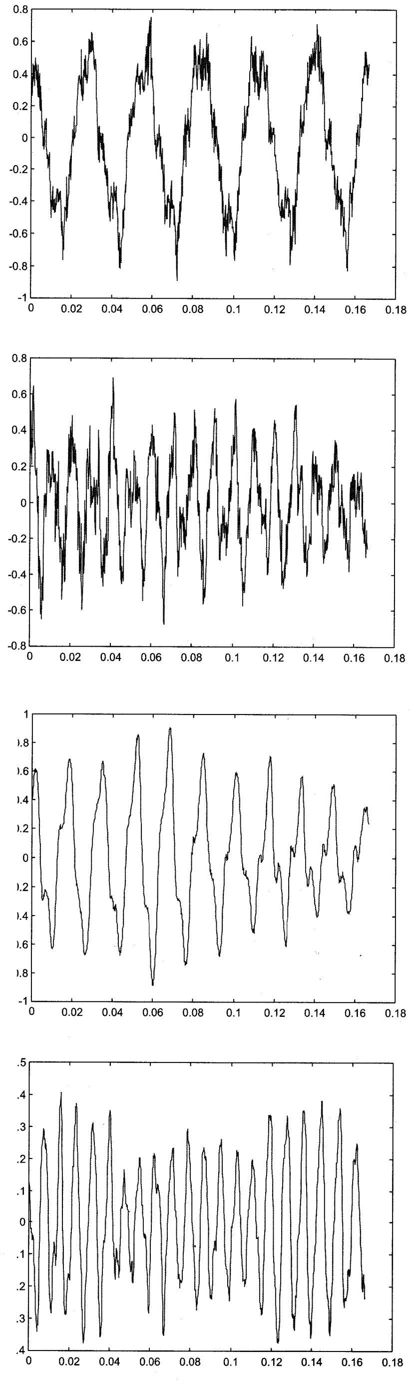

Fig. 1 Samples of real-world sounds: 'sound 1' - car, inside the cabin, idle running; 'sound 2' - car, inside the cabin, velocity 40km/h; 'sound 3' - washing machine; 'sound 4' - gas furnace.

In fact researchers usually use three types of signals to excite ANC systems: pure sine (uni-tone), multisine (3-5 sines with different frequency) and band-limited noise. The need for comparison, however, addresses only two questions: how does ANC system reduce single tones and how does it behave under broad band noise activation? It is well known that the first case is easiest while the second is the most difficult one. The simplest solution is to parameterize benchmark signals with two values: frequency of the single tone and level of the broad-band noise. Let us look on samples of real-world noises. Fig. 1 presents the examples of the noises. Fig. 2 presents their frequency characteristics.

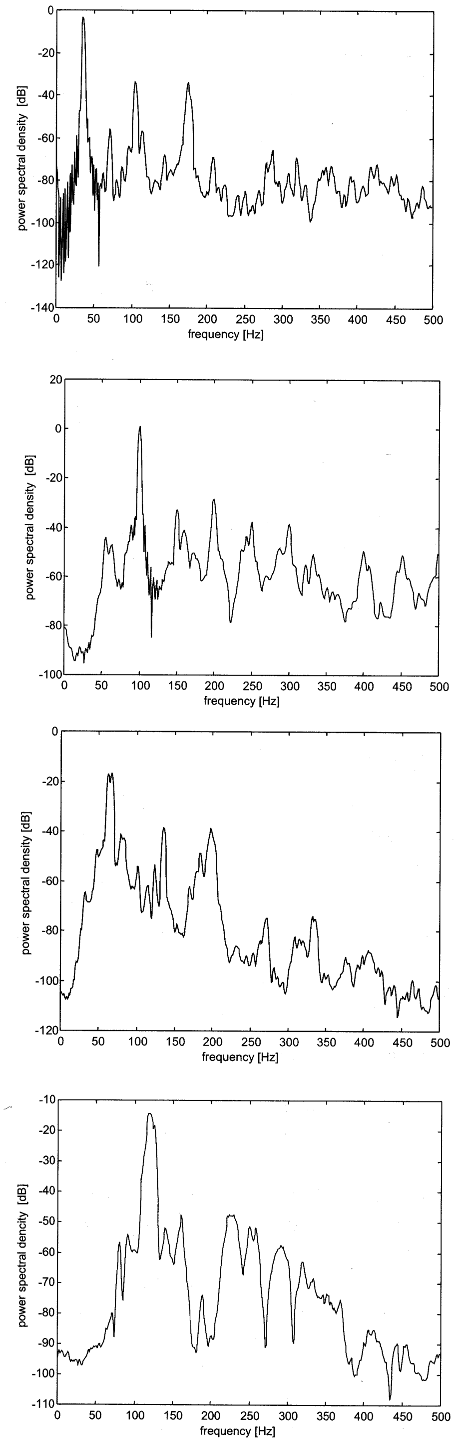

Fig. 2 Power spectral densities of samples of real-world signals (respect to Fig.1)

The samples presented illustrate that real-world noises usually contain one or only a few dominant frequencies embedded in disturbances. Thus constructing benchmark signal with one dominant (changeable) frequency and additional disturbances seems reasonable.

Yet another feature of real-world signals has to be taken into account namely nonlinear characteristics of sounds sources. Such signals contain higher moments. To illustrate this phenomenon let subtract dominant sine form one of the sample given in Fig. 1.

Remaining signal will still consists with the same dominant frequency. Keeping in mind that active noise attenuation is nothing else but destructive interference one should use as the benchmark signals with similar feature. The one proposition is a sine wave with random phases e.g.

$$v(t_i) = A\sin\left(\omega\, t_i + 2\pi\alpha\, \rho\left(t_i\right)\right)$$

where: t_i- discrete time, A - amplitude, ω - relative dominant frequency, $\alpha \in [0,1]$ - disturbance level (adjustable parameter), $\rho(t_i)$ - random number form the range [0,1].

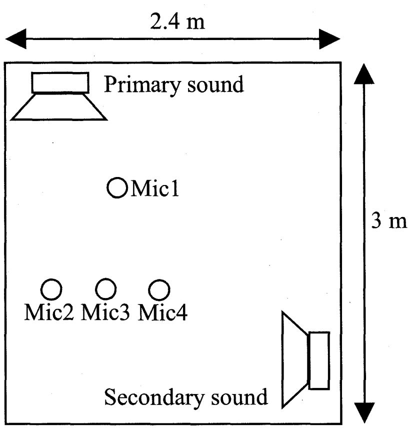

Fig. 3 Scheme of the enclosure

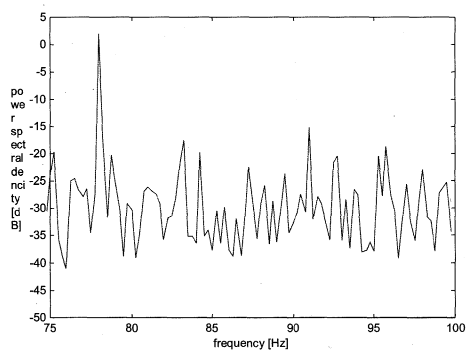

Fig. 4 Frequency characteristic of exciting benchmark signal

This signal has been tested in ANC laboratory in Institute of Automatic Control. Two loudspeakers and four microphones has been used as it is shown in Fig. 3. Number of experiments conducted in the laboratory showed utility of the signal proposed. Fig. 4 shows the power spectral density of the exciting signal with dominant frequency 78 Hz and α=1.1. Fig. 5 shows part (75-100 Hz) of frequency responses of the enclosure registered by four microphones (see Fig. 3). It is clear that dominant frequency appears (78 Hz). But disturbances in the excitation activate frequency characteristic of the enclosure together with electronic elements. This can be seen in frequency 91 Hz for instance - especially in mic1.

The benchmark signal proposed tests ANC system similarly to a real one. By changing dominant frequency and disturbances level one can obtain almost full information about dynamics of the enclosure.

5. Benchmark indices

There is only a few aspects of evaluation of ANC systems performance. The most important are level of the attenuation and convergence of adaptive algorithms. The first should be measured as the mean square value of the acoustic signal in observer point. The measure has to be done in a steady state with standard measurement units according to the proper scale. The only critics can addressed computer-processed signals. Usually the measure of the noise cancellation concerns ratio of mean square deviation:

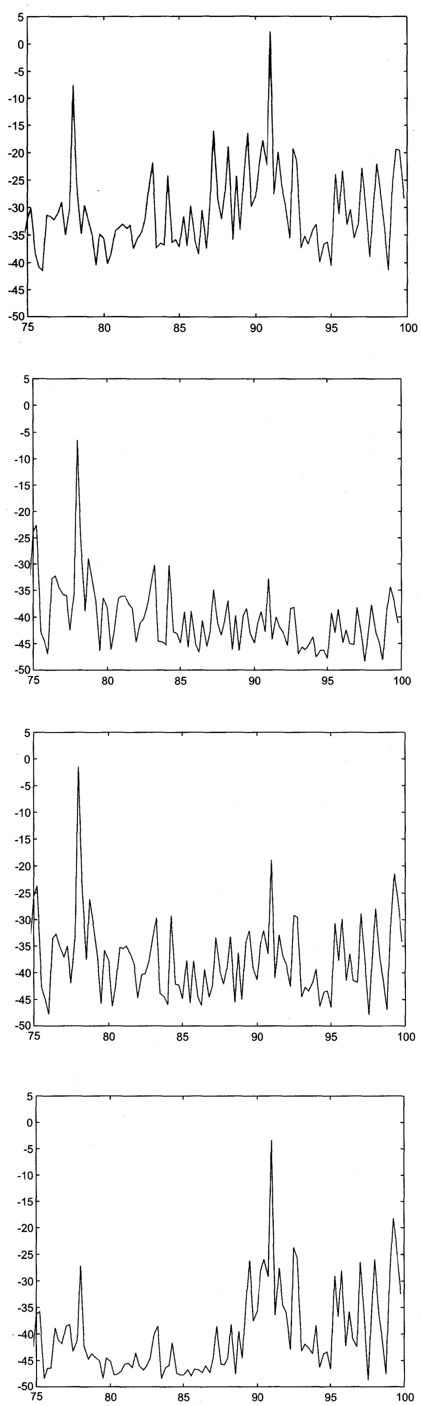

Fig. 5 Frequency response of the enclosure.

$$\vartheta[\mathrm{dB}] = 10\log\frac{\sigma_{on}^2}{\sigma_{off}^2}$$

where: ϑ - cancellation level, σ^2_{on} - mean square deviation of the signal measured in the observer point with ANC system on, σ^2_{off} - mean square deviation of the signal measured in the observer point without ANC system. The above index differs form the result obtained from standard measurement unit. To obtain the comparable results signals should be filtered by isophonic curves as it is done in the measurement units.

The second index concerns transient of mean square deviation σ^2_{on} (σ^2_{off}- does not depends on time). Fig. 6 presents dependence of ϑ on different value of parameter μ being the step of LMS algorithm (here μ depends on maximal singular value of autocorrelation matrix of reference signal [5]). Dependence $\vartheta(time)$ can be easily approximated with exponential function and the time constant of this function seems reasonably index characterizing speed of the convergence.

6. ANC benchmark experiment

Experiments has been conducted in ANC laboratory in Institute of Automatic Control. The control structure was adaptive feed-forward with cancellation of acoustical feed-back path. Fx-LMS algorithm has been used in the adaptation layer. Excitation signal was disturbed sine as described above. Dominant frequency has been changed in the range 50-80 Hz and disturbance level α has been chosen from the range [0,0.6].

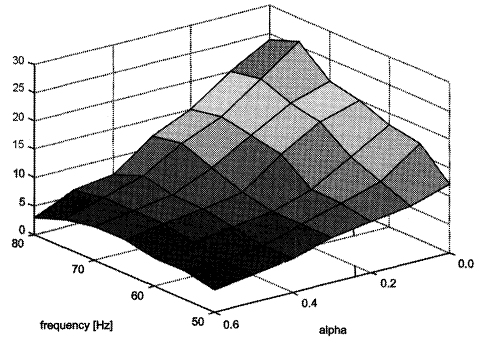

Fig. 7 Cancellation ratio versus dominant frequency and disturbance level in the illustrative experiment conducted I ANC laboratory in Institute of Automatic Control

The results of attenuation are given in Fig. 7 where level of cancellation ϑ [dB] is plotted versus dominant frequency and disturbances level. As can be seen from Fig. 7, cancellation level depends much on disturbances level. Not acceptable cancellation ratio begins from about α=0.3. It is clear that much should be done to achieve proper cancellation in this case if the level of disturbance is greater (maximal value of α is 1).

7. Conclusions

Obviously, benchmarking is necessary to provide methods of comparing different solution of the same problem. In the field of active noise control benchmarking is very difficult due to dedicated nature of ANC systems. Anyway, the need for comparison makes trials of benchmarking reasonable. It has been shown in the paper that certain elements of ANC systems can be standardized. A proposition of standardization has been also presented. What should be emphasised is that the value of benchmarking is not only to provide the base of comparing research results. It is also (at least) addition of some order to the field of ANC. The role of this paper will be fulfilled if it begin a discussion concerning benchmarking of ANC systems.

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References

[1] M.J. GRIMBLE and D. UDUEHI: Process control loop benchmarking and revenue optimization, "American Control Conference", Arlington, USA, 2001.
[2] D. UDUEHI, A. ORDYS and M.J. GRIMBLE: A Generalized Predictive Control Benchmark Index for MIMO Systems, CCA Conference, Glasgow, Scotland, 2002.
[3] B. ANDERSEN and P. PETTERSEN:, The Benchmarking Handbook 1996.
[4] M. PAWEŁCZYK: Control of Sound in an Active Headrest System, IEEE (No. 8119) Conference on "Methods and Models in Automation and Robotics" - MMAR'2002, 1157-1162, Międzyzdroje, 2002.
[5] C.H. HANSEN, S.D. SNYDER: Active Control of Noise and Vibration. Cambridge University Press, 1997.
[6] J. FIGWER and M. MICHALCZYK: Algorytmy RLS i LMS w zastosowaniu do aktywnego tłumienia hałasu - porównanie, Materiały XLVIII Otwartego Seminarium z Akustyki OSA'2001, Polanica-Zdrój 2001, Vol. 1, pp. 225-230.

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