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ACTIVE NOISE CONTROL SYSTEM IN PASSENGER CAR

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Abstract

Current car's technological development represents the similar level. The field for producers' competition becomes convenience of vehicle. One of comfort measure for users is level of noise in its interior. Recent years development of ANC systems makes possible to use it to decrease noise level in passenger car. As the subject is very important, an attempt to create such system was taken. The task necessary to develop working system, can be divided to three stages:

- preliminary research of object in which we want to decrease noise level
- essential calculations and numerical simulations
- technical design, building the system and testing it in real conditions

Last stage is the most expensive. In order to avoid possible big losses, very often it was preceded by extended laboratory research.

This paper concerns only two first stages of the whole project mentioned above - it is kind of report of realized researches and analyses. In the paper is presented research it was realized in different brands and types of passenger cars. It relies on acquisition of acoustic pressure in different points of interior, as well as vibrations of some elements of car body, suspension or engine. Results from numerical simulations (modeling real active noise control system) are presented. Different versions of control algorithm are analyzed, beginning from the simplest one to normalized least mean square algorithm. It is studied measurement points, which can be used in real system. Modification of active noise control algorithm, which increases theoretical performance of ANC system, is proposed in the paper. Conclusions drawn in the paper indicate aims of future works.

INTRODUCTION

Everybody likes driving a luxury car. However, only few are conscious about to what extend the comfort depends on the level of noise inside it. Is it then possible to reduce the number of decibels in the car cabin? It would mean for car producers the necessity of using more soundproof insulating materials, which would imply bigger mass of vehicle and its higher price. The result is then that smaller the car is, worse the acoustic conditions are inside of it. Whereas adding some extra soundproof protection in a car currently in use requires its almost complete dismantling, or it will not have any noticeable effects. Obviously for many car owners this solution is not acceptable. Therefore the idea of fighting noise in the cabin by “anti-noise”, or an acoustic wave exactly opposite to the one produced by the noise sources has been born.

One of disadvantages of active systems has been rather big size of electroacoustic converters necessary for producing the sound wave of particular parameters. The problem can be solved by using the on-board audio system as a compensation wave source. Car producers, especially those manufacturing luxury vehicles include in their equipment high quality multiple-channel audio systems of power counted in hundreds watts. The room for their elements is prepared already at the stage of car designing. They fit nicely in the car’s body, as the designers take into account ergonomic, aesthetic as well as acoustic factors.

The aim of this project is to work out and test by experiments the methodology of implementation of the multiple-channel system for active noise control in car cabin, using a standard audio system for vehicles. Vehicle submitted to active noise control is a passenger version of the Toyota Hiace van (Fig.1). The car is a mobile laboratory which males possible to carry out varied tests outside of the Faculty building. Therefore it has been adapted to the purpose: at the back there is some room for the measurement devices. In its center there is a swivel chair for an operator. The chair is equipped both with a seatbelt and a position lock, so the operator is able to work while the car is running. However, taking into account the character of the tasks, the noise in the cabin can influence the way they are carried out. The aim of the project has been then to soundproof the workplace of the operator using a single-channel active system of noise reducing..

THEORETICAL APPROACH

Studies on the subject should start with choosing a system to be applied. The LMS (Least Mean Square) algorithm and its derivates has been the most frequently used. The algorithm operates by adapting the vector of coefficients of the FIR filter after every work cycle of system has been completed (or after one sample has been filtered), according to the equation [1]:

$$\underset{i\in<0,L-1>}{\Lambda} w_i(n+1) = w_i(n) + \mu \cdot x(n-i) \cdot e(n) \tag{1}$$

The number L corresponds to the FIR filter’s order, so the vector of filter weights will be L long. The number marked with the letter n corresponds to subsequent samples of digitized signal. The symbol μ means the correction step conditioning the adaptation rate of compensation signal to the optimum shape, as well as stability of the entire system. There is a variety of the already mentioned LMS algorithm called Normalized Least Mean Square (NLMS) that proved to be very important because of its effects. It differs from the classic form by the equation of actualization of the vector of FIR filter weights:

$$\underset{i \in <0, L-1>}{\Lambda} w_i(n+1) = w_i(n) + \mu(n) \cdot x(n-i) \cdot e(n) \tag{2}$$

The adaptation step in the LMS algorithm has been replaced by a coefficient, its value being defined in every cycle of running the program. It is determined according to the following formula [4]:

$$\mu(n) = \frac{\alpha}{L\hat{P}_x(n)} \tag{3}$$

The coefficient α in numerator of the above relationship is called normalized adaptation step, while $\hat{P}_x(n)$ we call an estimate of signal power. According to [5] the formula for estimating the parameter looks as follows :

$$\hat{P}_x(n) = \frac{1}{M}\sum_{m=0}^{M-1} x^2(n-m) \tag{4}$$

where M corresponds to the width of window applied. As the value of parameter has been taken equal to the filter's order, the final relationship that allows us to determine adaptation step will have the following form:

$$\mu(n) = \frac{\alpha}{\sum_{m=0}^{L-1} x^2(n-m)} \tag{5}$$

EXPERIMENTAL STUDIES ON CARS

An important problem in the course of implementation of the system for active noise control in car consists of selecting signal of reference sources. A perfect source is the one that contains the components related to all the noise sources existing in the car and at the same time is characterized by a very weak function of transmission from the secondary source.

Due to the lack of complex data concerning the problem of implementation of the system for active noise control in car cabin the Vibroacoustic Laboratory carried out some preliminary tests in vehicles. The intention was to determine the acoustic pressure levels, get the noise spectrum and check in practice some measurement procedures. Three passenger cars were used:

- Nissan Micra
- Ford Sierra
- Toyota Hiace.

The recordings have been analyzed in order to:

- determine the main noise sources
- identify the most important ways of noise propagation
- determine the frequency band corresponding to emission of the majority of acoustic energy
- select the best sources of signal of reference

Figure 1 - The soundproofed car.

SIMULATION

The time runs recorded in digitalized form made possible to simulate performance of the system for active noise damping. Although the simulation does not fully represent the actual conditions, it will make possible the selection of a correct algorithm of steering or a converter that could be used as a source of signal of reference. Furthermore, it will let us test the influence exercised on the results by some parameters of algorithm or by indirectly accessible calculating power of a controller. Applying correct sampling frequency is also important, as on the one hand it will influence accuracy of representing the processed signals, and on the other number of calculating cycles in time unit that the controller will have to perform.

During the simulation the algorithms LMS (Least Mean Square) and NLMS (Normalized Least Mean Square) were tested for different sources of signal of reference, as well as for different error signal (of the soundproofed place). Efficiency of the system using NLMS algorithm (Table 1) has been calculated on the base of recording effectuated in the Toyota Hiace car running at 100 km/h in the fifth gear.

	microphone above the middle seat in the first row	microphone above the middle seat in the second row	microphone above the operator's seat
accelerometer on the upper mounting of front suspension	6,6	7,0	7,3
accelerometer on the firewall	3,0	2,6	2,8
accelerometer on the engine head	-0,7	-0,5	-0,1
microphone inside the engine compartment	12,4	11,7	11,7
accelerometer on the windshield	9,1	10,1	10,9
accelerometer on the right side windowpane, next to the mirror	11,4	11,6	11,0
accelerometer on the rear sill	3,0	1,6	0,0
microphone above the middle seat in the first row		19,2	17,4
microphone above the middle seat in the second row	11,9		17,9
microphone above the operator's seat	7,8	8,7	

Table 1 - Damping results with NLMS applied, according to the signal source; the columns denote sources of compensated signal, the rows of signal of reference (all the values in dB).

The best results in noise damping, independently of the place in cabin it was calculated for, were achieved using the acoustic signals only. However, using a microphone as signal source we have to take into account the acoustic feedback in the controller. Noise control using a microphone placed in the engine compartment is highly efficient, especially in the front seat. On this case acoustic feedback will be very small, so there is a possibility of using a controller that will not take it into account. Good results were achieved using signals of windowpanes vibrations in windshield and side windows, slightly better for the accelerometer placed on the side windowpane. The compensated signal received was characterized by relatively low peak-peak value meaning quite good impressions at its hearing. Spectrum analysis of compensated noise showed that the signal of reference contains all the most important components related to the main sources of noise in car, so the damping is even in the whole band. Further analyses were not carried out for all the recorded signals: the ones that had given the worst results were discarded.

MODIFIED NLMS

Having carried out the simulations, the efforts to modify the NLMS algorithm were undertaken in order to make it more efficient. Consequently a method allowing it was found which does not complicate calculations very much, hence it will not overload the controller hopefully. Modified scheme of steering algorithm is shown in the Fig 2.

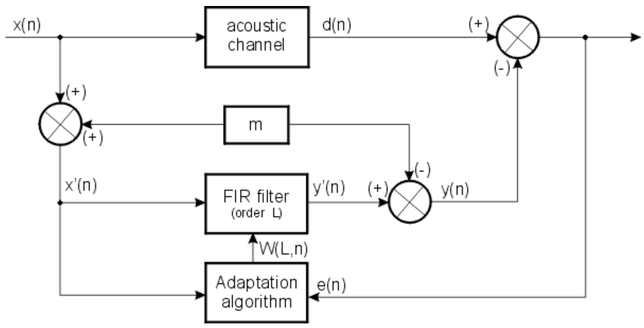

Figure 2 - Modified steering algorithm in the system for active noise control.

Modification gives positive effects while applying both LMS and NLMS algorithms. The results achieved by a system using NLMS algorithm are shown in the table 6.1; the values are for the recording used in the previous simulations. Value of the component amplitude of constant *m* was equal to the half of maximum amplitude of signal of reference.

Amplitude of the received compensated signal is extremely low and the modification gives very good results in damping noise in car cabin. However, we can see that it proves to be much more efficient for lower frequencies, reaching even 50 dB. Maximum frequency of a signal still damped by the system was about 10000Hz.

	microphone above the middle seat in the first row	microphone above the middle seat in the second row	microphone above the operator's seat
accelerometer on the right side windowpane, next to the mirror	32,5	33,9	28,7
microphone above the middle seat in the first row		31,6	34,9
microphone above the middle seat in the second row			36,2

Table 2 - Damping results with modified NLMS applied; the columns denote sources of compensated signal, the rows of signal of reference (all the values in dB).

Time runs and frequency spectrum for the best case of the table above are shown in the Figures 3 and 4.

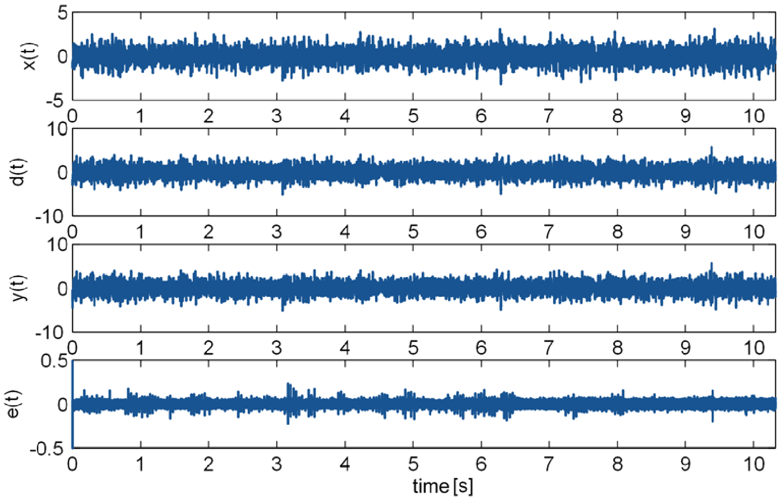

Figure 3 - Time runs of the ANR system using modified NLMS algorithm.

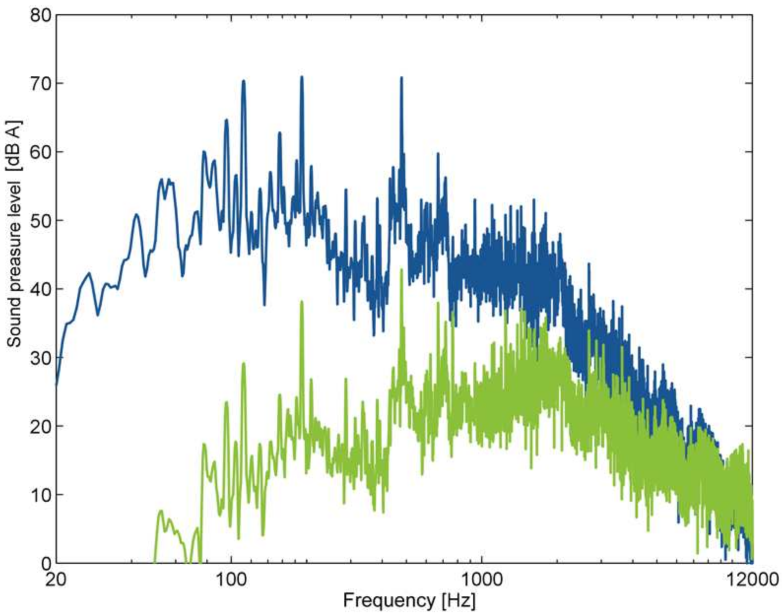

Figure 4 - Spectrum of power corrected by the characteristic A.

CONCLUSIONS

Having checked different steering variants we arrived to the conclusion that the algorithm developed in the Vibroacoustic Laboratory had proved to be the best. The best effects in damping noise, independently of the place in cabin it was calculated for, were achieved using the acoustic signals only. However, using a microphone as signal source we have to take into account the acoustic feedback in the controller. Good results were achieved using signals of windowpanes vibrations in front and side windows, slightly better for the accelerometer placed on the side windowpane. The compensated signal received was characterized by relatively low amplitude value meaning quite good impressions at its hearing. Spectrum analysis of compensated noise showed that the signal of reference contains all the most important components related to the main sources of noise in car, so the damping is even in the whole band. Thus the active systems of noise damping seem to be perfectly suitable for reducing quantity of decibels in car cabins, as they are efficient precisely for the low frequencies.

The studies and analyses indicate directions of future activities in the next stages of the project. First, the simulation results will be tested in laboratory experiments. The last stage, after their verification, will consist of constructing and testing the real system in the Toyota.

Taken the fact that the conventional methods of reducing noise level, consisting of soundproofing and acoustic insulation are efficient for high frequencies (in order to make them efficient for lower ones their mass should be increased quite importantly), the future of reducing noise in cars belongs to hybrid systems, using both the active and the passive methods. Therefore, as we can see, in future quite big family of electronic systems in cars may grow when it the active noise control systems join it.

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