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FIRST INVESTIGATIONS ON ACTIVE NOISE CONTROL APPLIED TO DAYBEDS

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Abstract

The pollution of relaxation rooms with noise, especially during the nights, results in an unwanted limitation of comfort and causes indispositions. In order to prevent serious diseases caused by continuous noise pollution and to guarantee a restorative sleep, the concept of active noise control has been applied to daybeds. A transmission test system – consisting of an anechoic chamber and a reverberation room – has been used to simulate an apartment with an open window. The primary noise field has been generated inside the anechoic chamber. Tonal as well as broadband noise ($f \leq 1$ kHz) has been applied to excite the reverberation room. A conventional daybed with a dummy head microphone has been used to model the sleeping person. In addition an array – consisting of 16 microphones – has been installed to measure the sound field around the dummy head. Two microphones that have been placed close to the dummy head ears have been used as error sensors for the active control system. An FxLMS-Algorithm – implemented on real time hardware – has been applied to generate the secondary sound field. For this purpose two small loudspeakers have been mounted 25 cm above the dummy head. The results of the experiments show that the sound pressure level around the dummy head has been significantly reduced by the application of active noise cancelling. For tonal noise a minimum reduction of 10 dB has been achieved for every tested frequency. In case of broadband noise the sound pressure level has been lowered by 8 dB. The resulting zone of quiet around the error sensors depends on the excitation frequency or the frequency band of the broadband noise.

INTRODUCTION

According to German law, noise is regarded as a form of environmental pollution [1]. Recurrent exposure to high noise levels can cause serious diseases. An aspect of particular importance is noise that keeps a person off from restorative sleep. This paper documents the results of first experimental investigations on active noise control (ANC) applied to daybeds. The motivation for this arises i.e. from the request to sleep with open windows even in areas with a high volume of traffic. The goal is to create a local zone of silence around the head of a person lying on a bed or daybed. This is basically similar to other workings which are described i.e. in [2]. But the long-term objective of this work is to develop a simple, small, portable, and highly effective ANC system to be utilized in a multitude of situations with various noise exposures.

EXPERIMENTAL SETUP

Figure 1 displays the transmission test system of the professorship for Mechatronics at the HSU, which is used to simulate a bedroom with an open window. The primary noise is generated inside the anechoic chamber with commercial PA speakers (1). In the reverberation room two error microphones (3) are installed next to a dummy head microphone (4) that is placed on a daybed (2). Two small speaker systems (5) are positioned above the dummy head to generate the anti-noise. An additional microphone array (6) is used to measure the sound pressure level (SPL) around the dummy head. The transmission port (7) represents the open window.

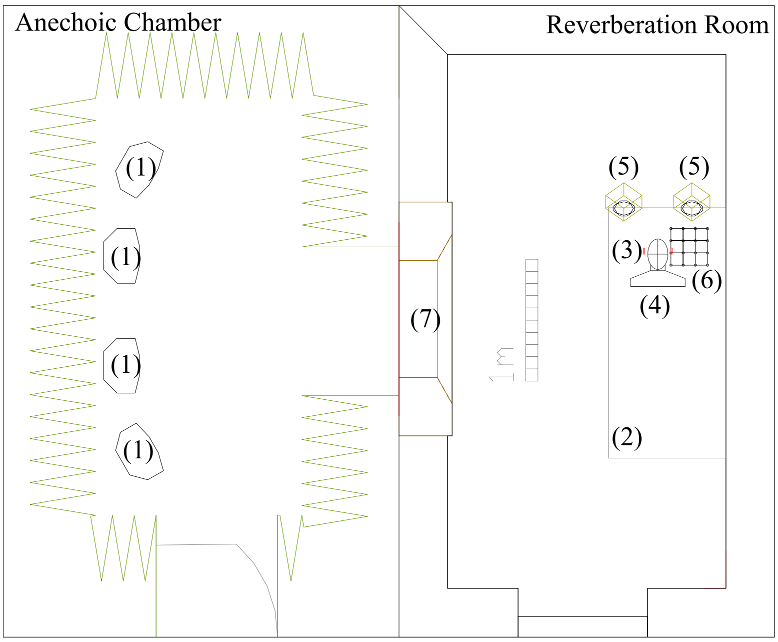


Figure 1 – Experimental Setup (top view)

A HMS III.0 system from HEAD Acoustics is used as dummy head microphone. All other microphones are from Bruel&Kjaer, a Pulse analysis platform of the same manufacturer is used for the measurements. The sensors of the microphone array form a 4x4 grid with a constant row- and column spacing of 100 mm. The secondary speakers are custom made and consist of a 6 inch driver mounted in an enclosure with a volume of only 4 liters. They represent an attempt to achieve a high output at low frequencies with a compact box. For the signal processing task an RTI1103 system from dSPACE is used. It is equipped with a PowerPC processor running at 1 GHz and multiple fast A/D- and D/A-converters (hardware latency ≈ 5 µs). Furthermore, several analogue high- and low-pass filters respectively (Kemo VBF21) and a multi-channel microphone preamplifier from B&K are applied.

Control Algorithm

The computation of the drive signals for the secondary speakers is performed with a matrix implementation of the multi-channel FxLMS algorithm with adaptive FIR-filters, which is described in great detail i.e. in [3]. Future work will also include the investigation of newer and maybe more suitable algorithms, but for this first stage the famous and widely-used approach of Widrow was selected. Figure 2 shows the top-level Simulink model of the control algorithm. The denomination of the signal paths refers to the nomenclature used in [3].

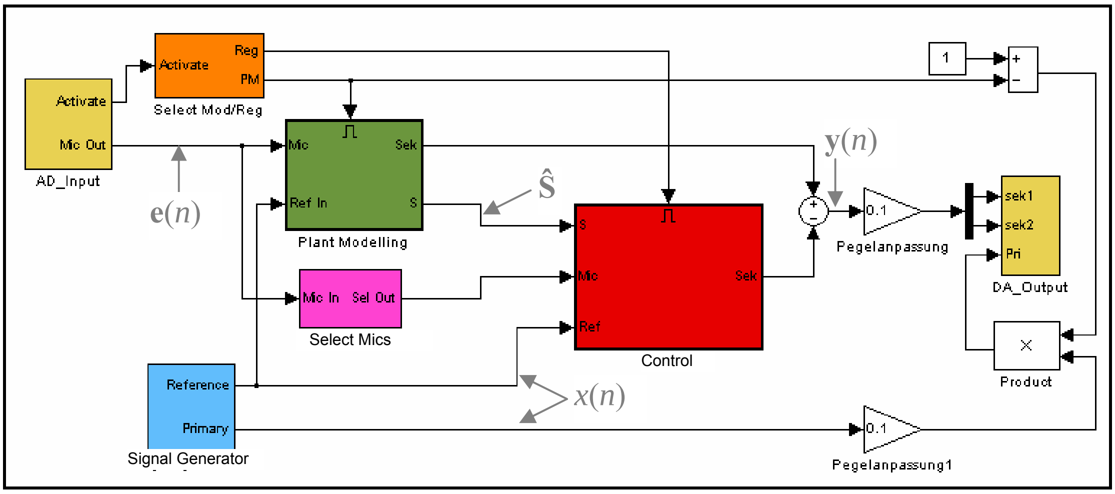


Figure 2 – Simulink model of the control algorithm

Access to the physical in- and outputs of the dSAPCE hardware is provided via *AD_Input* and *DA_Output* respectively (yellow). The operations for the underlying FxLMS algorithm are implemented in the *Control* subsystem (red) and the estimation of the secondary paths takes place in the *Plant Modelling* block (green). These subsystems are activated and deactivated respectively with the *Select Mod/Reg* block (orange). This block also implements an interruption of the active control by pressing an external button to allow A/B-comparisons of the ANC system by real test persons. The primary noise signal, which is at this point also the reference signal for the controller, is generated in the *Signal Generator* subsystem (blue). Depending on the actual experiment either a single sinus signal or band-limited white noise is used as stimulus. And finally the *Select Mics* block (pink) allows to select the error signals to be utilized by the control algorithm.

Table 1 specifies some important parameters for the controller. Values put in parentheses are valid for experiments with broadband excitation. In this case a much higher filter order is necessary to exactly adapt the signal form as if only a single sinusoid ought to be controlled. But this causes a large increase of the required calculating capacity. Therefore, the maximum number of error sensors is limited to 2 for the broadband case and the sampling frequency of the algorithm is not higher than 4 kHz, although a rule of thumb states that it should be at least five times the highest control frequency. The last column of the table indicates if a parameter can be modified at runtime.

Table 1 – Controller parameters

Parameter	(Start-) Value		Mod.
Maximum number of error sensors	4 (2)		
Maximum number of secondary actuators	2		
Sampling Frequency	4 kHz		
Convergence factor for Plant Modelling (PM) and Control (C)	PM	0,01	x
	C	0,01	x
Number of coefficients of the adaptive filters for Plant Modelling (PM) and Control (C)	PM	4 (600)	
	C	4 (600)	
Leakage factor	1		x

EXPERIMENTAL INVESTIGATIONS

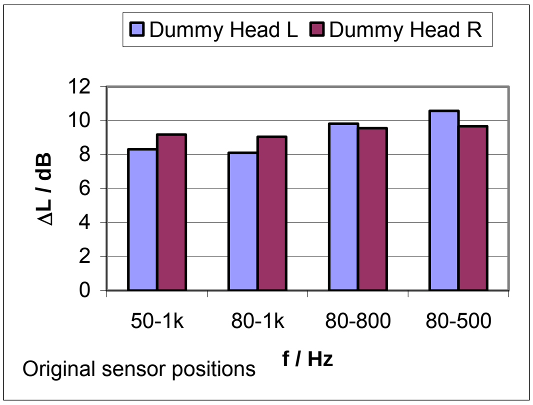
Tonal ANC

This preliminary test series is carried out mainly to identify an upper cut-off frequency for the broadband control task. The performance of the ANC system is successively measured for the ISO centre frequencies of the third octave bands between 50 Hz and 1.6 kHz. The uncontrolled SPL is always adjusted to a minimum value of 75 dB at the dummy head microphone. A test run is rated as successful if the SPL at the corresponding frequency is reduced by at least 10 dB at both “ears” of the dummy head when ANC is applied. This is achieved for every tested frequency between 63 Hz and 1 kHz. The mean noise reduction in this frequency range is 24 dB at the left ear and 21 dB at the right ear.

The measurements with the microphone array show the typical results for a local control strategy. A zone of silence is generated around each error microphone, its size being dependant on the respective wavelength. Below 250 Hz, the resulting zone of quiet (noise reduction ≥ 10 dB) extends across the overall width of the daybed (≈ 1 m), thus allowing some movement of the head on principle. Above 500 Hz, the activated ANC system can however cause an increased SPL in the adjacency of the dummy head, too. Hence, an upper cut-off frequency of 1 kHz should only be chosen, if virtually no movement of the head is expected or if the design of the ANC system is changed to widen the noise reduced area (i.e. by installing additional sensors).

Broadband ANC

Tonal or multi-tonal noise covers only a small fraction of the possible applications for this ANC system. Therefore, experiments with band-limited white noise are also carried out. Due to the results of the single frequency tests, four different band limits are chosen for the noise signal. Figure 3 shows the overall noise reduction at the dummy head microphone for the respective excitation (the uncontrolled SPL is again adjusted to $\geq$ 75 dB). The left diagram depicts the measurement results for the original positions of the error microphones – very close to the dummy head – as described above. But as the realization of such positions poses a very big challenge under real-life conditions, the experiments are repeated with the sensors moved to a virtual heading section of the daybed, approximately 200 mm above the original positions. The results of these measurements are presented in the right diagram.



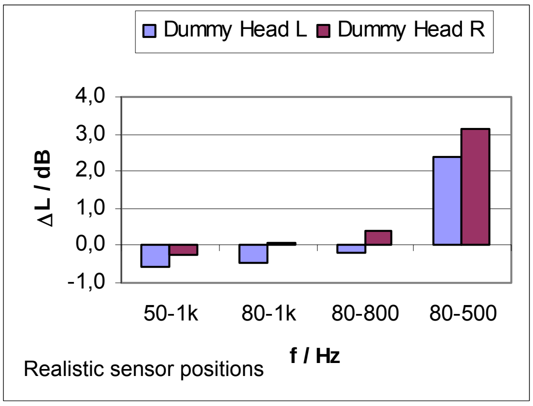


Figure 3 – ANC results at the dummy head microphone for broadband excitation

For the original sensor locations the noise reduction varies between 8.1 and 10.6 dB at the left ear, and between 9.1 and 9.7 dB at the right ear of the dummy head (a decrease in SPL of 10 dB is sensed as about half of the original volume). It is noteworthy, that there is just a slight increase in noise reduction if the bandwidth of the primary signal is narrowed. This can be explained by means of the auto-spectra of the dummy head microphone signals. An example is displayed in figure 4 on the next page for an excitation between 50 and 1000 Hz. It shows that for the uncontrolled case (blue graph) the frequency components with the highest SPL are found below 600 Hz. For the controlled case (red graph) a common reduction in SPL up to 1 kHz is measured. A higher total attenuation is solely not achieved because of individual peaks which are also located below 600 Hz. These peaks originate from the layout of the secondary loudspeakers and the error microphones, which results in adverse transfer behaviour at these frequencies. And due to their position on the frequency axis a decreased bandwidth cannot significantly improve the control profit.

For the new sensor positions there is virtually no noise reduction at the dummy head any more. Only for an excitation between 80 and 500 Hz a slight attenuation of 2.4 dB at the left ear and 3.1 dB at the right ear can be measured. Of course, this comes from the increased distance between the error sensors and the dummy head.

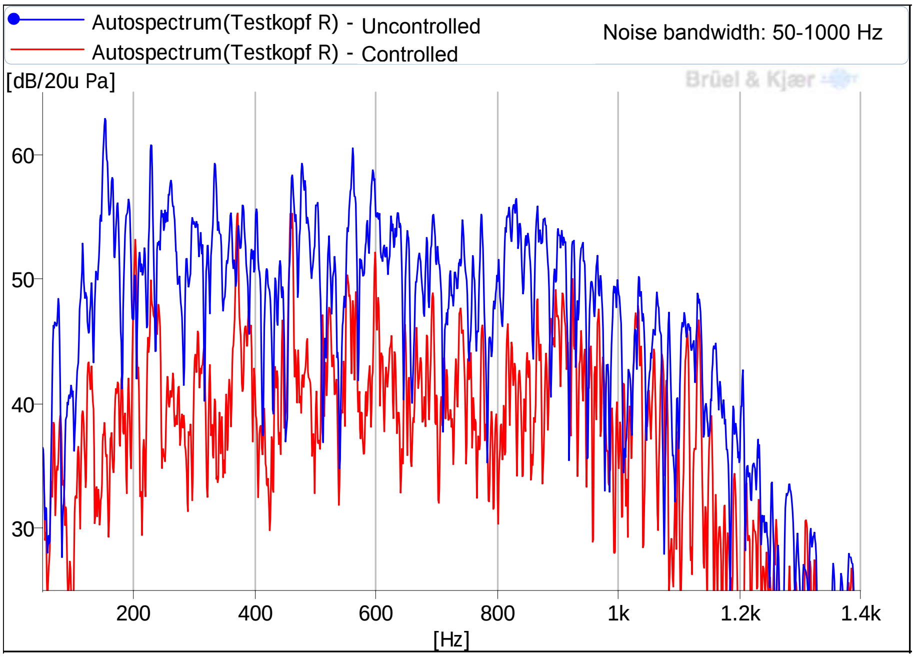


Figure 4 – Auto-spectra of the dummy head microphone signals

The preceding results are confirmed by the measurements with the microphone array. Figure 6 on the following page shows some contour plots that are extracted from these measurements. They represent the course of the SPL next to the right ear of the dummy head (excitation bandwidth: 50-1000 Hz). Especially (c) and (f) clearly show a part of the noise reduced areas around the error sensors – the right error microphone is situated next to array microphone A3 and A1 respectively for the different setups. A3 is also located next to the right ear of the dummy head and for the new error sensor positions the zone of silence simply does not reach the dummy head.

An aspect that shall only be covered shortly is the impact of the filter order on the controller performance. Regarding the computational demands a small filter length is preferable. But at the same time a higher order is required for an improved spectral resolution of the filter. Figure 5 shows a quasi linear increase in noise reduction for a rising order of each adaptive FIR-filter (4 for the plant modelling stage, 2 for the control stage) within the investigated range.

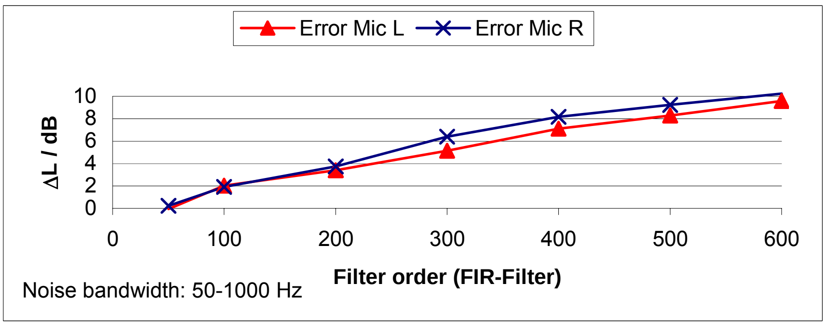


Figure 5 – Influence of the filter length on the controller performance

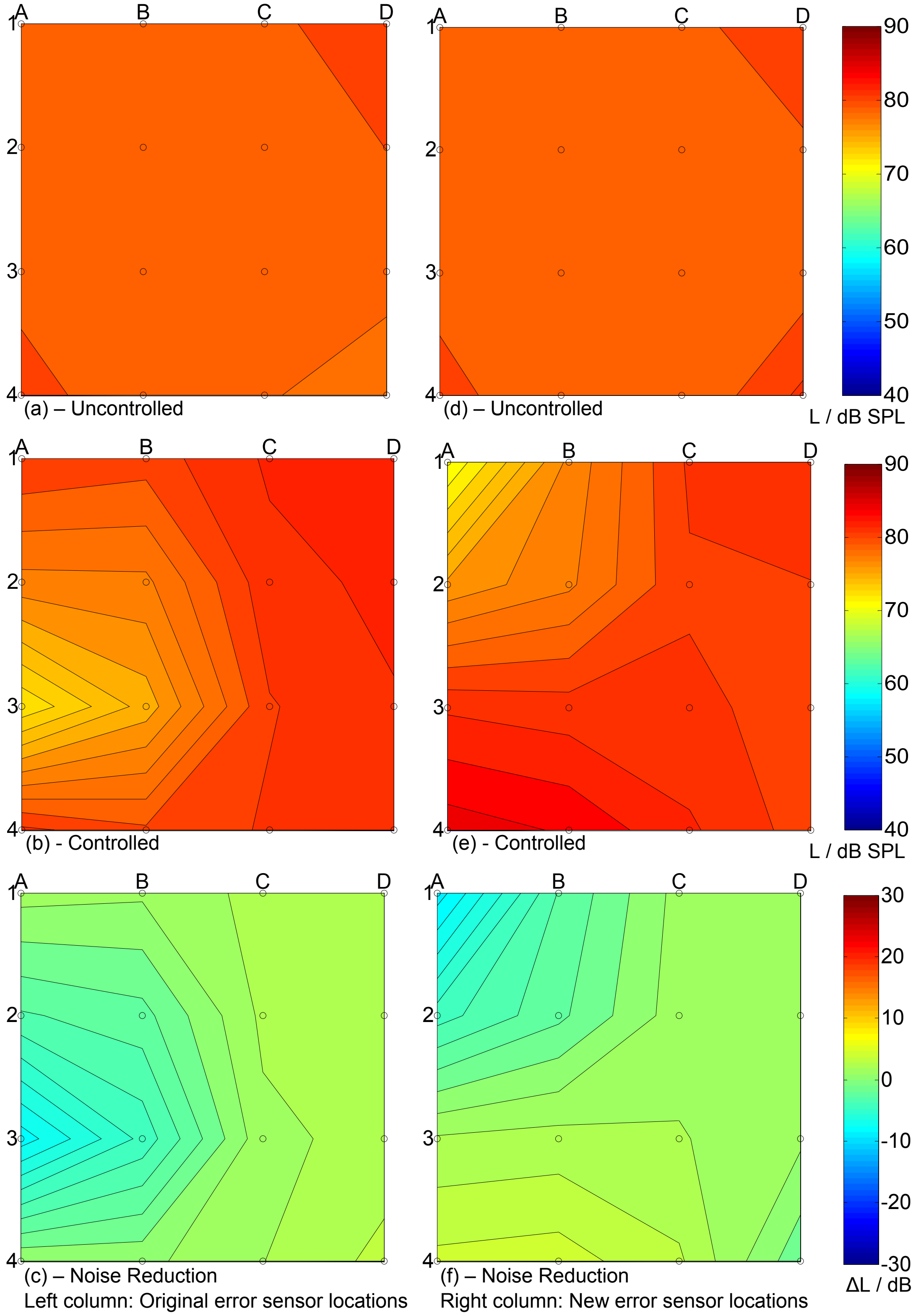


Figure 6 – SPL contour plots on the right side of the dummy head

SUMMARY AND OUTLOOK

This paper documents first investigations on the application of ANC to daybeds. An ANC system with two error microphones and two secondary loudspeakers is installed in a test rig to achieve local noise reduction around a dummy head microphone that is placed on a daybed. The drive signals for the canceling speakers are computed with the well-known FxLMS algorithm.

Tonal noise is used to specify a reasonable upper cut-off frequency for the ANC task under the present boundary conditions. Between 63 Hz and 1 kHz the noise reduction at the dummy head always exceeds 10 dB (> 20 dB on average). However, drawbacks can arise above 400 Hz. Above this frequency the SPL is increased in the proximity of the dummy head when ANC is applied.

Experiments with band-limited white noise show a control profit of 8 to 10 dB that is only slightly dependant on the excitation bandwidth. Virtually no repercussions are observed. But if the error sensors are moved to a position where they do not handicap a movement of the head the remaining noise reduction at the dummy head is only 3 dB below 500 Hz.

Two main conclusions are formulated:

- The presented ANC system enables a local noise reduction of ≥ 10 dB for tonal and broadband primary noise in the frequency range ≤ 1 kHz.
- To achieve this performance the error signals have to be sensed very close to the ears of the person lying on the daybed.

The second statement is very difficult to implement if at all possible. Hence, further extensive research is intended for this project. Aspects that will be covered are i.e. the use of virtual microphone techniques or sound intensity probes, different setups of the ANC system with modified quantities and placements of sensors and actuators, the impact of the quality of the reference signal on the ANC performance, and the investigation of further algorithms.

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