SELECTION OF ACTIVE NOISE CONTROL STRATEGY: TWO TEST CASES

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ABSTRACT

Active noise control is a technique in which unwanted sound, noise, is cancelled by introducing controllable secondary sources. Active noise control is applied to various applications from active hearing protectors to active attenuation of aircraft cabin noise. In the selection of appropriate ANC strategy to an application, several aspects have to be considered. In this paper, selection of active noise control strategy and the implementation of the ANC systems in two test cases are presented and discussed. The first test case is active attenuation of a moving machinery cabin, while the other one is active improvement of sound insulation of a double-wall structure. Simulation and measurement results from these cases are evaluated and the selections of the strategy in each case are validated.

1. INTRODUCTION

Active noise control is a technique in which unwanted sound, noise, is cancelled by introducing controllable secondary sources. The outputs of the secondary sources are arranged so that they interfere destructively with the noise from the primary source. The performance of an ANC system is monitored by error sensors that measure the residual noise. Active noise control works at low frequency range, typically from 20 Hz - 500 Hz, where passive methods become inefficient or expensive. Most efficient noise cancellation is usually achieved by the combination of active and passive methods.

Active noise control is applied to various applications from active hearing protectors to active attenuation of aircraft cabin noise. In the selection of appropriate ANC strategy to an application, several aspects have to be considered. In this paper, selection of active noise control strategy and the implementation of the ANC systems in two test cases are presented and discussed. The first test case is active attenuation of a moving machinery cabin, while the other one is active improvement of sound insulation of a double-wall structure.

2. SELECTION OF CONTROL STRATEGY

The selection process is started by characterization of the primary noise and defining the disturbing frequencies. Beside the absolute noise levels, psychoacoustic phenomena should also be taken into consideration. In many cases, there are annoying tonal components whose level is considerably higher than the basic noise level. The targets for the ANC system are affected by the physical limitations of the given application. These limitations can be studied using analytical models and simulations.

After the targets and requirements for the ANC system are set, the optimum performance of the ANC system can be simulated under ideal conditions. In the simulation, measurement data obtained from the physical system can be used and different control methods can be considered. Fundamental issues in choosing the control methods are the physical control strategy and the control approach [1], [2]. The performance of the system can be analyzed using techniques presented in [3]. It gives a generic methodology for examining an ANC system with practical constraints and performance limitations.

A critical point of an ANC system is the placement of the transducers including secondary sources and reference and error sensors. The number and location of the transducers depend on the selected approach. Several optimization methods have been applied for choosing the transducer locations [1], [4].

Finally, the control system is implemented using appropriate hardware. The core of the system is the signal processing unit which produces the output signal of the ANC system based on the input signals. Depending on the application, it can be as simple as an analogue filter or a complex digital signal processing system. In addition, digital systems also require anti-aliasing and reconstruction filters and data converters. After the control system has been implemented, the ANC system can be constructed and evaluated. The selection process is illustrated in Figure 1. In real life, steps of the process are typically done recursively. [1]

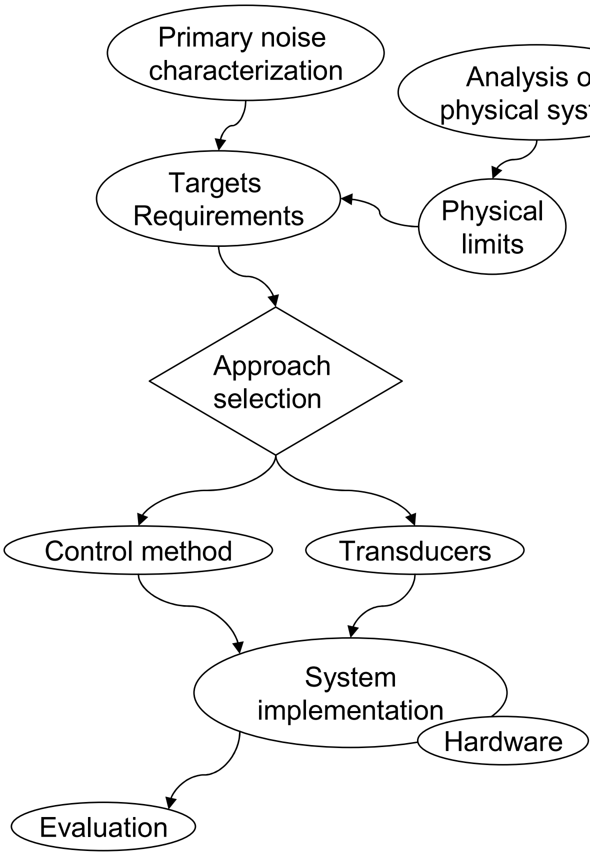

Figure 1. *Flow chart of the selection process.*

3. SELECTION OF ACTIVE NOISE CONTROL STRATEGIES FOR THE TEST CASES

3.1. Test case 1: Moving machinery cabin

The first test case is a moving machinery cabin which is a three-dimensional enclosure and there are several primary sources radiating noise into it. Such sources include the engine, ventilation and hydraulics. The tonal components that are relative to the engine speed sound particularly disturbing. The strategy is to produce "silent zones" around the driver's ears. A multichannel ANC system with at least two secondary sources and error sensors is required to obtain an adequate silent zone around the driver's ears.

Adaptive feedforward control approach is chosen since the cancelled noise components are relative to the engine speed and a tachometer reference can be obtained. The pulse train obtained from the tachometer must be further processed to produce a reference signal containing the cancelled frequencies. The multichannel control system with multiple sine wave generators requires a remarkable amount of computation. A DSP is thus used as the control system hardware. A block diagram of the ANC system is shown in Figure 2. The adaptation algorithm is filtered-x LMS (FXLMS) which modifies the coefficients of the adaptive filters based on the error signal and the reference signal filtered by the plant model.

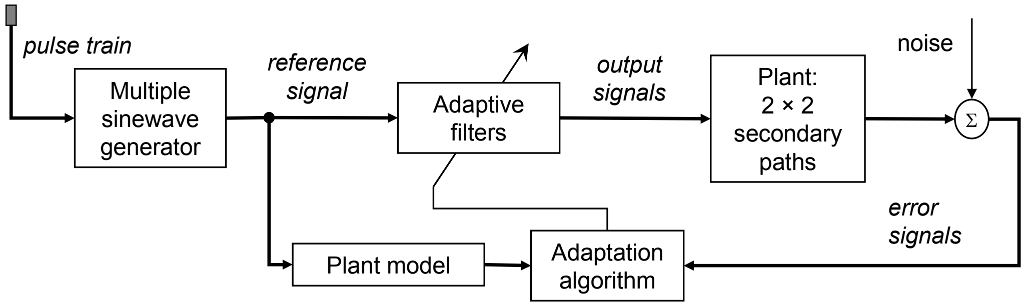

Figure 2. *Block diagram of the adaptive feedforward ANC system.*

The system was first simulated using Matlab/Simulink. According to the simulations, periodic components can be totally cancelled using the adaptive feedforward control approach. The system was then implemented and tested in a real moving machinery cabin. The audio loudspeakers were used as the secondary sources and the error sensors were two electret microphones located near the driver's head.

3.2. Test case 2: Active sound insulation system for a double-wall structure

The second test case is a double-wall structure whose sound insulation is improved by active means. In this case, low-frequency broadband noise is desired to be attenuated. The strategy is to increase the transmission loss of a structure containing passive material and the transducers of the active system. Both the secondary source and the error sensor are flat panel loudspeakers that can be used either as actuators or sensors.

Since a reference signal is typically not available, feedback control approach is chosen. In feedback systems, the delay of the control loop is critical and has a clear influence on the bandwidth of the ANC system. In analogue control, the delay is smaller compared to digital systems. A single-channel analogue feedback control system is thus chosen (see Figure 3). The control filter is implemented using second-order biquad filters.

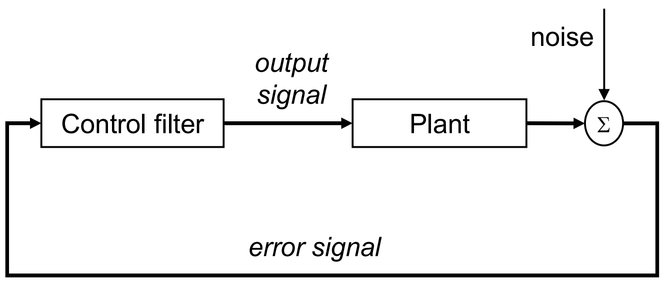

Figure 3. Block diagram of the analogue feedback ANC system.

The test system consisted of a plastic plate, the secondary source panel and the error sensor panel. Between them, porous material was installed to make the secondary-path transfer function less resonant. The control filter was designed using Matlab and implemented with digitally-controlled analogue biquad filters. For testing, the ANC system was installed in an opening between a sending room and a semi-anechoic laboratory.

4. RESULTS

In the first test case, the primary noise consisted of real moving machinery noise in which two periodic components were artificially added. The frequencies of the periodic components modeling noise caused by ventilation and hydraulics were 170 Hz and 184 Hz. The measurements were done using binaural microphones attached to a head of a dummy sitting at the driver's seat. The sound pressure levels were measured in five microphone pair locations with and without control and the attenuations were calculated. The distance between each measurement point pair was 0.06 m. The results are summarized in Figure 4 and Figure 5. They show that periodic noise is attenuated at all positions except position 4 at which the 170 Hz component is slightly amplified at the left microphone.

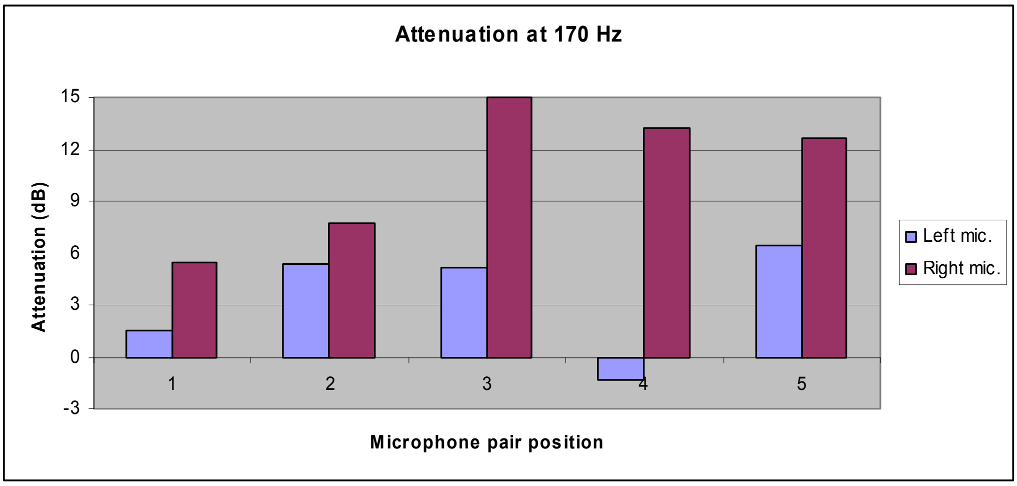

Figure 4. *Attenuation at 170 Hz at different microphone pair positions.*

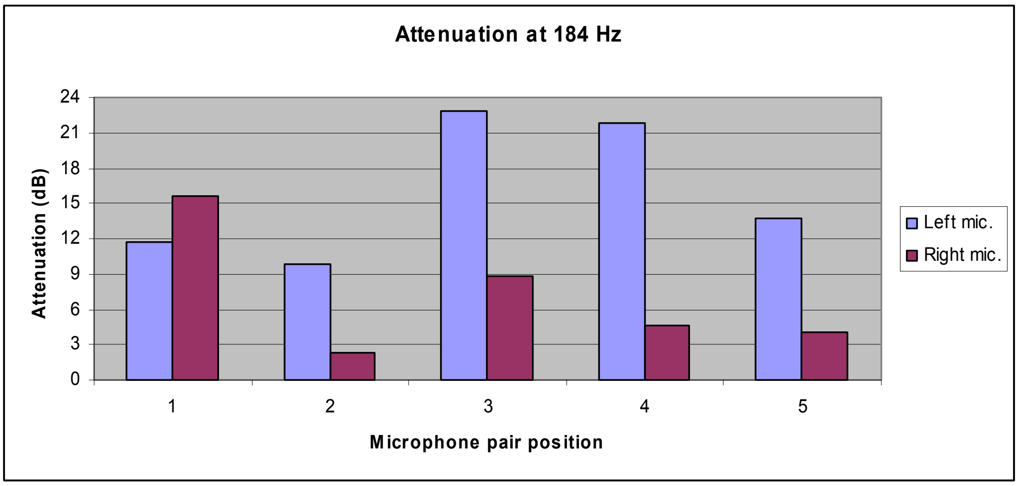

Figure 5. *Attenuation at 184 Hz at different microphone pair positions.*

The active sound insulatio system was tested with bandlimited noise. In Figure 6, a measurement result with 200-600 Hz bandlimited noise is shown . It indicates that noise reduction up to 10 dB is achieved at 200-400 Hz at the receiving side of the system. Noise is amplified at 450-1000 Hz due to waterbed effect inherent in feedback systems. Passive sound insulation becomes effective above 250 Hz, however, and the amplification has only a slight influence on the total noise level.

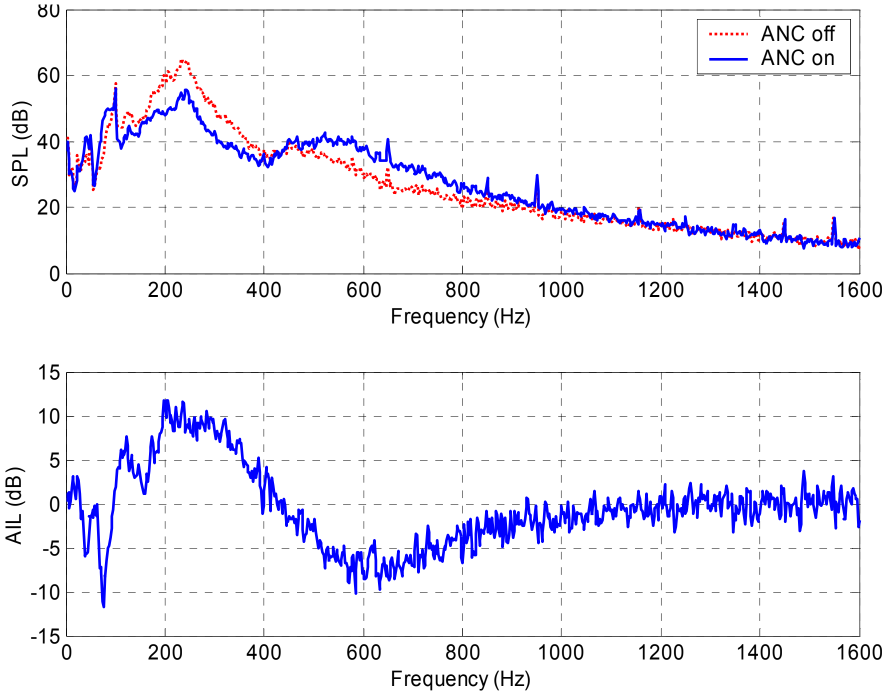

Figure 6. *Measurement results with 200-600 Hz bandlimited noise.*

5. RESULT ANALYSIS AND CONCLUSIONS

Selection of active noise control strategy for two test cases was presented. In the first test case, active noise control in a moving machinery cabin, adaptive feedforward control approach with sinusoidal reference was used. The results showed that tonal noise components are attenuated around driver's ears. The second test case was active improvement of sound insulation of a double-wall structure. The system was based on analogue feedback control. Measurement results indicated that low-frequency noise was noticeably attenuated and slight amplification above the attenuated frequency band occurred.

In both test cases, targets for the active noise control system were achieved. In the second test case, noise amplification could be avoided by selecting feedforward control approach instead of feedback. A reference sensor would then be required at the sending side of the system.

6. ACKNOWLEDGEMENTS

The presented research work has been partly done in the HILMA-project. HILMA-project was funded by Työsuojelurahasto (The Finnish Work Environment Fund), Valtra, Lännen Engineering and Vilakone.

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