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ACTIVE NOISE CONTROL AT THE OPENING OF AN ENCLOSURE FOR MACHINE WITH A STAND ALONE DSP

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ABSTRACT
The noise generated by machine tools theoretically can be effectively isolated by a closed acoustic enclosure. However, it is found very often that, due to the requirement of manufacture process, an inlet or outlet opening should be provided in the acoustic enclosure. The noise radiated from the opening becomes the main noise soure in this case. Although there are some active noise control systems available in the market, it was found that it was not easy to use an existing system in the market to solve the problem without significant modification of the system.. The main object of this work is to develop a stand alone active noise control system and use the control system to suppress the noise radiated from an opening of an enclosure. A DSP board manufactured by Orsys was used in this work to develop the control system. The DSP board includes a TMS 320 C 32 DSP Chip, 128K words SRAM and 512K Bytes Flash-EEPROM. According to the problem to be controlled, the system developed in this work includes three A/D and two D/A converters. The well-known feedforward control algorithm, FXLMS (filtered-X least mean square) was adopted in this work. The final system is very compact and is a stand-alone system, i.e., the system can work alone without PC or other equipments. A reference microphone and two error micrphones were used as input signals and two speakers (output) were used as the secondary source to cancel the main noise source. The dimensions of the experimental enclosure are 120 cm x 120 cm x 120 cm and the dimensions of the opening are 20 cm x 20 cm. The effect of the locations of the error microphones and the speakers on the attenuation results were discussed in this work. The results show that the reference microphone should be placed as close as possible to the main noise source while the error microphones and the speakers should be placed as close as possible to the opening. The total noise attenuation with white noise in the band 20-1000KHz as the main source was found to be 6.2dB. The results of this work demonstrate that (1) A stand-alone active noise control system is achievable with a reasonable price, i.e., less than 1000 US dollars, (2) A hybrid noise control strategy, namely, passive acoustic enclosure combined with a local active control system, is a good solution for the noise combat in plant.

1 - INTRODUCTION
The noise generated by machine tools is a troublesome problem found in most manufacture factories. Theoretically, the noise due to the manufacture process can be effectively isolated by a closed acoustic enclosure [1]. However, it is found very often that, due to the requirements of manufacture process, an inlet or outlet opening should be provided in the acoustic enclosure. As a result, the noise radiating from the opening becomes the main noise source in the factory. It is very difficult to reduce the noise from the opening by compact passive control measures when one should consider the easy access of the opening. Active noise control becomes an attractive solution for this problem. In the past decade, a vast amount of reports have been published to discuss the active control algorithms or the control systems, a good review can be found in [2]. Although there are some active noise control systems available in the

market, it was found that it was not easy to use an existing system found in the market to solve the above mentioned problem without a significant modification of the system.
The object of this work is to develop a stand alone active control system and use the control system to suppress the noise from an opening of an enclosure. The detail of the hardware system was introduced first in this work. The effect of the locations of the error microphones and the speakers on the control results were then discussed.

2 - DEVELOPMENT OF HARDWARE SYSTEM

One of the objects of this work is to develop an active control system which can work alone (without PC) in site and is suitable for suppressing the noise radiating from an opening. Because the noise radiating from an opening generally is not a plane wave, the number of control channel should be larger than two in order to get a good attenuation result. Based on this consideration, the diagram of the control system is shown in Fig. 1. The system includes the following main components: (1) low pass filters, (2) three A/D and two D/A converters, (3) DSP board,. (4) power supply, (5) two speakers and three microphones.

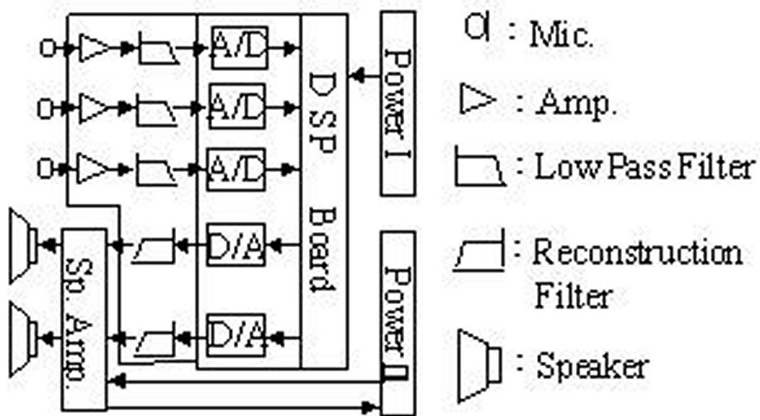

Figure 1: Block diagram of the control system.

Low pass filters: The low pass filters used in this work were designed by using the chip TL 072 (by T.I.) as the operational amplifier. Note that each low pass filter should use an independent TL 072 chip in order to avoid the cross talk effect.
A/D, D/A Converter: The LTC 1650C A/D converters by Linear Technology were adopted in this work. In order to match the sampling interval of the DSP board, two fast flip-flop latches (74F374) were used as a buffer and connected between each A/D converter and the DSP board. Two D/A converters by Analog Device (type AD 669) were connected directly with the DSP board.
DSP board: The DSP board is the key component of the system. The DSP board by Orsys includes a TMS 320 C32 DSP, 128K words SRAM and 512K Bytes Flash-EEPROM. The program can be loaded to the Flash-EEPROM via RS232 interface.
Power supply systems: As shown in Fig. 1, there are two power supply systems. One of the systems provides DC 5V for digital devices and DC 12V for analog devices; the other system provides 35V DC for the amplify of the speakers.
Microphones: Two error microphones and one reference microphone (Panasonic WM-60A) were used in this work..
The cost of the hardware system is less than 1000US dollars. We believe that it is really a low-cost system in comparison with other existing system in the market.The control system is very compact and can be easily installed in site, as shown in Fig. 2.

3 - ADAPTIVE ALGORITHM

The adaptive control algorithm which uses the filtered-X Least-Mean Square method (FXLMS) to find the coefficients of the adaptive filter was adopted in this work [3]. The FXLMS algorithm is a well developed algorithm, so, it is not necessary to describe the algorithm in this work. Only one thing which should be pointed out here is that the ANC system developed in this work is a multiple-channel system. As a result, the algorithm is a multiple-channel FXLMS algorithms, as shown in Fig. 3.

Figure 2: The compact ANC system developed in this work.

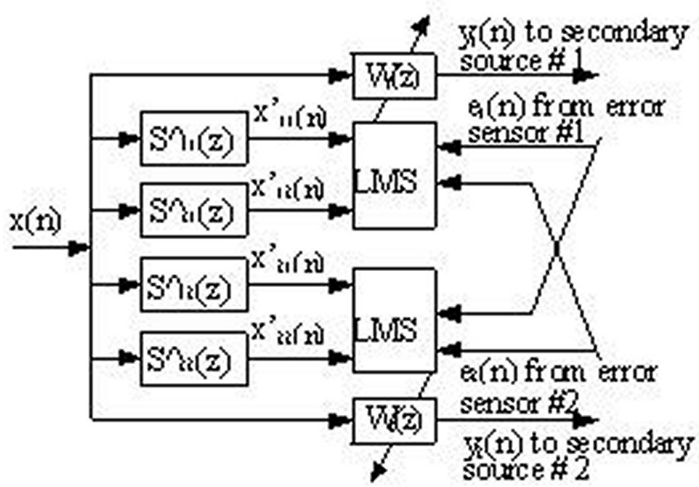

Figure 3: The structure of the FXLMS algorithm.

4 - EXPERIMENTAL RESULTS

Because the noise control in a duct is the simplest and a typical implementation of ANC, the system developed in this work was first tested in a duct to justify the capability of the system in comparison with other systems.

4.1 - Results of noise control in duct

The cross section and the length of the test duct are 23cm×25cm, and 101cm, respectively.One end of the duct was equipped with a speaker to generate the primary noise and a control (or secondary) speaker was 760 mm downstream apart from the primary source. The reference microphone was 50mm apart from the primary noise source and the error microphone was placed at the downstream end of the duct. The test signal was a broadband noise from 701000Hz, and the sampling frequency was 3000Hz. The attenuation result, i.e., 7.3dB, as shown in Fig. 4, is very good in comparison with some published results, for instance [4].

4.2 - Control in an opening of an enclosure

The dimensions of the acoustic enclosure are 120×120×120 cm^3 and the dimensions of the opening are 20×20cm^2.Because the acoustic wave radiating from the opening is generally not a plane wave, two error microphones and two control speakers were used in this case. As a consequence, four secondary paths (i.e., between two error microphones and two control speakers) should be identified in advance, and two adaptive filters should be used. The block diagram of the control algorithm is shown in Fig. 3. In the

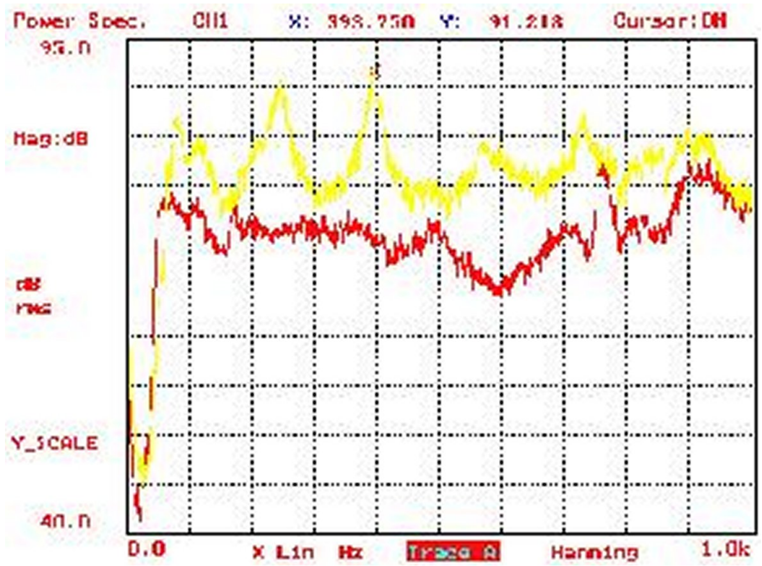

Figure 4: The control result of a broadband noise in a duct.

following, we will discuss the effect of the positions of the error microphones and the placements of the control speakers on the control results.

Effect of the positions of the error microphones.

If one can control the sound pressure at the opening, one can also control the sound power radiating from the opening as shown in Fig. 5. Therefore, the error microphones were first placed at the plane of the opening. The experimental setup is shown schematically in Fig. 5. The two control speakers were placed on the two sides of the opening and a primary speaker was placed in the center of the enclosure to generate the primary noise source. The reference microphone was placed 5cm from the primary speaker. A broadband random noise, 701000Hz, was used as the primary source. Because the sound pressure level at the opening is not uniform, the cross section of the opening is divided into 9 equal subsections. The average sound pressures at the midpoint of each subsection were measured. The attenuation level was then calculated as the differences between the average sound pressures without and with the control. The pressure attenuation at the 9 subsections is shown in Table 1. One can find that the average attenuation is about 6.8dB.

5.9 dB	6.8 dB	6.5 dB
7.3 dB	7.6 dB	7.3 dB
6.4 dB	6.7 dB	6.8 dB

Table 1: Pressure attenuation on the 9 subsections of the opening, test 1.

In practical implementation, the error microphones can't be placed in the opening because the opening should be free for manufacture process. So, in the second experiment, the error microphones were placed at the left and right sides of the opening. The other experimental conditions are the same as the first experiment. The attenuation result is shown in Table 2. The average attenuation is about 6.2dB, i.e., 0.6dB less than the first experiment. The results indicate that the error microphones should be placed as close as possible to the opening.

5.5dB	5.7 dB	6 dB
7.3 dB	7.1 dB	7.1 dB
5.1dB	5.6 dB	6.4 dB

Table 2: Attenuation result of test 2.

Effect of the positions of the control speakers.

To investigate the effect of the positions of the control speakers on the attenuation, the positions of the control speakers were varied inside the enclosure. For space reason, only one example is given here. The

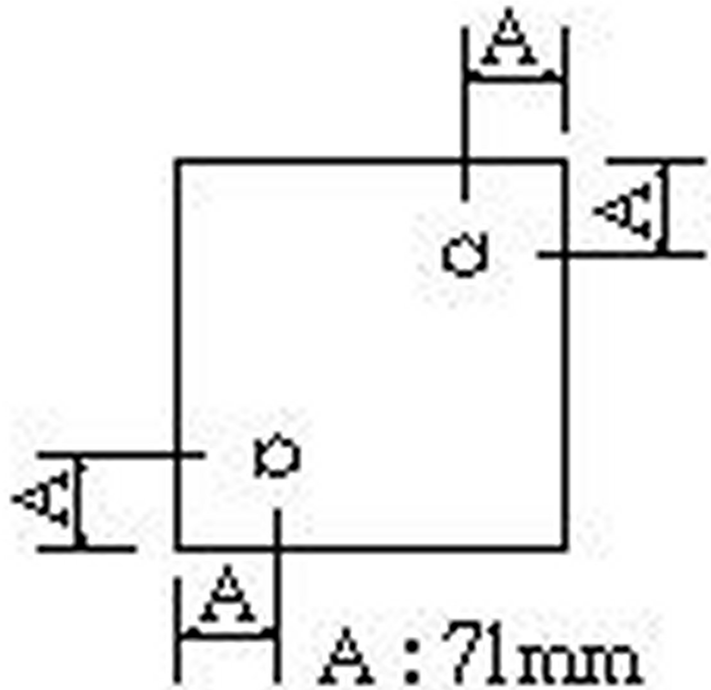

Figure 5: Positions of the error microphones for test 1.

experimental conditions are the same as that of the second experiment (result of Table 2) except that the control speakers are moved to the left and right sides of the enclosure with a distance 56cm from the opening. The result is shown in Table 3 with an average attenuation 4.7dB. The result is degraded in comparison with the result of Table 2.
From the above three experiments, an important conclusion can be drawn: The error microphones and the control speakers should be placed as close as possible to the opening.

4.3 dB	5.5 dB	4.6 dB
5.0 dB	5.8 dB	4.7 dB
4.4 dB	4.6 dB	4.1 dB

Table 3: Attenuation result of test 3.

5 - CONCLUSIONS

A stand alone ANC system with one reference input, two secondary sources and two error sensors was developed in this work. The system was especially designed to control the noise radiating from an opening of an acoustic enclosure. The capability of the system was first verified by typical noise control in a duct. The experimental results indicate that a broadband noise radiating from an opening of an enclosure can be effectively suppressed by using a ANC system with two error sensors and two secondary sources. The results of this work also demonstrate that a low cost (less than 1000US dollars), multiple-channel ANC system is realizable.

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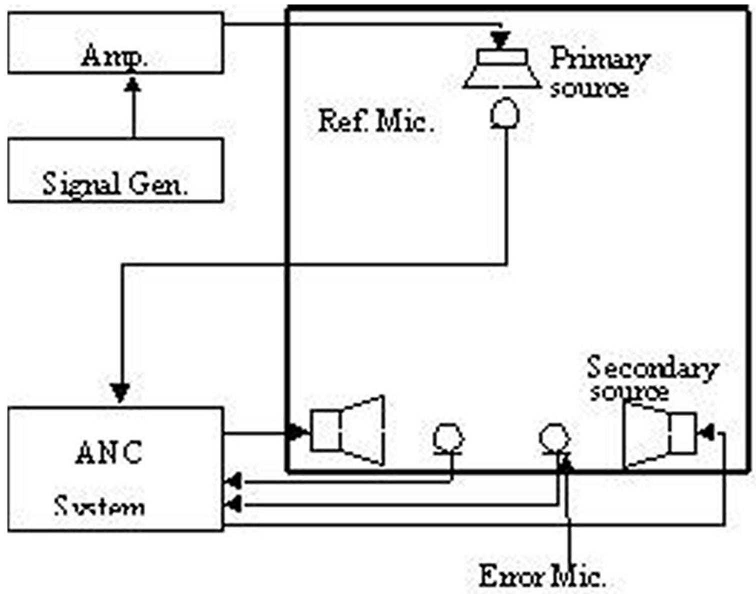

Figure 6: Experimental setup.

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