THE HIGH SPEED TRAIN INTERIOR NOISE REDUCTION USING MULTI-CHANNEL ANC SYSTEM

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ABSTRACT
In this paper, the high speed train interior noise reduction performance of the multi-channel ANC system was evaluated. A 1x2x2 multi-channel ANC algorithm was used for this purpose because high speed train interior noise has various noise sources. Experiments were carried out at two positions in floor, using pure-tone noise, to find the optimal positions of the control speakers and error microphones. At the selected optimal position, an ANC system performance evaluation experiment was carried out at variable heights, using high speed train interior noise. As a experiment result, the active noise control system shown good performance in the near position and high position from primary noise.

Keywords: Active noise control, multi-channel FXLMS, Noise canceling

1. INTRODUCTION

In terms of speed and reliability, the high speed train technology can reach the levels of the corresponding technologies in advanced countries, but interior noise reduction technological development is more needed.

In high speed train, passive interior-noise control system was applied to meet the interior-noise legal standards by structural design of the vehicle, but the passenger's demand for a pleasant environment has not still satisfied.

In addition, the use of the passive noise control method for interior-noise reduction increases the vehicle's weight and the fuel consumption. Therefore, active noise control research is needed [1].

In this paper, the experiment of the ANC system performance evaluate has been performed using pure-tone noise and high speed train interior noise, according to the positions and heights of the control speakers and error microphones.

2. MULTI-CHANNEL ANC SYSTEM

2.1. The multi-channel FXLMS algorithm[2~4]

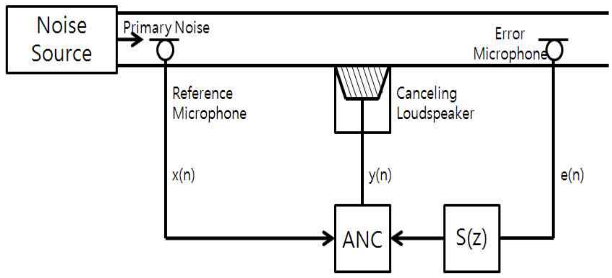


Figure 1: ANC system in duct

In the active noise control system, as shown in Fig. 1, noise signal $x(n)$ dose not correspond to control signal $y(n)$ due to the additional path transfer function $S(z)$ existing between error signal $e(n)$ and control signal $y(n)$. Thus, it will result in system instability. The FIR filter can solve this problem by updating a weight vector after the estimation of the secondary path to $\hat{S}(z)$. This method is called the FXLMS ANC system. Fig. 2 shows the structure of the FXLMS ANC system.

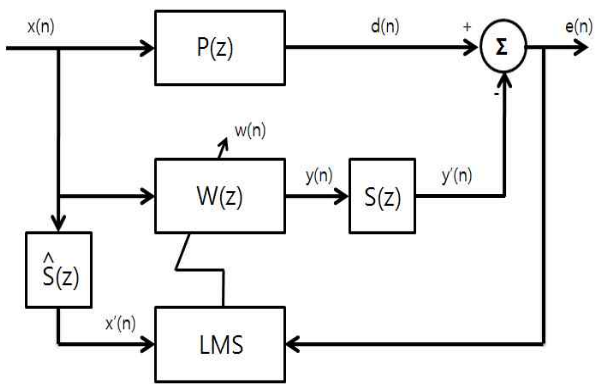


Figure 2: Block diagram of the FXLMS algorithm

Because the high speed train has a variety noise sources, the multi-channel ANC system should be applied to it instead of the existing single-channel ANC system.

The multi-channel (1x2x2, one noise source speaker, two control speakers, two error microphones) FXLMS algorithm was used for the reduction of the interior noise of a high-speed train. It has two primary transfer functions, four secondary path transfer functions, and four estimated secondary path transfer functions.

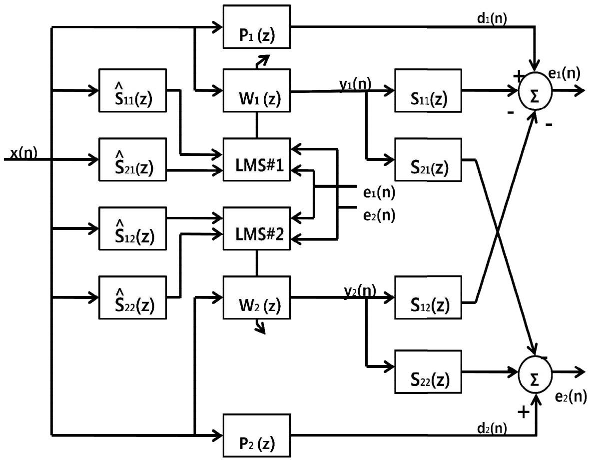


Figure 3: The Multi-channel FXLMS algorithm

Fig. 3 is block diagram of the multi-channel FXLMS. Here, $x(n)$ is the input signal, $y_1(n), y_2(n)$ are output signals, $d_1(n), d_2(n)$ are reference signals, $e_1(n), e_2(n)$ are error signals, $P_1(z), P_2(z)$ are primary transfer functions, $S_{11}(z) \sim S_{22}(z)$ are secondary path transfer functions, $\hat{S}_{11}(z) \sim \hat{S}_{22}(z)$ are estimated secondary path transfer functions, and $W_1(z), W_2(z)$ are adaptive filters.

3. SIMULATION

In this paper, the simulation were performed for high speed train interior noise reduction using open-space noises and tunnel noises. The simulation were performed in two positions. Two positions are shown in Fig. 4. The control speakers were located at the center. The distance between the control speakers and the error microphones is 75cm, and the control speakers height is 50cm.

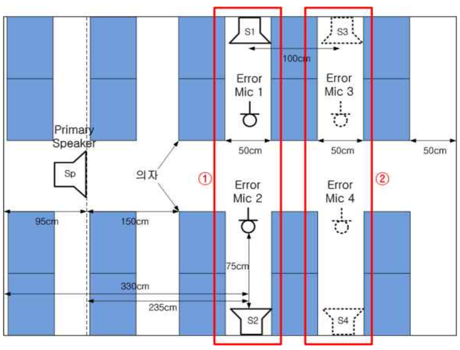
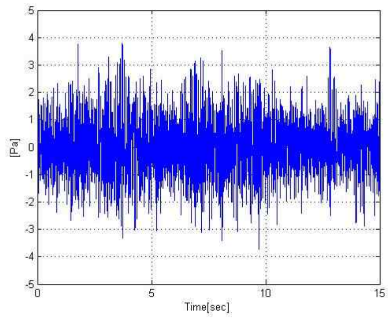


Figure 4: The ANC system position in the test-bed

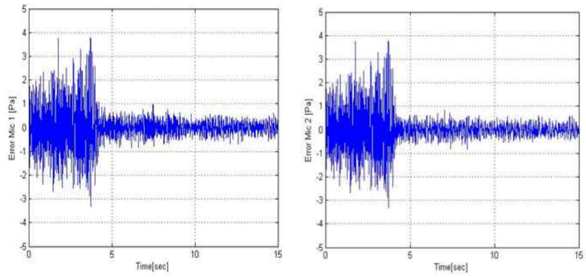
The simulation were performed to compare the performance of the ANC algorithm in positions ① and ② using 2 noises(The open space – window, aisle; and the tunnel – window, aisle; speed is 200~250km/h).

3.1. The simulation of open-space noise

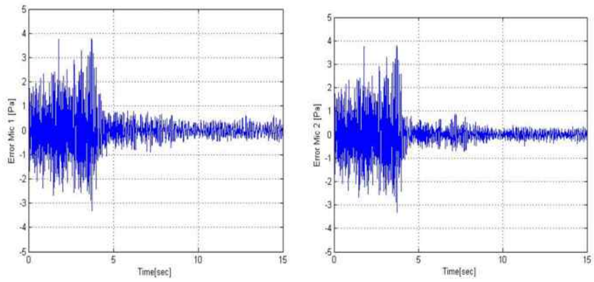
In the simulation, all the conditions are same, as follows. The step size : 0.0005, filter order : 256.



(a) The interior noise of high speed train in the open-space section



(b) The error mic 1 and 2 in position ①

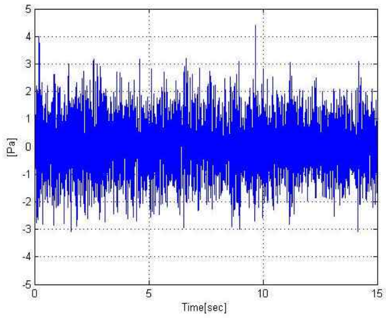


(c) The error mic 1 and 2 in position ②

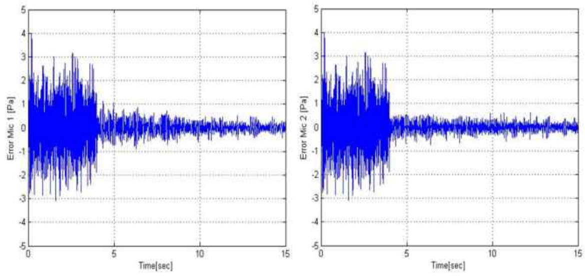
Figure 5: The simulation results of open-space window noise

In the simulation results, position ① was reduced by 43.3dB on average, and position ② was reduced by 36.6dB on average.

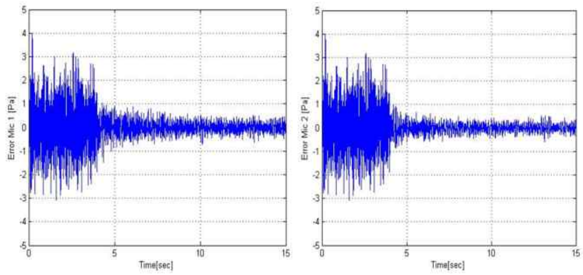
3.2. The simulation of tunnel noise



(a) The interior noise of high speed train in the tunnel section



(b) The error mic 1 and 2 in position ①



(c) The error mic 1 and 2 in position ②

Figure 6: The simulation results of tunnel window noise

In the simulation results, position ① was reduced by 38.3dB on average, and position ② was reduced by 32.1dB on average.

4. PERFORMANCE EVALUATION OF ANC SYSTEM

To evaluate the performance of the ANC algorithm, the following test bed experiment was performed. First, a pure-tone experiment was performed to find the optimal position of the control speakers and error microphones. In the pure-tone experiment, a good reduction effect position was selected, and the performance of the ANC algorithm was evaluated using the high speed train interior noise. The test bed's size was downscaled (length – 573cm, width - 290cm, height - 246cm) as compared with the actual size (length - 1870cm, width - 290cm, height - 348 cm), but the other parameters were similar.

4.1. Pure-tone experiment

The pure-tone experiment was performed to compare the performance of the ANC algorithm in positions ① and ② using 120, 280, and 360Hz pure-tones.

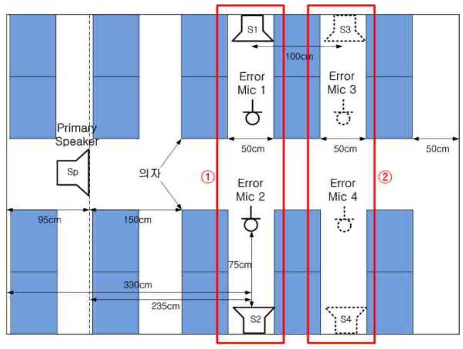
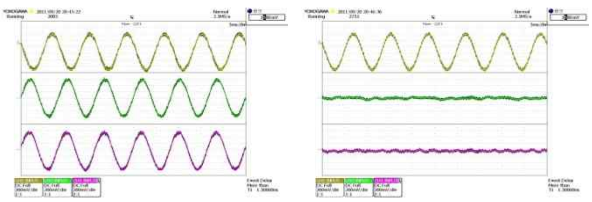


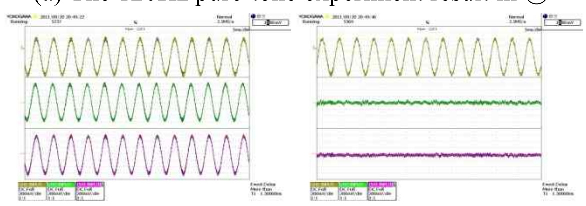
Figure 7: The ANC system position in the test-bed for pure-tone

The control speakers were located at the center. The distance between the control speakers and the error microphones is 75cm, and the control speakers height is 50cm.



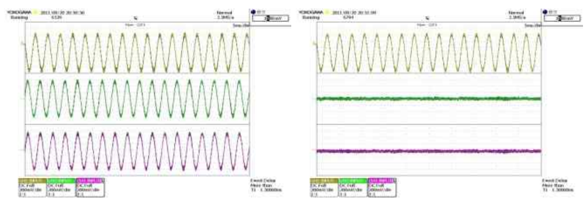
(before ANC) (after ANC)

(a) The 120Hz pure-tone experiment result in ①



(before ANC) (after ANC)

(b)The 280Hz pure-tone experiment result in ①



(before ANC) (after ANC)

(c) The 360Hz pure-tone experiment result in ①

Figure 8: The experiment results using pure-tone noise

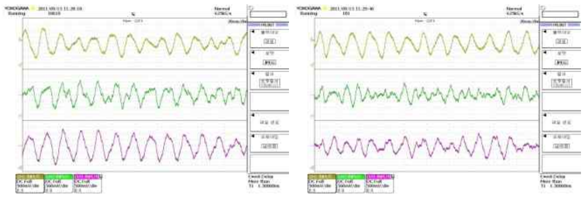
In the experiment results, position ① was reduced by 6.5dB on average, and position ② was reduced by

3.6dB on average. The reduction effect was more effective at position ① near the noise source.

4.2. High speed train interior-noise experiment

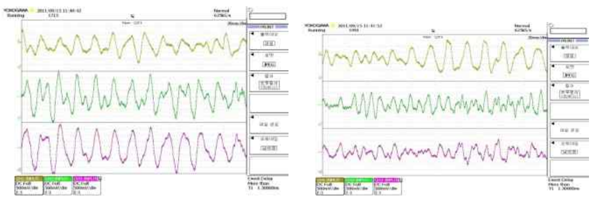
The high speed train experiment was performed in position ①, which shown a good result in the previous experiment. Each noise was divided as follows: open space - window, aisle; and tunnel - window, aisle. Fig. 9 is ANC system in the test-bed.

Figure 9: The ANC system in the test-bed at the 50cm height



(before ANC) (after ANC)

Figure 10: The open-space window noise experiment result with 50cm



(before ANC) (after ANC)

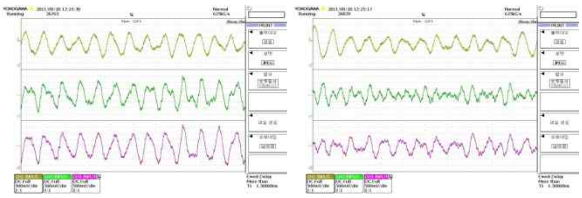
Figure 11: The tunnel window noise experiment result with 50cm

In the experiment results at the 50cm height, the open-space-window noise was reduced by 6dB on average, and the open-space-aisle noise was reduced by 5.8dB on average. On the other hand, the tunnel-window noise was reduced by 4.7dB on average, and the tunnel-aisle noise was reduced by 4.8dB on average.

In the graph, the first wave is the noise source signal, the second is the waveform of error microphone 1, and the third is the waveform of error microphone 2.

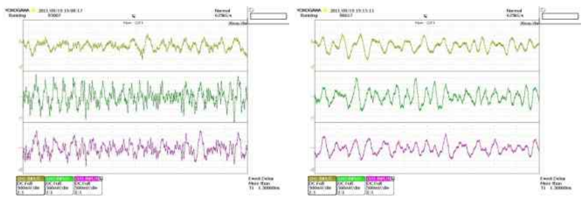
Fig. 12 shows that the speakers and microphones heights were changed to 80cm. To evaluate the performance of the ANC algorithm depending on the height change, the speakers and microphones were placed at a height of 80cm. Like the previous experiment, the high speed train experiment was performed using open-space and tunnel noises.

Figure 12: The ANC system in the test-bed at the 80cm height



(before ANC) (after ANC)

Figure 13: The open-space window noise experiment result with 80cm



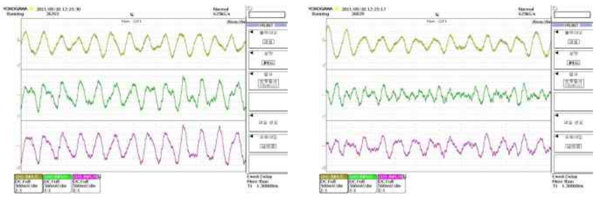
(before ANC) (after ANC)

Figure 14: The tunnel window noise experiment result with 80cm

In the experiment results at the 80cm height, the open-space-window noise was reduced by 7.1dB on average, and the open-space-aisle noise was reduced by 5.8dB on average. On the other hand, the tunnel-window noise was reduced by 8.3dB on average, and the tunnel-aisle noise was reduced by 7.5dB on average.

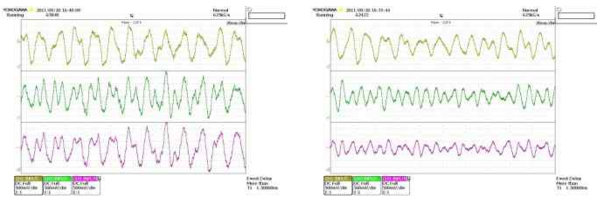
Figure 15: The ANC system in the test-bed at the 110cm height

In the experiment results at the 110cm height, the open-space-window noise was reduced by 10.6dB on average, and the open-space-aisle noise was reduced by 10.1dB on average. On the other hand, the tunnel-window noise was reduced by 11.4dB on average, and the tunnel-aisle noise was reduced by 10.8dB on average.



(Before ANC) (After ANC)

Figure 16: Open-space window noise experiment result with 110cm height



(Before ANC) (After ANC)

Figure 17: Tunnel window noise experiment result with 110cm height

5. CONCLUSION

In this study, simulations and ANC system performance evaluation experiments were carried out at various positions and heights, using pure-tone noise and high speed train interior noise. The results were as follows:

First, the result of simulation using multi-channel FXLMS algorithm show average reduction index by 39.9dB in the open-space section, and show average reduction index by 35.2dB in the tunnel section. Therefore, applying the active noise control in the tunnel section was more effective than open-space section.

Second, for the pure-tone noise experiment at various positions, at a location near the noise source, the noise was reduced by 6.5dB on average, and at a location far from the noise source, the noise was reduced by 3.6dB on average. In this experiment, better results were shown at the location near the noise source.

Third, the high speed train noise experiment was performed at the position where the position was selected in the previous experiment. The results of the experiment at the 50cm height are as follows: the open-space noise was reduced by 5.9dB on average, and the tunnel noise was reduced by 4.8dB on average.

Fourth, the results of the high speed train noise experiment at the 80cm height are as follows: the open-space noise was reduced by 6.5dB on average, and the tunnel noise was reduced by 7.9dB on average.

Fifth, the results of the high speed train noise experiment at the 110cm height are as follows: the open-space noise was reduced by 10.4dB on average, and the tunnel noise was reduced by 11.1dB on average.

Finally, As simulations and experiment results, the active noise control system shown good performance in the near position and high position from primary noise.

In the future, more experiments are needed at various locations to find the optimal positions of the control speakers and error microphones. There is a plan to expand the multi-channel system into a 2x2x2 or 2x2x4 system.

Table 1: The result of experiment(Error Mic 1)

Section	Noise position	The height of ANC system	Before ANC [dB]	After ANC [dB]	Reduction [dB]
Open-space	Window	50cm	99.8~ 103.1	94.8~ 97.2	5.5
		80cm	99.5~ 103.4	93.7~ 96.7	6.3
		110cm	98.5~ 102.6	90.1~ 92.9	9.1
	Aisle	50cm	95.6~ 98.7	89.4~ 93.5	5.7
		80cm	92.8~ 99.3	89.7~ 93.2	4.6
		110cm	95.9~ 99.4	86.9~ 90.4	9.0
Tunnel	Window	50cm	101.7~ 103.3	96.8~ 99.4	4.4
		80cm	101.8~ 103.9	94.2~ 95.9	7.8
		110cm	100.5~ 103.4	89.5~ 91.2	11.6
	Aisle	50cm	102.0~ 103.8	98.4~ 99.2	4.1
		80cm	102.1~ 104.0	95.9~ 96.8	6.7
		110cm	99.8~ 104.2	90.5~ 93.4	10.1

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