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Construction of IIR filter for adaptive noise control system of boat noise reduction

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ABSTRACT

Noise from boats is often loud and can reach apartments or the offices located near Tokyo's canals. The aim of this research is to create quiet spaces in buildings using a sound damping system with adaptive noise control. This system does not use a reference microphone because there is sometimes no place to put it outside a window. We propose a tap length for an infinite impulse response (IIR) filter as an adaptive noise control system for reducing boat noise. In this paper, we analyzed the characteristics of boat noise as well as the adaptive damping filter. We investigated the step size and the tap numbers of the IIR filter to improve the performance of the adaptive noise control system with a digital signal processor. The results showed that boat noise is composed of a peak frequency and some other dominant frequencies caused by the boat engine which produces long continuous noise. We therefore designed the IIR filter to adapt to these frequencies. As a result, the system effectively reduced boat noise in a computer simulation.

Keywords: Adaptive noise control, Boat noise, Digital signal processor, Noise investigation

1. INTRODUCTION

The sound of the boats is perceived as annoying to the occupants of buildings located near a canal [1]. Many boats travel along canals from morning to night and may include tugboats, pleasure boats, fishing boats, houseboats, and others. The cause of boat noise is the boat's engine, which emits a low frequency sound. It would be natural to assume that reducing boat noise will improve the quality of life for people living and working near canals.

We speculated that adaptive noise control would be effective for reducing boat noise because of the low-frequency sound emitted by boat engines. Commercially available noise canceling earphones and headphones use such adaptive noise control. These devices are capable of providing planar noise control that covers some limited spaces; a few products can even cover an entire room. Shimitsu et al. performed adaptive noise control simulations of noise in a ship's cabin. A finite impulse response (FIR) adaptive noise control simulation was conducted to determine the usefulness of the adaptive noise control system [2]. However, such a system has not been tested in a real-world situation. In addition, the system was limited to controlling noise inside the cabin but not sound emitted from the ship toward the surrounding environment. Murao et al. studied spatial control of noise using active acoustic shielding, which consists of a small noise-controlling speaker that uses wave interference [3]. The system is incorporated into a window of the room and can be used as a window vent, but its presence blocks the view out of the window.

In this study, we propose a tap length suitable for an infinite impulse response (IIR) filter using as an adaptive noise control system for reducing boat noise. This system does not use a reference microphone because there is no place to put it. We consider IIR system to perform more effectively than the FIR system because of the low-frequency sound emitted by boats. In this report, in order to confirm the effectiveness of the adaptive noise system, we examined the characteristics of boat noise and conducted a computer simulation that showed the filter length of the IIR adaptive filter is effective in reducing boat noise inside a room.

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2. IIR ADAPTIVE FILTER COMPUTER SIMULATION

2.1 METHOD

We used the IIR adaptive noise control system to reduce boat noise. In order to examine IIR adaptive noise control by computer simulation, the effectiveness of individual tap lengths to reduce boat noise was evaluated on a trial-and-error basis. IIR adaptive noise control is used to conduct experiments in places where a reference microphone cannot be used. The of noise reduction level depends on the accuracy of the calculation. The tap length is the number of filter coefficients. By changing the tap length, the accuracy and speed of the operation can also be changed. The noise reduction level according to tap length, frequency, and type of boat were found in the frequency and time domains. The target value of the noise reduction level was set to 75 dB or less in the dominant frequency. The sound insulation of windows used in houses was determined based on the JIS standard. There is a 10-dB reduction at the frequency of boat noise penetrating windows with the lowest sound insulation. The maxium achievable noise reduction value is considered to be about 65 dB, which includes the effect of the window as a damping material.

The IIR filter used a least mean squares algorithm [4]. The filter update equation for the IIR filter coefficient $\mathbf{U}(\mathrm{n})=[U_1(n), U_2(n), \cdots, U_{\mathrm{L}}(\mathrm{n})]$ is

$$\mathbf{U}(\mathrm{n}+1) = \mathbf{U}(\mathrm{n}) + \nu \mathrm{e}(\mathrm{n})\mathbf{y}(\mathrm{n}),$$

where time is n, the tap length of the IIR filter of adaptive filter is L, and the step size is ν. The error signal is e(n) and the output signal of the IIR filter is $\mathbf{y}(\mathrm{n})= [y_1(n), y_2(n), \cdots, y_{\mathrm{L}}(\mathrm{n})]$:

$$\mathrm{e}(\mathrm{n}) = \mathrm{d}(\mathrm{n}) - \mathrm{y}(\mathrm{n}),$$

$$\mathbf{y}(\mathrm{n}+1) = \mathbf{U}(\mathrm{n})\mathbf{y}^T(n),$$

where the desired signal was d(n).

2.2 SIMULATION CONDITIONS

A tap length suitable for boat noise was proposed for the IIR adaptive noise control system. To determine the most effective tap length, the level of noise reduction according to tap length was analyzed using tugboat noise at the highest sound pressure level. Step size ν was 1.0×10^{-13}, sampling frequency was 48 kHz, and the tap lengths of the feedback section were 2, 4, 6, 8, 10, 12, 14, 16, 20, 24, 30, and 36. We examined the difference in noise reduction level for each tap length. The frequency response was analyzed according to the tap length.

Next, computer simulations of IIR adaptive noise control were performed for tugboats, pleasure boats, houseboat, and fishing boats using the optimal tap lengths determined from the examination. Step size ν was 1.0×10^{-12} and sampling frequency was 48 kHz. For each boat, the level of noise reduction in the frequency and time domains was measured. The cruising boat was excluded because its peak sound pressure level was less than 70 dB.

2.3 BOAT NOISE USED FOR EXPERIMENTS

The boat noises used in the simulations were audio of boat passes recorded near a canal made on March 16, 2015 from the veranda of a room on the 10th floor of an apartment building. Recordings were made of tugboats, pleasure boats, houseboats, fishing boats, and cruising boats. Boat noise has high signal strength in the lower frequency range due to the periodic nature of the sound generated from the boat engine. Figure 1 shows the frequency characteristics of tugboats, pleasure boats, and houseboats. Figure 2 shows the frequency characteristics of fishing boats and cruising boats.

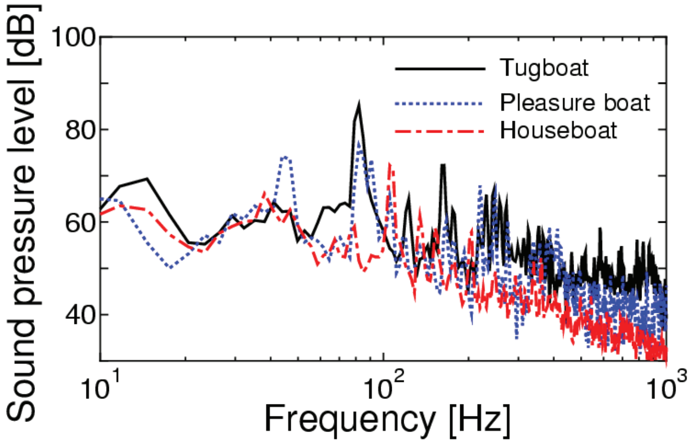

Figure 1. Frequency characteristics of tugboats, pleasure boats, and houseboats.

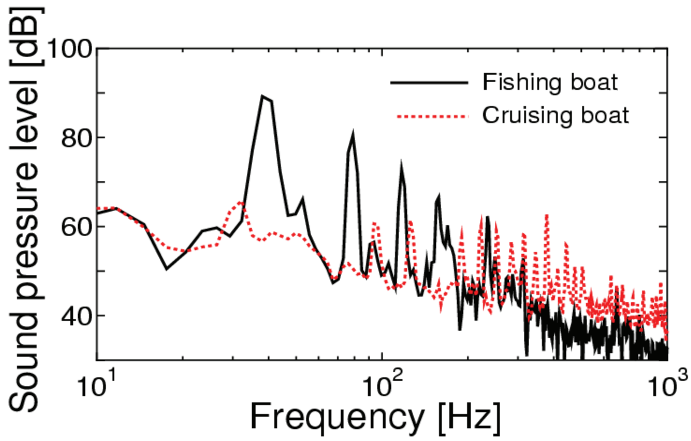

Figure 2. Frequency characteristics of fishing boats and cruising boats

3. RESULTS

To obtain an effective tap length for IIR adaptive noise control by computer simulation, tap lengths were examined. Figure 3 shows the noise reduction level for each tap length of the IIR adaptive filter. For tap lengths of 2 and 36, there was a noise reduction of 8 and 14 dB, respectively. The noise reduction level increased according to increase in tap length. Figure 4 shows the frequency analysis results for each tap length of the IIR adaptive filter. The signal before noise control was activated is the original sound pressure level, and the signal after noise control was activated shows the signal corresponding to tap lengths of 20, 24, 30, and 36. There were differences in the corresponding dominant frequencies due to differences in tap length. From these results, a tap length of 30was considered to be appropriate for boat noise because when the sound of the tugboat used in the research was 85 dB, a tap length of 30 was well below the target value of 65 dB or less. We attempted to minimize both the tap length and computational noise level. We applied a tap length of 30 and observed the noise reduction level for each boat. Figures 5–12 show frequency characteristics and noise reduction levels before and after activation of adaptive noise control for each type of boat. The system was able to reduce the noise of tugboats, pleasure boats, houseboats, and fishing boats by 14, 16, 18, and 16 dB respectively. The adaptive noise control signal converged in 0.1 s. As a result, the reduction target value of 70 dB was reached for each type of boat.

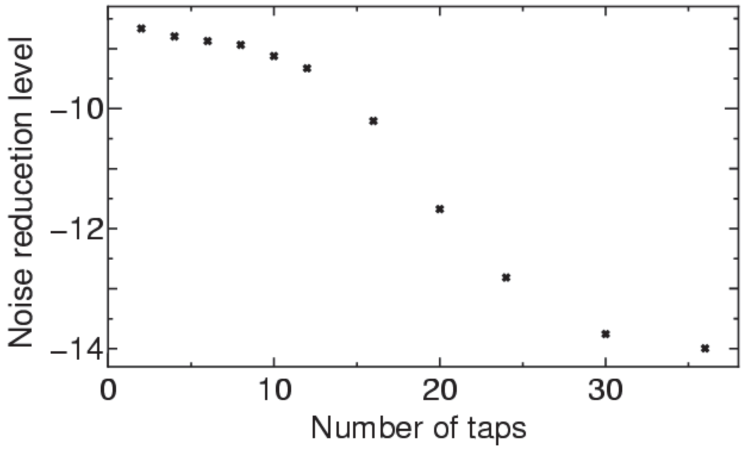

Figure 3. Noise reduction level for tap lengths 2–36

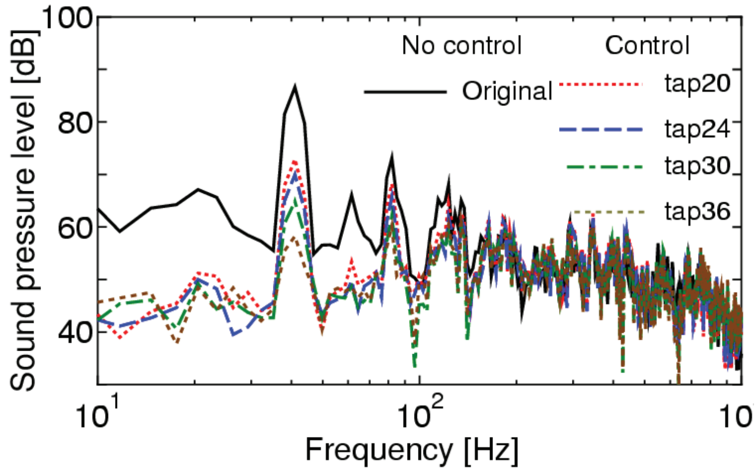

Figure 4. Frequency characteristics for each tap lengths 20–36

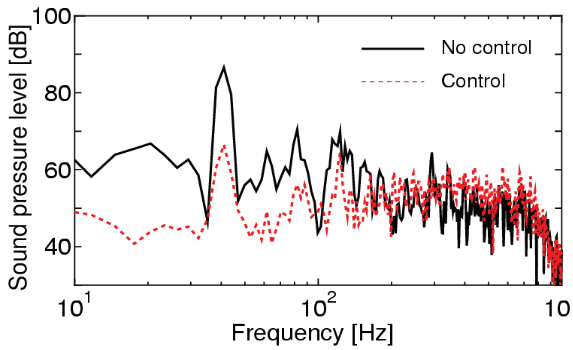

Figure 5. Frequency characteristics of tugboat noise

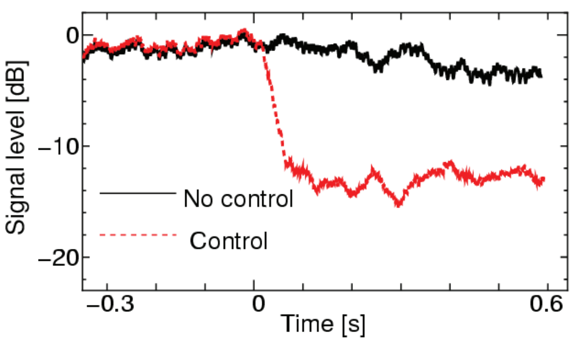

Figure 6. Noise reduction levels before and after adaptive noise control for tugboat noise

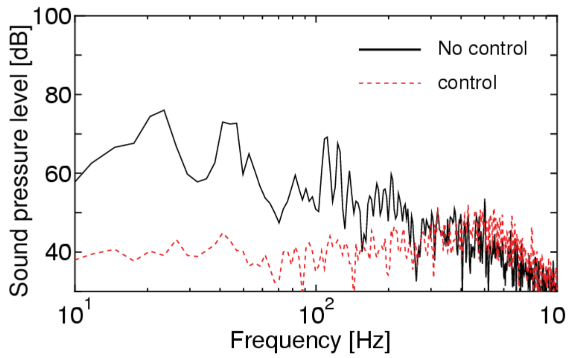

Figure 7. Frequency characteristics of pleasure boat noise

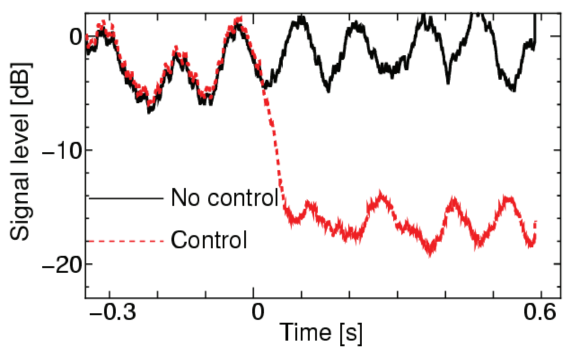

Figure 8. Noise reduction levels before and after adaptive noise control for pleasure boat noise

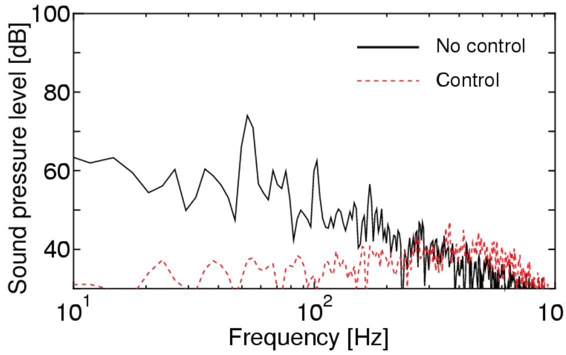

Figure 9. Frequency characteristics of houseboat noise

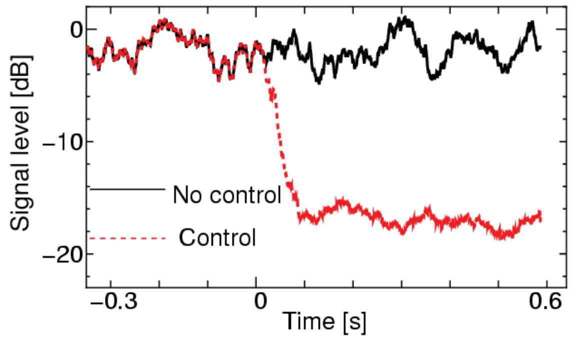

Figure 10. Noise reduction before and after adaptive noise control for houseboat noise

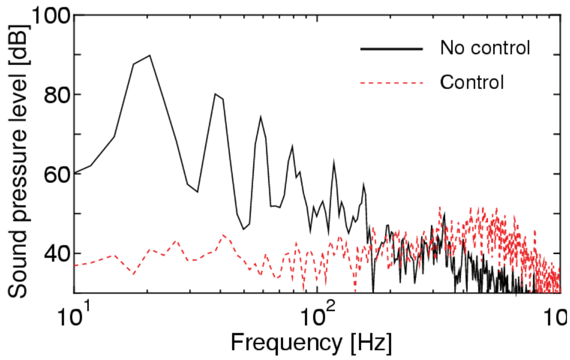

Figure 11. Frequency characteristics of fishing boat noise

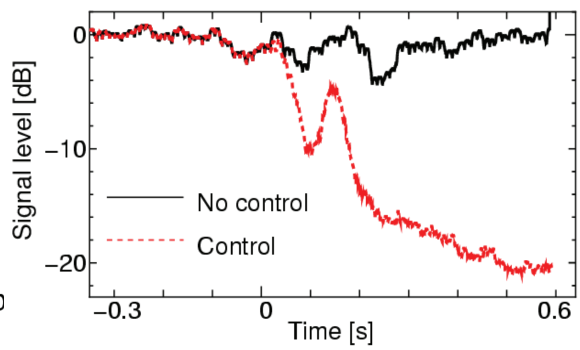

Figure 12. Noise reduction level before and after adaptive noise control for fishing boat noise

4. Conclusion

Computer simulations were performed to check whether the IIR adaptive filter could adapt to boat noise. Frequency analyses were performed to reduce the boat noise. In addition, the performance according to tap length of the IIR filter was confirmed to correspond to the dominant frequency of the boat noise, meaning that the boat noise was a sound emitted at a low frequency with a small number of dominant frequencies. The noise reduction level increased as the tap length increased. We considered that a tap length of 30 was effective for reducing boat noise. According to the results of computer simulation, the noise four types of boat could be reduced to the target value of 75 dB or less. Based on these results, we can conclude that IIR adaptive noise control is effective for reducing boat noise.

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