ICIC Express Letters ICIC International ©2020 ISSN 1881-803X
Volume **14**, Number **8**, August **2020** pp. **807–812**

STUDY OF BROADBAND ACTIVE NOISE CONTROL

Shintaro Sato[1], Shunsuke Ishimitsu[1], Takashi Kimura[2]
and Kohei Kurokawa[3]

[1]Graduate School of Information Science
Hiroshima City University
3-4-1, Ozuka-Higashi, Asa-Minami-Ku, Hiroshima-ken 731-3194, Japan
s-sato@hfce.info.hiroshima-cu.ac.jp; ishimitu@hiroshima-cu.ac.jp

[2]RYOBI MHI Graphic Technology Ltd.
800-2 Ukai-cho, Fuchu-shi, Hiroshima-ken 726-0002, Japan

[3]EIKOSHA Co., Ltd.
4-5-15 Matsuhama-cho, Fukuyama-shi, Hiroshima-ken 720-0802, Japan

Received February 2020; accepted May 2020

Abstract. *Loud noise has a negative effect on human hearing and prolonged loud noise may cause deafness, so it is necessary to use noise control to prevent the onset of hearing loss. Noise control comprises passive noise control (PNC) and active noise control (ANC), which have different effective sound bands. Although noise control should be performed by combining PNC and ANC, the cost of doing so is high. Therefore, we investigated the expansion of the controllable bandwidth of ANC using the field programmable gate array (FPGA) and the enabling of broadband control with only ANC. The control target was the noise of an industrial printing machine, which has a noise level of least 85 dB. In this study, we simulated and experimented with real-time processing of ANC using FPGA to confirm the possibility of broadband ANC. The results showed that high-frequency control of printing-machine noise is possible with FPGA.*
Keywords: ANC, FPGA, Filtered-x LMS algorithm

1. **Introduction.** Numerous loud noises occur in factories, and these noises can have psychological effects such as discomfort and loss of concentration and physiological effects such as neurosis and sleeplessness. Furthermore, deafness due to noise is a serious problem. Several workers still develop deafness caused by factory noise. Therefore, the Ministry of Health, Labor and Welfare in Japan strengthened measures against noise problems in 1992. Consequently, loud workplaces with noise levels of 85 dB or more are subject to regulation, and such work environments need to be improved.

Noise control comprises two different methods, passive noise control (PNC) and active noise control (ANC), which have different effective frequency bands. PNC is effective for controlling high-frequency noise, and examples include sound-absorbing materials and earplugs. However, it is difficult to control low-frequency noise with PNC. Because low-frequency noise has less vibration, it has difficulty creating friction within the material absorbing the sound and is thus difficult to absorb. The size of the sound-absorbing material must be increased to control low-frequency noise. ANC is a technology that cancels noise by generating a control sound of the opposite phase and same amplitude as the noise. ANC is effective for low-frequency noise, especially noise within a maximum frequency of 500 Hz. However, it is not effective for high-frequency noise because high-frequency sounds with short wavelengths require a dense arrangement of secondary sources because of the principle of wave superposition [1]. Ideally, noise control should be performed by

DOI: 10.24507/icicel.14.08.807

combining PNC and ANC; however, the cost of doing so is high. A previous study reported a reduction of noise in the cabin of the bullet train by using ANC in the form of a field programmable gate array (FPGA) [2]; however, noise above 500 Hz was not reduced. In addition, in the control of ambient noise in outdoor ceremonies, it has been confirmed that high-frequency noise can be reduced more by FPGA than digital signal processing (DSP) [3]. Furthermore, wideband ANC has been proposed by combining ANC using FPGA and another method [4]. However, this proposal does not extend the control band of ANC. Thus, in this study, we investigated the expansion of the controllable bandwidth of ANC using FPGA. As a result, we expected to control low- to high-frequency noise with only ANC. We targeted the operating noise of industrial printing machines as the factory noise. This noise level is above the regulatory level.

2. **Control Algorithm.** The most popular adaptive algorithm used for ANC applications is the filtered-x least mean square (FxLMS) algorithm which is a modified version of the LMS algorithm. This algorithm updates the adaptive filter coefficients to converge the error signal to zero. LMS does not take secondary path effects into account. Therefore, a precise control signal cannot be generated using LMS. The FxLMS algorithm is a method that compensates for the effects of the secondary path in ANC applications. In this study, we controlled the noise by feedforward control of the FxLMS algorithm. We adapted this algorithm in simulation and in an actual control experiment. Figure 1 shows the FxLMS algorithm, where $x(n)$ is the reference signal, $d(n)$ is the desired signal, $y(n)$ is the control signal, $e(n)$ is the error signal, $r(n)$ is the filtered reference signal, $w(n)$ is an adaptive filter, c is the secondary path, $\hat{c}$ is the model of the secondary path (i.e., transfer function), μ is the convergence coefficient (i.e., step-size parameter), and $z(n)$ is the control signal reaching the control point via the secondary path. The adaptive filter $w(n)$ is then expressed by Equation (1).

$$w(n+1) = w(n) + \mu(n)e(n)r(n) \tag{1}$$

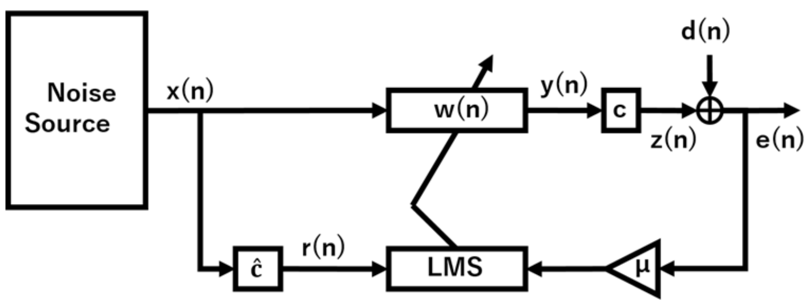

FIGURE 1. Block diagram of the FxLMS algorithm

3. **Simulation.** First, we conducted simulations using two methods: (A) not including the secondary path (ideal state), and (B) including the secondary path. The control target was the prerecorded sound of an industrial printing machine operating at a printing speed of 13,000 sheets per hour (SPH). The reference signal was at a distance of 43 cm and height of 127 cm from the paper-output unit of the printing machine, and the desired signal was at a distance of 182 cm and height of 128 cm from the paper-output unit of the printing machine (near the control panel). Figure 2 shows the arrangement of the microphone during noise-data recording. In (A), the sampling frequency was 51,200 Hz, the filter length of the adaptive filter was 50 taps, and the step size was 4.0×10^{-1}. In (B), the sampling frequency was 51,200 Hz, the filter length of the adaptive filter was 16 taps, and the step size was 1.0×10^{-2}. The secondary path was calculated assuming a distance of 5.0 cm between the error-signal microphone and the control speaker. Figures 3(a) and

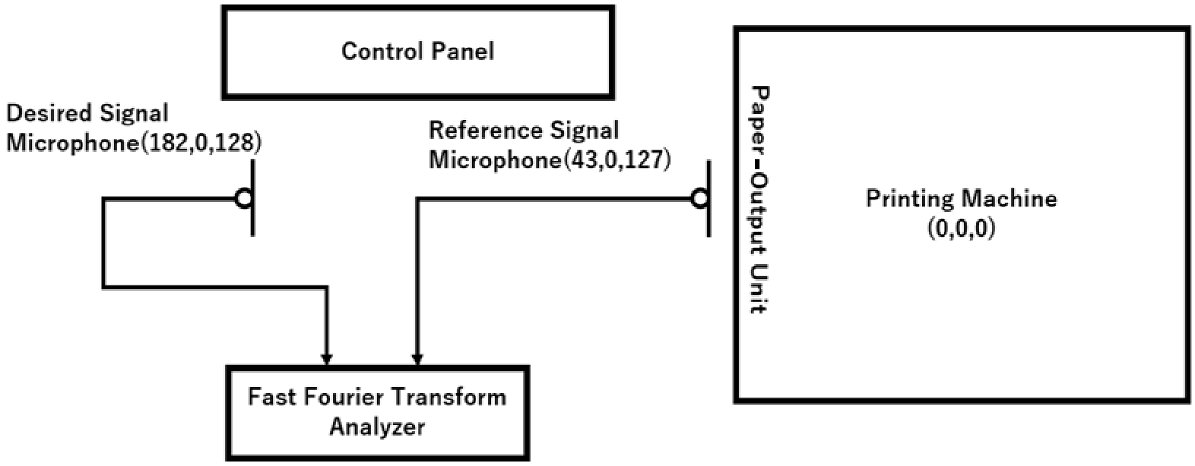

Figure 2. Arrangement of microphone during noise-data recording (unit of coordinates is [cm])

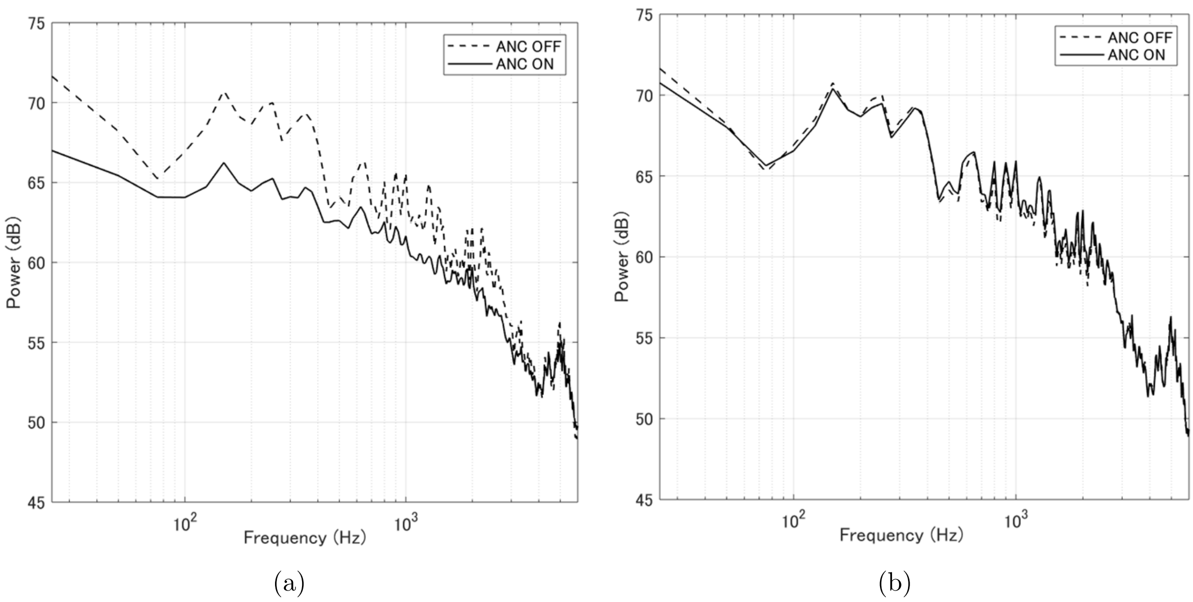

Figure 3. Frequency characteristics before and after ANC

3(b) show the results of (A) and (B), which represent the frequency characteristics before and after ANC, respectively.

In (A), the sound in each frequency band was reduced sufficiently. The noise-cancellation level was 4.5 dB at the peak of 150 Hz and 4.2 dB on average at the other peaks. The overall level of noise cancellation was 2.5 dB (from 83.4 to 80.9 dB). By not considering the transfer function, the control signal could be delivered directly without delay to the desired signal. Therefore, a sufficient noise cancellation level was secured. In (B), the noise level decreased at lower frequencies, but it increased above 500 Hz. The noise cancellation level was 0.51 dB at the peak of 250 Hz and 0.90 dB at the peak of 1,675 Hz, but the level increased 0.79 dB on average at the other peaks. The overall level of noise cancellation increased 0.10 dB (from 83.4 to 83.5 dB). We attribute the increase in the overall level to the worsening of the high-frequency sound. These results confirm that control of high-frequency noise becomes difficult when the secondary path is considered. We believe that it was necessary to speed up the algorithm and causality to solve them.

4. **Actual Control Experiment.** Next, we experimented with an industrial printing machine. We conducted this experiment to confirm the effectiveness of high-frequency control in real-time processing; we experimented using FPGA. FPGA can set the sampling frequency higher than conventional DSP. The control target sound was the noise near the control panel when an industrial printing press was operated at 13,000 SPH. We placed the reference signal microphone at a distance of 41 cm and height of 148 cm from the paper-output unit of the printing machine, the control speaker at a distance of 212 cm and height of 62 cm from the paper-output unit of the printing machine (near the control panel), and the error-signal microphone at 6 cm above the control speaker for stability. Figure 4 shows the experimental schematic. Figure 5 shows the results of real-time processing, which represents the frequency characteristic before and after ANC. At this time, the sampling frequency was 8 kHz, the filter length of the adaptive filter was 50 taps, and the step size was 9.0×10^{-4}.

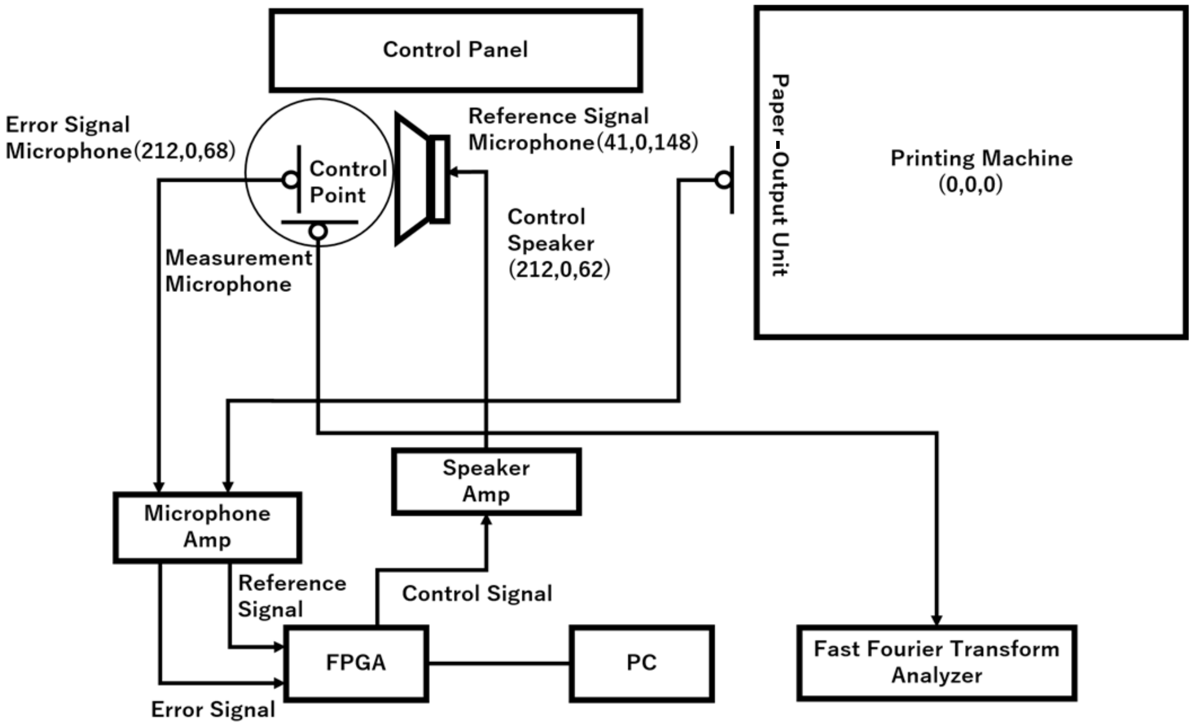

FIGURE 4. Experiment schematic (unit of coordinates is [cm])

A reduction of less than 2 kHz was possible. The noise-cancellation level was 3.0 dB at the peak of 136 Hz and 2.0 dB on average at the other peaks. The overall level of noise cancellation was 0.30 dB (from 89.92 to 89.62 dB). When limited to 500 Hz or less, it was 0.72 dB. Conventional ANC was effective below 500 Hz. However, in terms of the frequency characteristics, the sound pressure level decreased both below and above 500 Hz. It is suggested that ANC of this type can control high-frequency noise better than conventional ANC. However, the overall level of noise cancellation did not change significantly. Because the high-frequency sound above the controlled band deteriorated, it cannot currently be concluded that ANC broadband control of large printing-machine noise is effective. Furthermore, the noise cancellation level increases as the coherence between the reference signal and the desired signal increases [5]. The maximum sound reduction ATT_{MAX} is expressed by Equation (2):

$$ATT_{\mathrm{MAX}} = -10\log_{10}\left[1 - \frac{|S_{xd}(z)|^2}{S_{xx}(z)S_{dd}(z)}\right] = -10\log_{10}\left[1-\gamma^2(z)\right] \quad (2)$$

where $S_{xx}(z)$ is the auto power spectrum of the reference signal, $S_{dd}(z)$ is the auto power spectrum of the desired signal, $S_{xd}(z)$ is the cross-spectrum of the reference signal and the desired signal, and $\gamma^2(z)$ is the coherence function of the reference signal and the desired signal. For example, if the coherence is 0.90 or more, the theoretical maximum noise-cancellation level is approximately 10 dB. The coherence of the reference signal and the desired signal in this experiment was 0.41. However, to clear the regulation level requires a noise-cancellation level of at least 4.0 dB. Therefore, it is also necessary to consider the input of the reference signal so that the coherence is high. This indicates that it is necessary to further consider the arrangement of the microphone and speaker, the method of inputting the reference signal, and the settings of the algorithm parameters to reduce the sound pressure level to the regulation level.

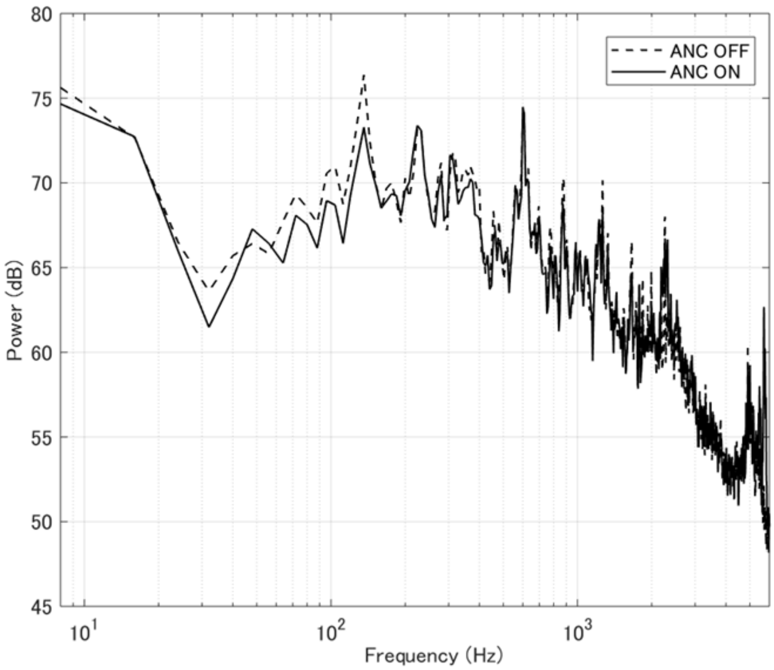

FIGURE 5. Frequency characteristics before and after real-time processing of ANC

5. **Conclusions and Future Work.** In the present study, we investigated the possibility of broadband control of the operating noise of industrial printing machines. The outcomes and findings of this study are as follows.

- The effect of ANC has been stated to be less than 500 Hz. However, we were able to expand the effect to high-frequency sound of 500 Hz or more.
- As the coherence between the reference signal and the desired signal was low, it did not reach the noise-cancellation level required to clear the regulation level.
- By using FPGA, it is possible to apply high-frequency control to the noise of a printing machine, but this is not broadband control. Therefore, it is necessary to study the topic further.

As future works, we will examine the positions of the microphone and control speaker, as well as the sampling frequency, step-size parameters, control algorithm, quiet zone, multi-channel input of the reference signal, and desired signal input using the virtual sensor.

REFERENCES

[1] M. Nishimura, T. Usagawa and S. Ise, *Active Noise Control*, Corona Publishing Co., Ltd., 2006.

[2] H. Hashimoto and K. Terai, Seat audio system of bullet train "MAX", *Noise Control*, vol.20, no.6, pp.360-364, 1996.

[3] D. Tanaka, *Basic Examination of Noise Control in Peace Commemoration Ceremony*, Bachelor Thesis, Faculty of Information Science, Hiroshima City University, 2015.

[4] Y. Tatsuka, M. Nishimura, T. Murao and K. Shigeki, Development of a high-speed signal processing board with FPGA for ANC (Application to AAS), *USB Proc. of the Japan Society of Mechanical Engineers*, 2012.

[5] T. Yoshida, Sound interference and noise control, *Journal of the Japanese Society for Agricultural Machinery*, vol.59, no.3, 1997.