***inter.noise 2000***
***The 29th International Congress and Exhibition on Noise Control Engineering***
***27-30 August 2000, Nice, FRANCE***

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**I-INCE Classification:** 7.5

# ACTIVE CONTROL OF THE ROOM NOISE OF SHIP BY THE CORRELATION ANALYSIS OF MEASURED WAVELET

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**Keywords:**
WAVELET, ACTIVE CONTROL, SHIP, CORRELATION

## ABSTRACT

To actively control of time-varying noise signals, a new calculation of instantaneous correlation is introduced. A measured signal is used for the analyzing wavelet, AW, of wavelet transform, and a concept of instantaneous correlation factor, ICF, is proposed. Applying the proposed method, we analyzed the correlation between acoustic and vibration noise signals from both a wall and a floor in a mess hall adjacent to an engine room of a ship. We prove that a dominant feature of the correlation can be estimated by the ICF. From the applications to both the noise analysis of a mess hall and the active control of noises, a time-varying correlation between acoustic and vibration noise signals is clearly analyzed, and this method enables an active noise control, ANC, to select the reference signal effectively.

## 1 - INTRODUCTION

Generally, a stationary signal of sound is analyzed in either a time domain or in a frequency domain. But a nonstationary signal must be represented simultaneously in a two-dimensional time-frequency plane, because frequencies of the signal change over time. This is called a time-frequency, *t-f*, representation of signals.

Methods for analyzing nonstationary signals include Spectrogram, WD (Wigner Distribution) [1] and WT (Wavelet Transform) [2]. In contrast to the Spectrogram, which uses a single analysis window, the WT uses short windows at high frequencies and long windows at low frequencies. In this method, basis functions called AW (analyzing wavelets) are obtained from a single prototype wavelet by dilations and contractions as well as shifts. In fact, WT covers quite a large area [3]. We have proposed a correlation function using WD on the *t-f* plane, and we performed instantaneous coherence analyses [4]. However, this method needs a WD of each signal. Therefore, by applying the measured signal to the analyzing wavelet, we can obtain the correlation between signals from the *t-f* function immediately.

Whereas the conventional method requires the averaging of many samples, this technique makes it possible to analyze the instantaneous correlation for time-varying signals. By applying vibration signals in a training ship, *Oshima Maru*, to the analyzing wavelets, we estimated the correlation using the proposed method. In addition, the result applied to the selection of the reference signal for ANC is discussed.

## 2 - APPLYING THE MEASURED SIGNAL TO THE ANALYZING WAVELET

WT using the affine transform of AW $\varphi_{a,b}(t)$ can be expressed by Eq. (1).

$$WT_f(b,a) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} \varphi^*_{b,\mathrm{a}} \left(\frac{t-\mathrm{b}}{a}\right) f(t)\, dt \tag{1}$$

where $a$ is scale factor and $b$ is shift factor. Each factor performs dilations and contractions as well as shifts for $\varphi_{a,b}(t)$.

The conventional research on time-frequency analysis using wavelet transform has focused on analyzing wavelets derived from a mathematical approach. In this study, we applied the measured signal to the analyzing wavelet. At first, in order to localize in time and frequency, a signal that was sampled at $\Delta t$ was cut off in a period and windowed.

Though the feature cannot be varied mathematically with the AW using the measured signal, we can dilate and contract that AW with resampling.

$$\varphi\left(t\right)=\sum_{n=-\infty}^{\infty}\varphi\left(n\Delta t\right)\frac{\sin\{\,(\pi/\Delta t)\,(t-n\Delta t)\}}{(\pi/\Delta t)\,(t-n\Delta t)} \tag{2}$$

When a set of AW can be dilated and contracted with $2^a$, we can use a simple interpolation and decimation. Many AW $\varphi_a\left(t\right)$ obtained by that procedure was prepared for the correlation analyses. This WT using that AW can be as a time-varying correlation function $C(t,a)$.

$$C\left(t,a\right)=k_a\int_{-L_a/2}^{L_a/2}\varphi_a\left(\tau\right)f\left(t+\tau\right)d\tau \tag{3}$$

where $L_a$ is window length determined from dilations and contractions, and $k_a$ is parameter determined the same way.

## 3 - ANALYSIS OF A CHIRP SIGNAL

At first, we analyzed a chirp signal, which is illustrated in Fig. 1. A basic AW signal can be cut at the center of that signal and is half its length. The analyzed result is illustrated in Fig. 2. The vertical axis means the length of the AW, which is varied in $2^n$ with respect to the basic AW length. In this case, as this analysis is an auto-correlation at the center of this observation time (80 ms, $2^0$), the dilation and contraction rate is zero and the correlation value can be robust. At the edge of this observation time, the values are shifted toward the construction. This part means mutual-similarity analysis. Thus, the correlation analyses of the time-varying signals allow including the mutual-similarity feature.

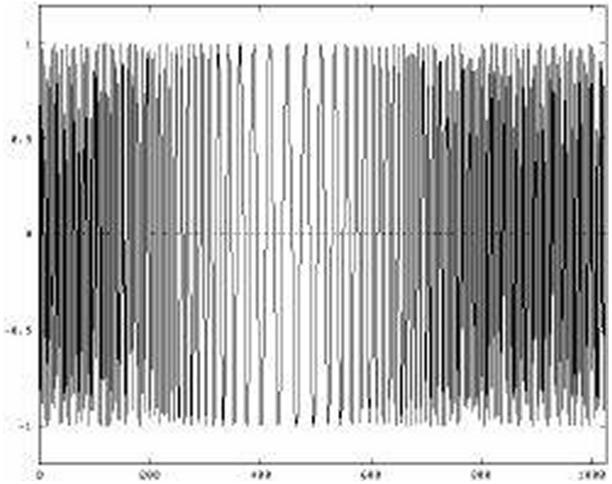

**Figure 1:** Chirp signal.

## 4 - EXPERIMENT

The *Oshima Maru* is a 226-gross-ton training ship equipped with one 1300 ps, 370 r.p.m. diesel engine. In this vessel, various structural measures against vibration and noise were taken. However, next to the engine room, in the mess hall where crews take their breaks, unpleasant low-frequency sound persisted.

Fig. 3 shows the upper deck of the *Oshima Maru*. The main engine room, located on the lower deck, is adjacent and partially below the mess hall. The space directly above the main engine allows clearance to the 2nd deck, for engine access. By applying vibration signals from both a wall and a floor in the mess hall next to the engine room to the analyzing wavelets, we estimated the correlation that is obtained from robust values in time-scale analysis using the proposed method.

The sampling frequency was 6 KHz and the cut-off frequency was set at 2.5 KHz. The arrangement of sensors is illustrated in Fig. 3.

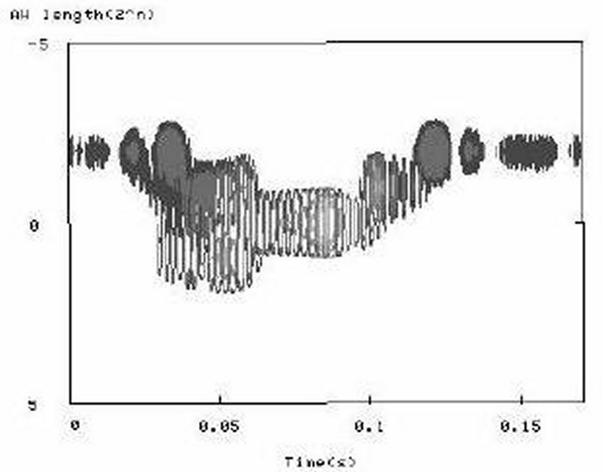

**Figure 2:** Wavelet analysis by the measured AW.

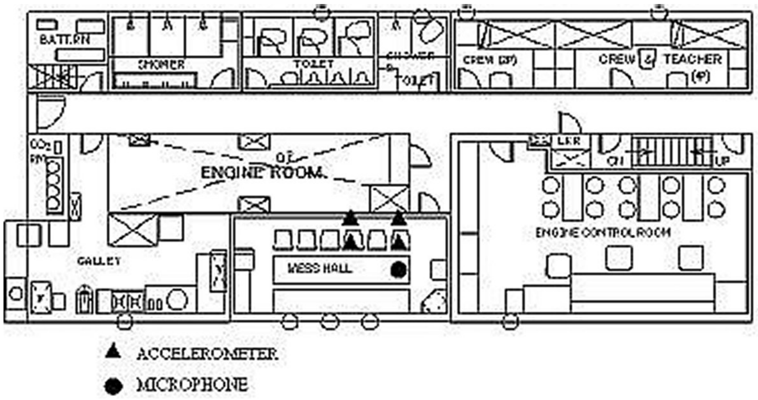

**Figure 3:** The arrangement of sensors.

When the main engine was slowed suddenly from 350 r.p.m. to 280 r.p.m., the time-varying correlation between the mess hall's interior sounds and vibrations were analyzed. The results, using AW prepared with vibration signals at 350 r.p.m. are illustrated in Fig. 4 and Fig. 5. We detected the main engine as it started to decline at 1.2 seconds with non-continual points, which are observed at the same parts in both figures. Other methods, for instance WT and Spectrogram, could not detect these.

In Fig. 4, when the dilation and contraction rate is zero, the correlations are 0.5 continually. So the vibration components from a floor can be included much more in the sound field. However, when the vibration from a floor was adopted for AW, not much information on the slowdown was produced. Thus, the sound field of the mess hall is deeply related to the vibration components originating at anywhere except the main engine.

In Fig. 5, the components constructed AW to 1/4 have low correlation value after 1.2 seconds. These components are assumed to be the components of the main engine; the correlation relation broke off as the engine started to decline. Though these components are much included in the vibration of the wall, the WT, by applying the vibration of the wall to AW, have low values at the non-construction components. Thus, we assume that the components' contributions to the sound field of the mess hall are not remarkable. We confirmed that the time-frequency feature at the changing point did not become a simple continuous pattern of the frequency modulation with the construction.

Taking advantage of these results, we have simulated the multi-channel ANC. It was observed that the element after the urgent slowdown remained highly correlated with the results of the time-varying correlation analyses. Therefore, it is clear that setting the floor element and generator element as the reference signal will be benefit for ANC. This result is shown in Fig. 6. The ANC effect is improved more than it is if each point is set in the engine room as the reference signal.

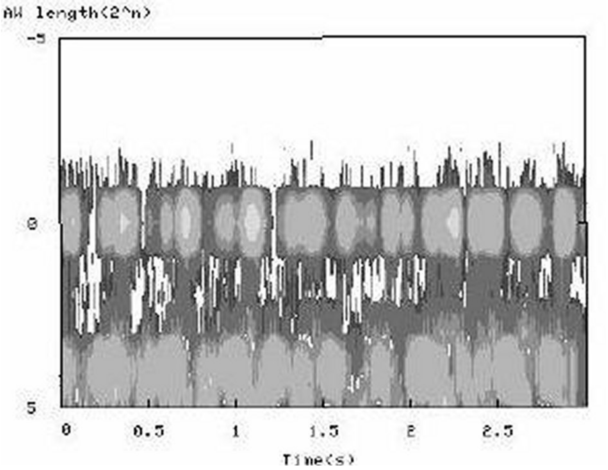

**Figure 4:** The time-varying correlation analyses between the mess hall's interior sounds and floor vibrations.

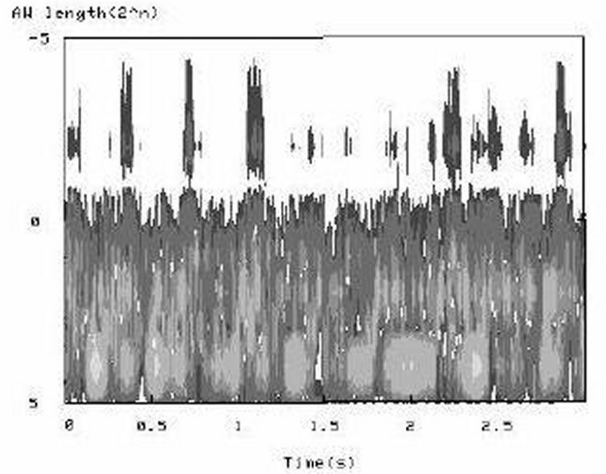

**Figure 5:** The time-varying correlation analyses between the mess hall's interior sounds and wall vibrations.

## 5 - CONCLUSION

In this paper, by applying a measured signal such as a vibration to an analyzing wavelet, we can obtain the correlation between a ship's interior sounds and vibrations in a time-varying condition. It was also found that these results were useful for the selection of a reference signal to improve the effect on ANC. In the future, we will reveal the relation between the vibrations in the mess hall and engine room and examine the method of extracting features clearly. In addition, we will determine the best method of an AW's window length and the automation of t-s estimation.

## ACKNOWLEDGEMENTS

Part of this study was done with the aid of a Mazda Foundation research grant.

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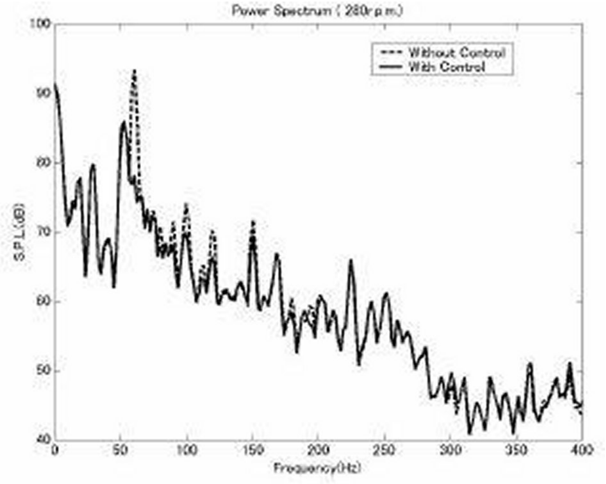

**Figure 6:** The result of ANC using the time-varying correlation.

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