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SELF-SIMILARITY ANALYSIS OF THE FLOOR IMPACT SOUND

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Abstract

The vibration is propagated to the downstairs room by the floor impact of the upstairs. The sound radiated in downstairs room strongly depends on the floor impact of the upstairs. Japan Industrial Standards(JIS) A 1418-1 describes the measurement method of the light-weight floor impact sound level. The floor is driven by the impact hammer. The vibration acceleration on the upstairs and the sound pressure in the downstairs room are measured. Their signals of the vibration acceleration and the sound pressure are analyzed by the self-similarity method in time domain. By the self-similarity analysis, the acoustic characteristic of the sound wave by the floor impact is estimated. The vibro-acoustic impulse response can be reconstructed by the elements calculated by the self-similarity analysis.

INTRODUCTION

In an multiple dwelling houses, the sound is radiated by the floor impact of the upstairs to the downstairs. The sound environment of the downstairs is deteriorated by the radiation sound, and it becomes a noise trouble between residents in the the upstairs and the downstairs. To prevent this problem, it is necessary to estimate the sound generated in the downstairs according to the floor impact of the upstairs. The vibration is propagated to the downstairs by the floor impact of the upstairs. By these vibrations, the sound radiated in downstairs strongly depends on an architectural structural characteristic of the building and the acoustic characteristic[1]. The self-similar features for the signals of the vibration acceleration and the sound pressure are calculated. By the self-similarity analysis, the acoustic characteristic of the building is estimated.

In this paper, the vibration acceleration on the upstairs floor and the sound pressure of the downstairs room are measured by using the measurement method described in Japan

Industrial Standards(JIS) A 1418-1. JIS A 1418-1 describes the measurement method of the light-weight floor impact sound level. And the Hausdolf distance between the vibration acceleration and the sound pressure is calculated. By dependence on the periodicity of the Hausdolf distance, the length of the frame of the self-similarity analysis is determined. The signal of the sound pressure is self-similarity analyzed as a function of the length of the frame. And the self-similar characteristic of the sound pressure is examined. By the self-similarity analysis of the sound pressure, the acoustic characteristic of the sound wave by the floor impact is estimated. Because the reliability of the feature elements the self-similar characteristic obtained from the analyses was confirmed, the results of self-similarity for the impulse response calculated from the transfer function between the vibration acceleration and the sound pressure are shown.

MEASUREMENT SETUP AND RESULT OF THE VIBRATION ACCELERATION AND THE SOUND PRESSURE

MEASURENT SETUP

Measurement is set in a second floor house. The upstairs is a Japanese-style room. The downstairs is a half basement. The room of the upstairs is set as the driving room, and the size of the driving room concrete slab is 3.64m in width $\times$ 3.64m in depth $\times$ 0.2m in thickness. The driving point is set to central point S on the slab. The vibration acceleration of the floor is measured by point R in the diagonal on the slab 0.9m away from the driving point. The room of the downstairs is set as the sound receiving room. The sound receiving room size is 1.82m in width $\times$ 3.64m in depth $\times$ 3.64m in height. The ceiling of the downstairs is sharing with the concrete slab of the upstairs. The sound receiving room wall is composed of walls of concrete. By the floor impact generated in the upstairs, the sound pressure of the sound wave in downstairs is measured. The measuring location of sound pressure is 0.62m apart from the ceiling. The measurement setup is shown in Fig.1.

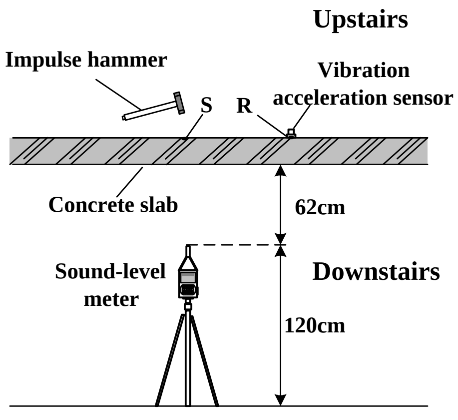

Figure 1: Measurement setup

MEASURED RESULTS

The floor impact is driven by the impulse hammer by hand power. The reverberating time is 0.5 msec or less. And, the driving time is selected every about 2 sec. Sampling frequency F_s is 22.05kHz. The waveforms of the measured vibration acceleration and the the sound pressure are shown in Figs.2(a) and (b).

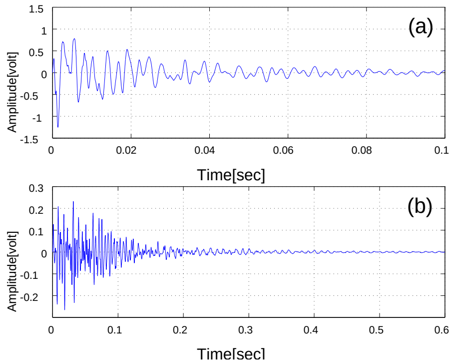

Figure 2: (a): The vibration acceleration wave form, (b): The the sound pressure wave form

SELF-SIMILARITY ANALYSIS METHOD

Let the signal $f(t)$ be divided in N frames as follows:

$$f(t) = (f_1(t_1), f_2(t_2), \cdots, f_N(t_N)). \tag{1}$$

Here, let frame $f_i(t_i)$ be in time range $\alpha_i \preceq t_i \preceq \beta_i (i = 1, 2, \ldots, N)$. And, suppose $\alpha_{i+1} = \beta_i$, the numbering for the divided frame becomes continuous. To affine-transforme of the frame $f_i(t_i)$, let x_i be as follow:

$$x_i = (t_i|_{\alpha_i \preceq t_i \preceq \beta_i}, f_i(t_i))^T. \tag{2}$$

And, suppose y_i be the affine-transformation of x_i as follows:

$$y_i(k) = A_i(k)x_i + B_i \tag{3}$$

in which

$$A_i(k) = \begin{pmatrix} a_k & c_i \\ d_i & b_i \end{pmatrix} \tag{4}$$

$$B_i = \begin{pmatrix} e_i & q_i \end{pmatrix}^T. \tag{5}$$

Here, the element $c_i, d_i = 0$ because the factors to rotate the signal $f(t)$ are unnecessary. Element a_k is selected from the view of decimation point in signal processing. The maximum value of decimation point that is integer number depends on the both the magnitude response of the signal and the sampling frequency. And, we will describe an example in other section. b_i, e_i and q_i are evaluated in the Iterated Funtion System(IFS) algorithm.

To obatin the attractor, Euclidean distance $d(y_i, y_{i+1})$ between y_i and y_{i+1} for any two points need satisfie the following condition:

$$d(y_i, y_{i+1}) \preceq ||A||d(x_i, x_{i+1}) \tag{6}$$

in which,

$$||A|| = max\{\frac{|A|}{|x|}\}, x \neq 0 \tag{7}$$

is norm of A. Scaling coefficient s is given as follows:

$$s = max\{a, |b|\}, (0 \preceq a < 1, |b| < 1). \tag{8}$$

When the affine-transformation of the frame $f_i(t_i)$ is scaling transformation, attractor g_i of decimation point k estimated from IFS is defined as follows:

$$\begin{aligned} y_i(k)^0 &= y_i(k) \\ y_i(k)^1 &= A_i(k)y_i(k)^0 + B_i \\ &\vdots \\ y_i(k)^p &= A_i(k)y_i(k)^{p-1} + B_i \end{aligned}$$

$$g_i(k) = y_i(k)^p. \tag{9}$$

Becasue of the continuous in numbering time-domain of the divided frame, the time-domain of $g_i(k)$ by the affine-transformation is continuously$(a_{i+1}\alpha_{i+1} + e_{i+1} = a_i\beta_i + e_i)$.

$$G(k) = \bigcup_{i=1}^{N} g_i(k) \tag{10}$$

And, $g_j(k)$, which Hausdolf distance h is the shortest, can be determined from all frames in IFS. The Collage theorem for the scaling transformation in time series signal is defined as follows:

$$h(f_i(t_i), G') < \frac{h(f_i(t_i), \bigcup_{j=1, j\neq i}^{N} g_j(k))}{1-s}. \tag{11}$$

The reconstructed signal $f(t)$ can be generated by the attractor that is calculated from the IFS.

In addition, the Hausdolf distance h between the frame $f_i(t_i)$ and the attractor $g_j(j = 1, 2, \ldots, N, j \neq i)$ is given as follows:

$$h(f_i(t_i), g_j) = max\{\delta(x_i, y_j), \delta(y_j, x_i)\} \tag{12}$$

$$\delta(x_i, y_j) = max\{min(|x_i - y_j|)\}. \tag{13}$$

The flow diagram of the self-similarity analysis method is shown in Fig.3.

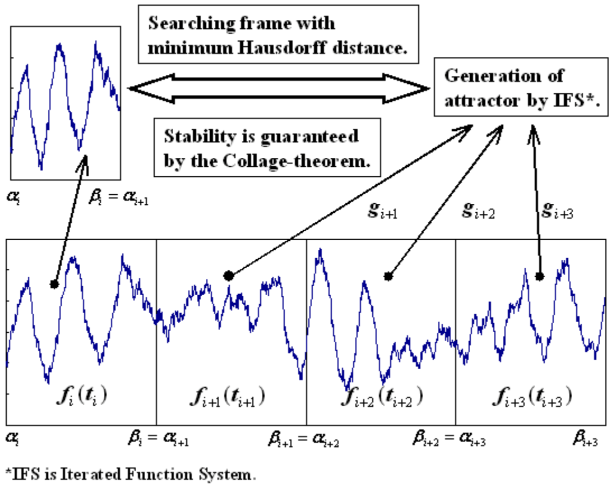

Figure 3: Self-similarity analysis method

SELF-SIMILARITY ANALYSIS OF THE ACOUSTIC WAVE

THE HAUSDOLF DISTANCE BETWEEN THE VIBRATION ACCELATION AND THE SOUND PRESSURE

The frame length for the self-similarity analysis is determined by change of the Hausdolf distance between the vibration acceleration and the sound pressure. The time length is selected from 0.1 sec to 0.6 sec. And, the Hausdolf distance is calculated every $1/F_s$ sec. The Hausdolf distance as a function of the frame begining time is shown in Fig.4. Time of the shortest Hausdolf distance between the vibration acceleration and the sound pressure is 56 msec. From the results of the Hausdolf distance within 200 msec, the period is 3 msec. In other time domain, the the period becomes remarkably longer.

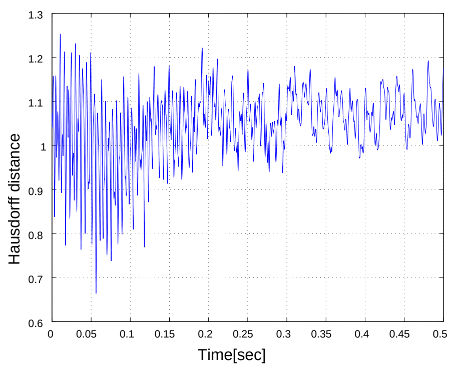

Figure 4: The Hausdolf distance between the vibration acceleration and the sound pressure

THE RECONSTRUCTED ACOUSTIC WAVE

The frame length of the self-similarity analysis is determined from the time function of the Hausdolf distance between the vibration acceleration and the sound pressure. Mentioned previously, the shortest period is 3 msec. As the frame length for the self-similarity analysis, we set 3 msec. The sound pressure signal is analyzed by the self-similarity method. As the element a_k in the matrix $A_i(k)$ of the linear transformation in the affine-transformation, we select three parameters from the view of decimation point in signal processing. The maximum value of decimation point that is integer number depends on the both the magintude response of the signal and the sampling frequency. In the experiments, we select the maximum value=3. As a result for k=1 $\sim$ 3, a_k = $\frac{1}{2}$, $\frac{1}{3}$ and $\frac{1}{4}$.

For the sound pressure signal, we show the reconstructed results that are calculated from the attractors obtained by the affine-transformation of IFS. The original and the reconstructed sound pressure are shown in Figs.5(a) and (b). The correlation coefficient between the sound pressure and the reconstructed sound pressure is 0.99. The spectrum charcteristics of the sound pressure and the reconstructed sound pressure are shown in Fig.6, respectively. The spectrum charcteristic of the sound pressure agrees well with the one of the reconstructed sound pressure in frequency band from 10Hz to 800Hz . The magnitude of the error between the spectrum of the original and the estimated signal is within 1dB.

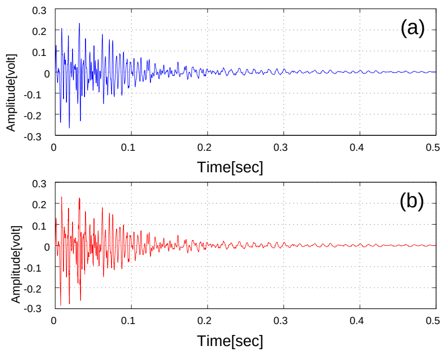

Figure 5: (a): The sound pressure, (b): The reconstructed sound pressure

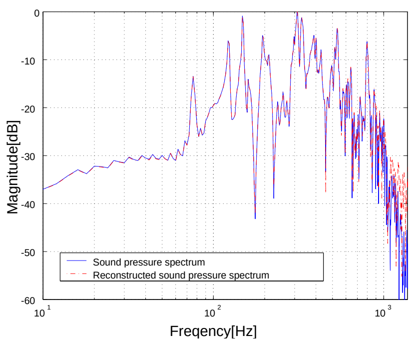

Figure 6: The spectrum charcteristics of the original and the reconstructed sound pressure

SELF-SIMILARITY ANALYSIS OF THE IMPULSE RESPONSE

THE IMPLUSE RESPONSE BETWEEN THE VIBRATION ACCELERATION AND THE SOUND PRESSURE

The impulse response between the vibration acceleration and the sound pressure is estimated by the cross-spectral method. The impulse response is shown in Fig.7.

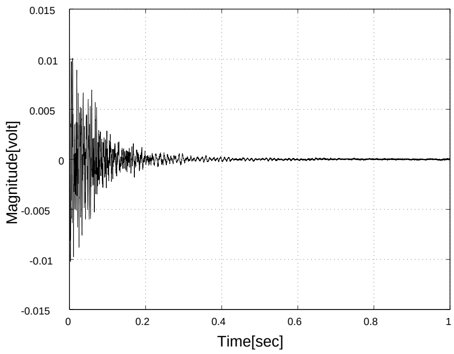

Figure 7: The impulse response between vibration acceleration and sound pressure

THE RECONSTRUCTED IMPULSE RESPONSE

The self-similarity analysis technique of the sound pressure is applied to the estimation of the features of the impulse response. We can detect the parameter of the impulse response in the measuring room. The original and the reconstructed impulse response are shown in Figs.8(a) and (b). The correlation coefficient between the impulse response and the reconstructed wave-form is 0.98. The spectrum charcteristics of these impulse responses are shown in Fig.9. The spectrum characteristic of the impulse response agrees well with the one of the reconstructed impulse response in frequency band from 10Hz to 1000Hz.

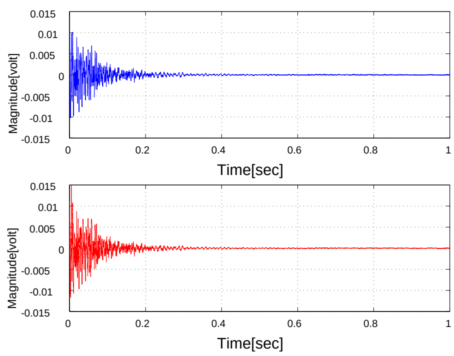

Figure 8: (a): The impulse response , (b): The reconstructed impulse response

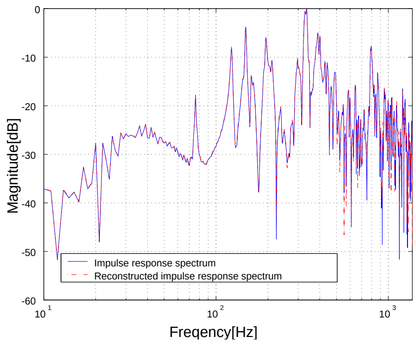

Figure 9: The spectrum charcteristics of the original and the reconstructed impulse response

CONCLUSIONS

In this paper, the vibration acceleration on the upstairs floor and the sound pressure of the downstairs room were measured by using the measurement method described in JIS A 1418-1. And, the Hausdolf distance between the vibration acceleration and the sound pressure was calculated. By dependence on the period of the Hausdolf distance, the length of the frame of the self-similarity analysis was determined. The signal of the sound pressure was self-similarity analyzed as the function of the length of the frame. And the self-similar characteristic of the sound pressure was examined. By the self-similarity analysis of the sound pressure, the acoustic characteristic of the sound wave by the floor impact was estimated. Because the reliability of the element obtained from the analysis was confirmed, the impulse response that is calculated from the transfer function between the vibration acceleration and the sound pressure were analyzed by the self-similarity method.

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