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ESTIMATION OF DIRECTION OF INFRA SOUND BY MUSIC METHOD

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ABSTRACT
This paper describes the estimation of direction of infrasound arrival by the MUSIC (MUltiple SIgnal Classification) method. We can feel an existence of the sound from the vibration of the pane and the shake of furniture. The distance attenuation of the sound is less than one of audio sound. We observed the infrasound generated by the power machine used for manufacturing gravel. A basic frequency of the measured sound waves is 14Hz, and the sound level is about 120dB at a position 100m apart from the sound source. We estimate direction of arrival of the infrasound wave with a linear microphone array, which is composed of three microphones, and the each spacing is 11m. It is possible to estimate the propagation direction within 10-degree accuracy by the MUSIC method.

1 - INTRODUCTION
The change has taken place in the life environment sound at night while the life custom shifts to the type all day. The complaint number of noise pollution has an increase along with it every year. Not only the complaint according to the life noise but also the complaint by infrasound has increased. We often live without knowing the existence of the sound even if exposed under the condition of high sound level for a long time. Infrasound is generated from boilers, bridges and the transportation facilities such as cars and trains. We can feel the existence of infrasound from the sound generated by a shaking window frame and unpleasant feeling etc., sometimes. International Organization for Standardization has been examining the method concerning the measurement of infrasound under this situation. However, the individual variation for the influence of infrasound is large. We can learn the sense characteristic to infrasound more accurately from the relation between the amount of the sense and a physical amount by measuring the frequency and sound level at the same time.
As one of the difficulties of estimation for localization of an infrasound source, a sound wave occasionally reaches a microphone from the position of several km because the wavelength of the sound wave is long and the attenuation coefficient of the sound is low. In generally the sound has a characteristic spectrum structure, we can find it and estimate the sound source localization by use of the acoustic characteristics. The sound wave is measured by a microphone array, and the method for estimating the direction of the sound generator and these results are described.

2 - MUSIC METHOD [1], [2]
Figure 1 shows a uniformly spaced linear microphone array with spacing d that is constructed by the M microphones and the P sound waves observed in the array direction of arrival angle.
The signal received at each microphone consists of microphone noise as well as signals from P sound sources, assumed to be uncorrelated with one another. The observed data are of the form

$$y\left(n\right)=\sum_{k=1}^{p}\alpha_k\exp\left(j2\pi nf_k+j\Phi_k\right)+w\left(n\right)=x\left(n\right)+w\left(n\right) \quad (1)$$

where $w(n)$ is additive noise, α_k's are the amplitudes, f_k's are the frequencies, and Φ_k's are the phases. The typical assumption is that the phases are independent random variables uniformly. Such an assumption implies that multiple realizations are available as follows:

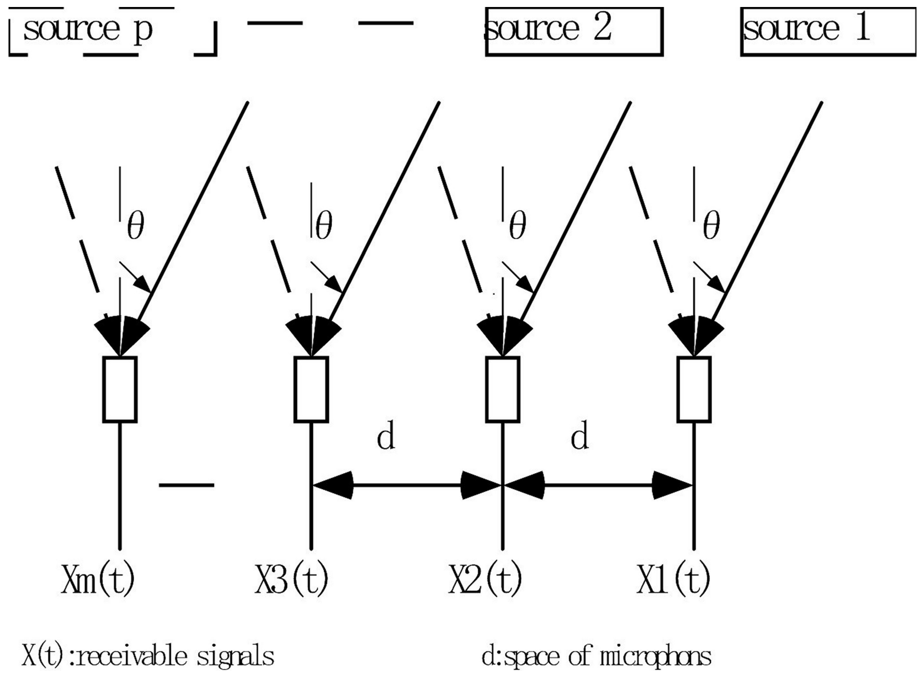

Figure 1: A uniformly spaced linear microphone array and arrival sound waves.

$$y_m\left(n\right)=\sum_{k=1}^{p}\alpha_k \exp\left(j2\pi n f_k+j\Phi_{k,m}\right)+w_m\left(n\right)=x_m\left(n\right)+w_m\left(n\right) \tag{2}$$

where m denotes the realization number.
Autocorrelation matrix of the $y(n)$ in Eq. (1) may be written as

$$R_{yy}=R_{xx}+\sigma^2\mathrm{I}=SDS^H+\sigma^2\mathrm{I} \tag{3}$$

where S is a Vandermonde matrix, m=1,. . ., P and D is the diagonal matrix. Let $M>P$. The autocorrelation matrix R_{yy} has a linearly independent set of eigenvectors. Denote the eigenvalues and eigenvectors by λ_k and V_k. Define the M element signal vector,

$$\mathbf{e}_k=e^{j2\pi f_k}\left[e^{-j2\pi f_k},...,e^{-j2\pi M f_k}\right]^T \tag{4}$$

The eigenvectors corresponding to the P largest eigenvalues are said to constitute the signal subspace; the remaining M-P eigenvectors constitute the noise subspace. Signals lie in the signal subspace and are orthogonal to the noise subspace, that is,

$$\mathbf{e}_\mathbf{k}^H\mathbf{v}_i=0,\ i=p+1,\ldots,M;\ k=1,\ldots,p \tag{5}$$

hence, with

$$\mathbf{e}\left(f\right)=e^{j2\pi f}\left[e^{-j2\pi f},...,e^{-j2\pi M f}\right]^T \tag{6}$$

one can search for the set of frequencies such that. $\mathbf{e}^H\left(f\right)\mathbf{v}_k=0,\ k=p+1,...,M.$
In MUSIC, one determines the frequencies of the harmonics by looking for peaks in the spectrum defined by

$$P_{yy}\left(f\right)=\left[\sum_{k=p+1}^{M}w\left(k\right)\left|\mathbf{e}^H\left(f\right)\mathbf{v}_\mathbf{k}\right|^2\right]^{-1} \tag{7}$$

where $w(k)$=1.

3 - LOCALIZATION AND EXPERIMENT

Figure 2 shows a location map for measuring sound sources. Environmental noise is measured with a sound level meter and a microphone array that was composed of three infrasound level meters. The microphone space is d=11.0m. The array was set up on level ground of the height of 3.1m from the roadside. There is a concrete block wall of 4.3m in height in back 3.0m of the array. There are the driving motors and filters, which are the noise sources in the direction of 15 degrees from the right edge of the array microphone, and they are set in the building surrounded with the slate.

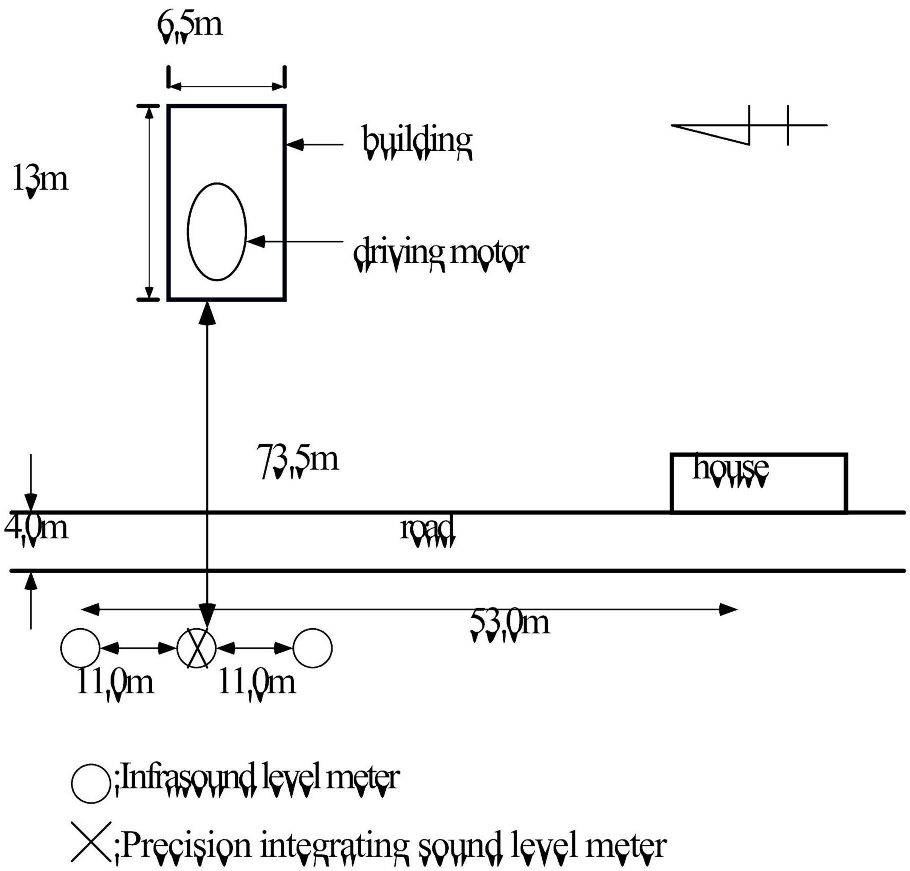

Figure 2: A map for measuring sound sources.

4 - RESULTS

The sampling frequency of the measurement data is 480Hz, and the data length is 4096 points. Figure 3 shows the result of a spectrum analysis. The power spectrum has concentrated on frequencies of 14Hz and 29Hz. The frequency of 14Hz is a condition to satisfy $d < \lambda/2$ in the MUSIC method.

Figure 4 shows the results of the MUSIC spectrum calculated by Eq. (7). The maximum value of spectrum calculated by the MUSIC method is 0.13 and its angle ranges over $0°$ and $20°$. In this direction, there are the driving power sources in the building.

5 - CONCLUSIONS

Because the wavelength is long, and the image sound source is generated easily in the sound source put on the measurement environment by interference, it is necessary for estimating the direction of arrival of the infrasound to solve some problems. Directional angle estimated for arrival direction of the infrasound wave generated from the driving motors agreed within the range of 10 degrees or less.

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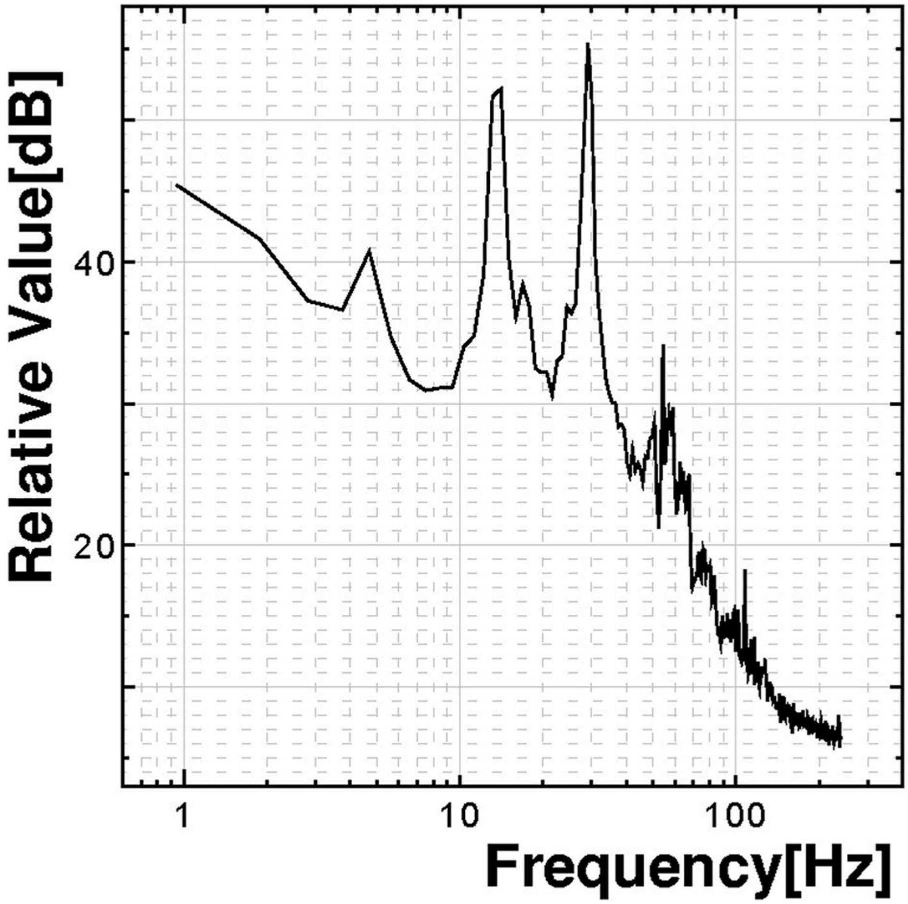

Figure 3: The spectrum of measured sound wave.

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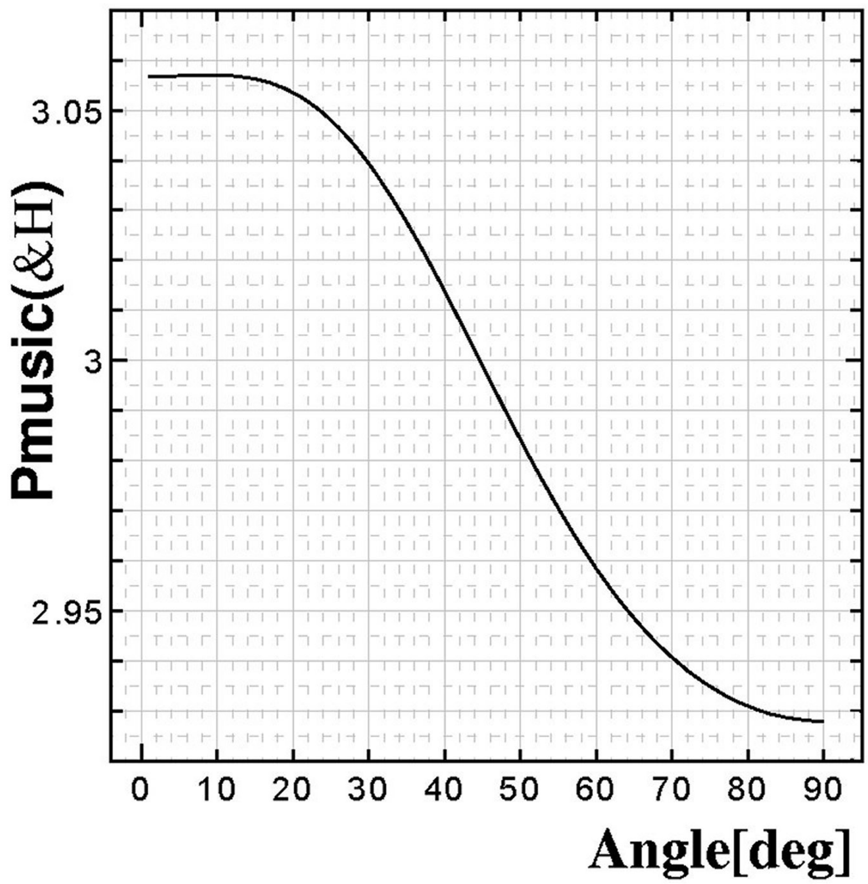

Figure 4: The MUSIC spectrum.