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TECHNICAL REPORT

Prediction of outdoor sound propagation by geometrical computer modeling

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Abstract: The municipal public address (M.P.A.) system for disaster prevention is an important information facility in communities. The speech intelligibility of such a system, however, tends to be deteriorated by multipass echoes with long time delay owing to reflections from nearby buildings and by the sounds from loudspeakers covering other subareas. When designing such an M.P.A. system, a tool effective for the prediction of outdoor sound propagation should be developed. For this purpose, the authors have been investigating the applicability of a computer modeling technique based on geometrical acoustics. To elucidate the effectiveness of the modeling technique, two case studies were examined by comparing impulse responses (echo diagrams) calculated by computer modeling and those obtained by field measurements. As a result, it was found that this modeling technique can be effectively applied to the prediction of outdoor sound propagation and the basic design of M.P.A. systems.

Keywords: Municipal public address system, Outdoor sound propagation, Multipass echo, Geometrical computer modeling

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1. INTRODUCTION

In Japan, municipal public address (M.P.A.) systems are widely used to transmit verbal information to communities. In these systems, announcements such as those for disaster prevention, evacuation and crime prevention are broadcast simultaneously from loudspeaker systems located at various points in a certain area. The speech intelligibility of the announcements, however, tends to be deteriorated by multipass echoes with long time delay owing to reflections from nearby buildings and by the sounds from loudspeaker systems covering other subareas. When designing such an M.P.A. system, a tool effective for the prediction of outdoor sound propagation should be developed. For this purpose, the authors have been investigating the applicability of a computer modeling technique based on geometrical acoustics [1,2]. In this paper, the results of two case studies are presented, where the impulse responses (echo diagrams) calculated by the image-source method of geometrical acoustics and those obtained by field measurements by applying the cross-spectrum method and the swept-sine method were compared.

2. COMPUTER MODELING BY IMAGE-SOURCE METHOD

In this study, computer modeling based on the image-source method was applied as the simplest technique to predict the direct sounds from each loudspeaker system and dominant reflections. As the software for this modeling, the image-source method included in the software "ODEON" version 11.0 [3–5] was used.

In the modeling of large-scale buildings in the area under study, their shape and size were approximated from the measurement results obtained using a laser range finder. As the absorption coefficients of the boundary surfaces, the

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Table 1 Absorption coefficients of the boundary surfaces.

Surface	Absorption coefficient [%]
Building surface	2.5
Ground surface	10
Surrounding boundary	100

Table 2 Calculation conditions.

Component	Value
Transition order	10 (Upper limit)
Surface scattering	Neglected
Temperature	20.0°C
Relative humidity	50.0%

Fig. 1 Loudspeaker system of the M.P.A. system.

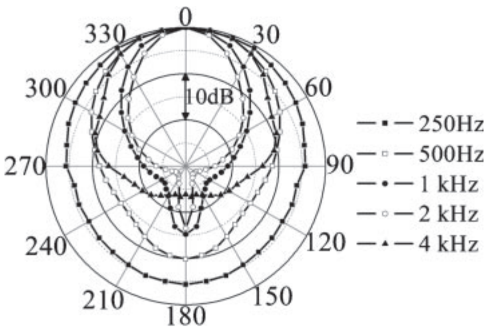


Fig. 2 Directional characteristics of a horn-type loudspeaker (TOA: TC-730M) measured in an anechoic room.

values shown in Table 1 were assumed for all frequency bands.

The loudspeaker system used in the M.P.A. system under investigation in this study is a set of four horn-type loudspeakers, as shown in Fig. 1. In the modeling of this loudspeaker system, the data of sound pressure directional characteristics in five octave bands from 250 Hz to 4 kHz measured for a horn-type loudspeaker (TOA: TC-730M) were used (see Fig. 2). In the computer modeling, the angle of each directional characteristic was changed orthogonally and combined while ignoring the interference effect. The direction of the loudspeaker system at each position was carefully considered in the modeling.

The result of the calculation by the image-source method consists of a series of impulses was convolved with a band-pass filter covering three octave bands from 500 Hz to 2 kHz to enable comparison with the results of the field measurements presented below. To visualize the envelope

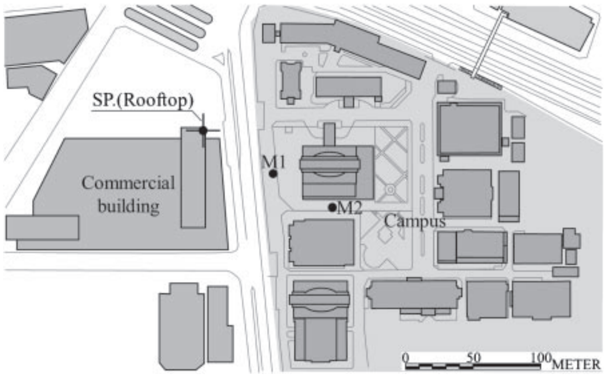


Fig. 3 Geometry of the sound source and the measurement points.

of the impulse response calculated as described above, the Hilbert transform of the impulse response was calculated.

3. CASE STUDY 1

As the first study, the sound propagation from a loudspeaker system of an M.P.A. system in a relatively small area with large buildings was investigated to examine the efficiency in the detection of reflections by computer modeling.

3.1. Area under Investigation

Figure 3 shows the area investigated in this case study, in which the loudspeaker system is set on the rooftop of a commercial building at a height of 53 m above the ground and two measurement points (M1 and M2) were chosen in the adjacent university campus (Tsudanuma Campus of Chiba Institute of Technology) at a height of 1.5 m above the ground. The loudspeaker system can be seen from point M1, while point M2 is behind a building and hidden from the sound source.

3.2. Impulse Response Measurement by the Cross-Spectrum Method

The M.P.A. system broadcasts an announcement in a female voice for children going home at 5 pm every day. Using this announcement, the transfer function between the signal of the announcement monitored by a wideband receiver and the sounds received at each of the measurement points was calculated for 32.5 s. The calculation of

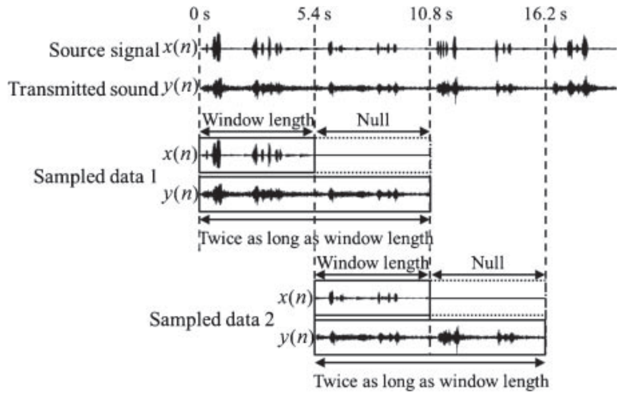
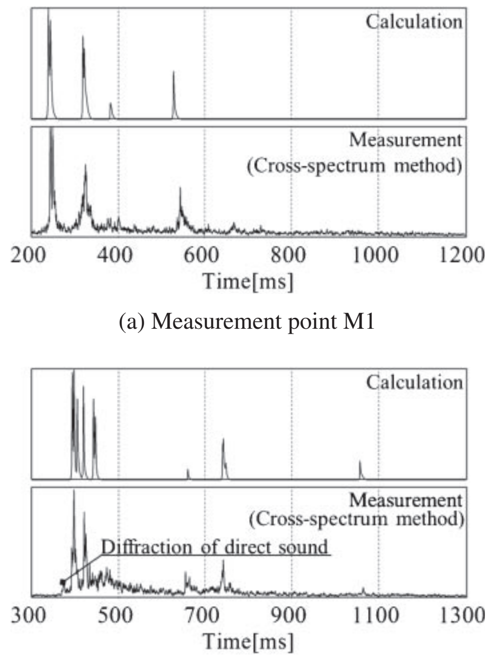


Fig. 4 Diagram of time-averaging process in the cross-spectrum method.



(a) Measurement point M1

(b) Measurement point M2

Fig. 5 Echo diagrams (frequency: three octave bands from 500 Hz to 2 kHz).

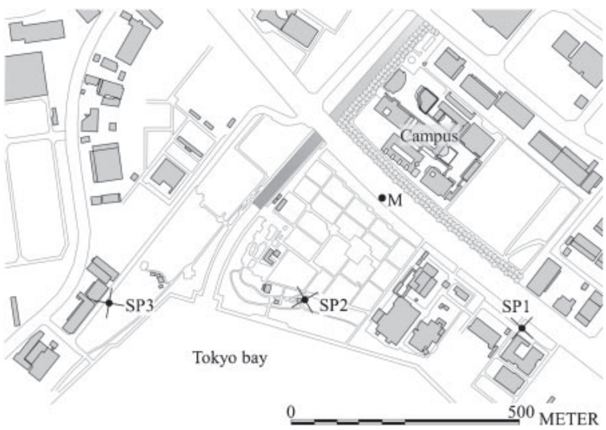


Fig. 6 Geometry of the sound sources and measurement point.

the transfer function $H(k)$ expressed by Eq. (1) was performed in accordance with the method proposed by Kido and coworkers [6–9].

$$H(k) = \frac{\overline{X^{*}(k)Y(k)}}{\overline{X^{*}(k)X(k)}} \tag{1}$$

where, $X(k)$ is the Fourier transform of the source signal $x(n)$, $Y(k)$ is that of the transmitted sound $y(n)$ and $X^{*}(k)$ is the complex conjugate of $X(k)$.

As shown in Fig. 4, the source signal $x(n)$ and the transmitted sound $y(n)$ were simultaneously extracted for 10.8 s. For the former, null was set for the latter half of the time period. From these signals, $X(k)$, $X^{*}(k)$ and $Y(k)$ were calculated and a sample transfer function was calculated. By performing this calculation five times every 5.4 s and by calculating the inverse Fourier transform of $H(k)$, the cross-correlation function in the time domain was obtained. To obtain the impulse response in the main frequency region for speech, the cross-correlation function was convolved with a band-pass filter covering three octave bands from 500 Hz to 2 kHz. To visualize the envelope of the impulse response measured in such a way, the Hilbert transform of the impulse response was calculated.

3.3. Comparisons of Calculation and Measurement Results

Comparisons of the impulse responses obtained by computer modeling and by field measurement are shown in Fig. 5. In the result for measurement point M1, the direct sound and several discrete reflections are clearly seen in both the calculation and the measurement. For the measurement point M2, the dominant reflections are in fairly good agreement between the calculation and the measurement. In the calculation, however, the direct sound is not seen because the point (M2) is behind a building and hidden from the sound source, whereas it is slightly visible in the measurement.

4. CASE STUDY 2

As another study, the sound propagation from multiple loudspeaker sound sources was investigated. In this study, the field measurement by the swept-sine method [10–13] was performed, in addition to the cross-spectrum method, with special permission from the municipal office.

4.1. Area under Investigation

Figure 6 shows the area investigated in this case study. Although there are three loudspeaker systems in this area, one of them (SP3) was unfortunately turned off at the time of the measurement. The measurement point (M) was

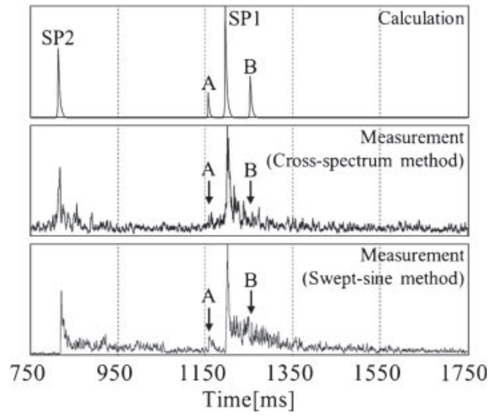


Fig. 7 Echo diagrams (frequency: three octave bands from 500 Hz to 2 kHz).

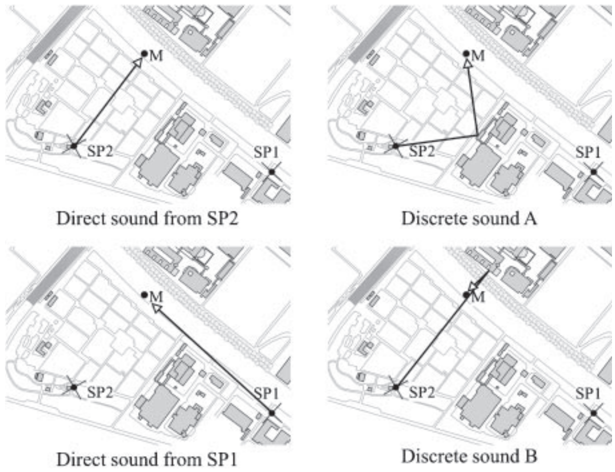


Fig. 8 Sound paths calculated by computer modeling.

located by the side of a two-story school building at a height of 1.5 m above the ground, from which the two loudspeaker systems (SP1 and SP2) can be seen.

4.2. Impulse Response Measurement

The field measurement was performed on a fine and calm day. In addition to an announcement in a male voice with a duration of 50 s, a test signal was sent out from the two loudspeaker systems (SP1 and SP2) simultaneously. As the test signal, a swept-sine signal with a duration time of 3 s covering five octave bands from 250 Hz to 4 kHz with a linear frequency increment was used.

Regarding the measurement by the cross-spectrum method, the same signal processing previously described was adopted and the impulse response was obtained. For the measurement by the swept-sine method, the impulse response was calculated by conventional deconvolution processing and it was convolved with a band-pass filter covering three octave bands from 500 Hz to 2 kHz. Hilbert transforms of the impulse responses measured by the two methods were also calculated in this case.

4.3. Comparisons of Calculation and Measurement Results

The results of the calculation and the two kinds of measurements are shown in Fig. 7. In these results, it can be seen that the direct sounds from the two loudspeaker systems are in fairly good correspondence. However, the discrete sounds (A and B) are clearly distinguishable in the calculation result, while they are inconspicuous in the two measurement results. The reason for this discrepancy was considered in terms of the sound paths obtained in the computer modeling shown in Fig. 8. As a result, it was found that sound A is due to reflection from a small building, which was treated as perfect reflection in the calculation. For sound B, there is dense foliage about 3 m high between the measurement point and the school building, which might have had some scattering effect that was not treated in the calculation.

5. CONCLUSIONS

To enable the design of M.P.A. systems, an effective tool to simulate outdoor sound propagation in a wide area should be developed, and hence the applicability of a computer modeling technique based on the image-source method of geometrical acoustics was investigated. The results were compared with field measurements by the cross-spectrum method and the swept-sine method. Regarding the measurements of sound propagation outdoors, the effect of time variance was anticipated to be very serious, but it was found that direct sounds from the loudspeaker systems and dominant reflections from nearby buildings are in fairly good agreement between the calculation and the measurements. Therefore, it can be concluded that the computer modeling technique applied in this study is effective for the simulation of sound propagation from an M.P.A. system. In computer modeling based on geometrical acoustics, however, a way of treating sound diffraction and scattering effects should be further developed.

On March 11, 2011, the Great East Japan earthquake occurred, which was followed by a catastrophic tsunami disaster. Through these experiences, the importance of M.P.A. systems as a facility for transmitting verbal information to communities was again realized. To enhance the effectiveness of these systems, the speech intelligibility of M.P.A. announcements should be improved by considering the positioning of the loudspeaker system and mitigating the adverse effects of multipass echoes. For this purpose, the methods described in this paper should be advanced in the future.

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