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Localization of Acoustic Reflective Boundary Using Microphone Array of Small Number of Elements

少数マイクロフォンアレーを用いた反射境界の位置推定

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1. Introduction

Recently, the method of boundary position estimation has been actively researched[1,2]. It is aimed to developing surround speaker system using reflected sounds or signal enhancement with using reflected sounds. For surround speaker system, the spatial shape is reconstructed from the boundary positions estimated with the reflection of the transmitted sounds using array system composed of microphones and loudspeakers. For signal enhancement, it operates with generating some “blind angles” to noise sources. However these methods offer arrays consist of large number of elements (microphones and loudspeakers). In this research, we aimed to develop the method of compassing the spatial shape using a small number of microphone array.

The proposed method offers the direction of arrival (DOA) of direct and reflected human speaking. The compassing the spatial shape provides the surround environments in which observation the sound comes from various angles to the listening point. Also it is expected in usage of the signal enhancement without reflected sounds with using time-reversal waves on simulated space. The purpose of this paper is to validate experimentally the utility of the method of the boundary position estimation with applying DOAs of direct and reflected sounds using a small number of microphone arrays.

2. Method

Authors has developed a method to estimate the DOA of the direct sound, θ_d, separated from the effects of reflected sound in reverberant environments by using a microphone array which consists of at least two elements[3]. In this method, DOA is estimated by measuring the time difference of arrival between microphones. Moreover, we can also estimate the DOA of the reflected sound, θ_r.

The proposed method offers the position of the sound source and the mirror image position of reflected sound to estimate the boundary position. The microphone array consists of two of microphones and assuming they exists on same side of the reflective boundary with the sound source as shown in **Fig. 1**. As known variables, c denotes the sound velocity, d denotes the distance between the microphones, and τ_d, τ_1, and τ_2 denote the time delay of the direct signal between microphones, the time difference of arrival between the reflected signal arriving at microphones #1 and #2 and the directed signal arriving at microphone #1, respectively. And as unknown variables, l denotes the distance between the sound source and microphone #1, $\Delta\theta_\mathrm{d}, \Delta\theta_\mathrm{r}$ denote the angular difference of the position of the sound source and the mirror image position of the reflected sound from the view between the center of array and each microphones, respectively.

We obtain eq. (1) from the law of cosines, the line segment joining the position of the sound source and the mirror image position of the reflected sound. And we also obtain eqs. (2) and (3) from the agreement of the position of sound source and the mirror image position of the reflected sound calculating from the each microphone and the DOAs. Solving the eqs. (1), (2), and (3), we obtain the solutions of $l, \Delta\theta_\mathrm{d}$, and $\Delta\theta_\mathrm{r}$. Therefore the position of the sound source and the mirror image position are estimated from the above variables from geometrical method. Consequently, we can estimate the position of the boundary as the bisector of the line segment joining the position of the sound source and the mirror

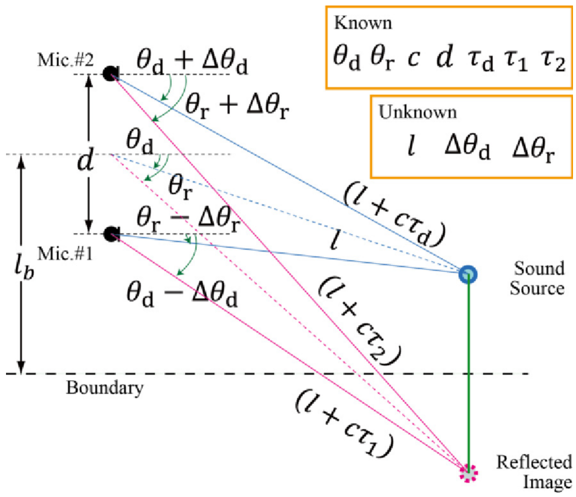

Fig. 1. Positional relationship of sound source, apparent reflected sound source, reflective boundary and the microphone array

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$$l^2 + (l + c\tau_1)^2 - 2l(l + c\tau_1)\cos\big((\theta_r - \Delta\theta_r) - (\theta_d - \Delta\theta_d)\big) = (l + c\tau_d)^2 + (l + c\tau_2)^2 - 2(l + c\tau_d)(l + c\tau_2)\cos\big((\theta_r + \Delta\theta_r) - (\theta_d + \Delta\theta_d)\big) \quad (1)$$

$$l\sin(\theta_d - \Delta\theta_d) + \frac{1}{2}d = (l + c\tau_d)\sin(\theta_d + \Delta\theta_d) - \frac{1}{2}d\,, \quad (2)$$

$$(l + c\tau_1)\sin(\theta_r - \Delta\theta_r) + \frac{1}{2}d = (l + c\tau_2)\sin(\theta_r + \Delta\theta_r) - \frac{1}{2}d\,. \quad (3)$$

image position of the reflected sound. We used plane wave approximation and the first argument of Taylor expansion as approximation conditions.

Although the approximation reduces the calculation cost, the estimation error exists. More specific, the estimation errors are caused by two of influences: the approximation around the small angle differences and the scale of geometric relations. Thus we had prepared a correction function from preliminary numerical experiments, see our previous work[4].

3. Experiment

The experiments were held with using several reflective boundaries, and two of the relationships of the microphone array, the reflective boundary, and the sound source (loudspeaker). We use four boards which are, glass, wood, metal, and plastic cardboard, as the reflective boundary. From the center of the microphone array, the reflective boundary was placed $l_b = 1.2$ (m) far and parallel. Two relationships were tried which the sound source was placed at (x, y) = (1.6, -0.5), (2.4, -0.5) (m,m). We use the human speaking ("Ko-n-ni-chi-wa") as sound source transmitted from the loudspeaker, the distance between microphones is $d = 0.2$ (m) and the sampling rate was $f_s = 96$ (kHz), which are required to calculate τ_d, τ_1, τ_2, θ_d, and θ_r, see our previous work[3] for more details.

Figure 2 shows the results of the estimations. Although, the estimated boundary without correction is close on the actual position that it still involves some estimate errors, we can find that the corrected estimated reflective boundary locates on the actual position for each boundary.

4. Conclusions

The purpose of this paper was to validate the utility of the method of the boundary position estimation with applying DOAs of direct and reflected sounds using a small number of microphone arrays, and the correction function made from the preliminary numerical experiments. As a result, the reflective boundary position was almost estimated correctly in several experiments. With applying this method, the spatial shape will be estimated, which may contribute to developing surround speaker system and signal enhancement, in acoustical method.

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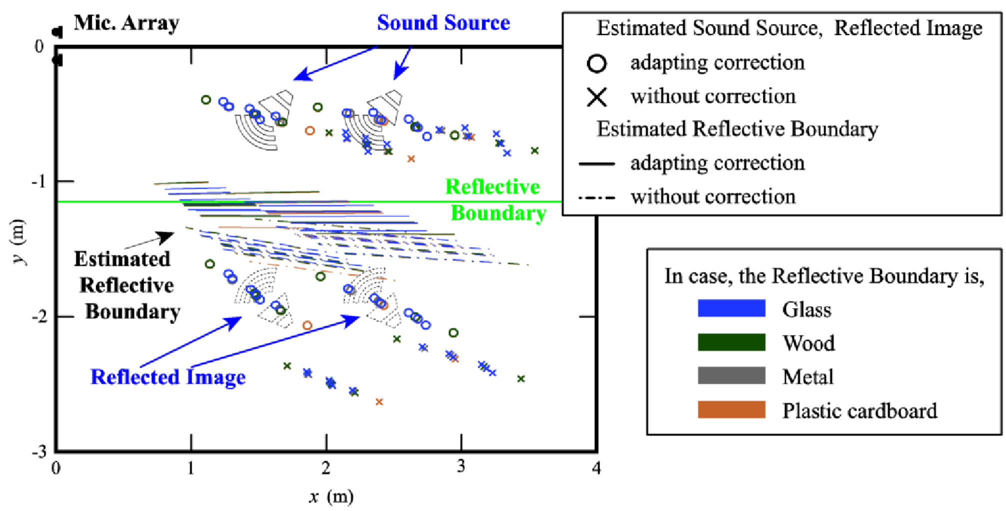

Fig. 2. Experimental setup and the results of the estimation of the reflective boundary
(Solid line: Estimated position of reflective boundary adapting the correction,
Dashed line: Estimated position of reflective boundary without correction)