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Source position estimation using single microphone and concave curved reflector

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ABSTRACT

We can estimate direction of arrival (DOA) or source location for many sound sources using just two ears, because we use fundamentally interaural time difference (ITD) and interaural level difference (ILD), and use sophisticatedly the spectral cues based on features of sounds reflected by his/her ear lobes, head or body, i.e., head-related transfer function (HRTF). We can also estimate DOA or source location by just single ear from an experience.

In this paper, we propose a new DOA or source location estimation method using single microphone and single concave curved reflector. We make a database consisting of template impulse responses around reflector, i.e., reflector-related transfer function (RRTF). We call these template profiles, which are associated with sound source locations. The received sound is identified among template profiles, and we can estimate DOA or sound source location. We was able to provide a rough estimation of source location in experiments.

1. INTRODUCTION

Many topics on microphone array processing, e.g., signal enhancement, noise reduction or direction of arrival (DOA) estimation, have recently been researched, and many methods have been suggested for them. The number of estimated DOAs is generally limited by the number of microphones and we have spatial aliasing problem on the basis of the relationship between microphone distance and wave length.

We had proposed a closely located four-point microphone method for figuring out a direct and some reflected sounds source positions, and has measured in many concert halls or opera houses since 1973[1]. We can get the spatial information of sound field from sound source distribution by this method. We also suggested a new DOA estimation technique, which is to use

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a matching pursuit algorithm, by which it becomes possible to find true DOAs even if the number of sources exceeds that of microphones[2].

On the other hand, the research on DOA estimation using microphones with reflector is suggested[3, 4]. In these methods we estimate DOA using the location cue, which is physically put in a sound by the reflector. Ichikawa used two microphones with each reflector at the back to estimated DOA[3].

In this paper, we propose a new DOA or source location estimation method using single microphone with a concave curved reflector. We make a database consisting of impulse responses around reflector, i.e., reflector-related transfer function (RRTF). We call these template profiles, which are associated with sound source locations. The received sound is identified among template profiles, and we can estimate DOA or sound source location.

2. REFLECTOR

A. Design

To estimate DOA or sound source location in three-dimensional space, we need three or more parameters of time difference between a direct sound and reflected sounds. So we design the shape that the three or more reflected sounds incident to microphone. The reflector we propose is concave shape, because the reflected sound is focused on the microphone position and the reflected sound level is larger compared with that of convex shape reflector.

Figure 1 shows the concave reflector we designed. Figure 2 shows the reflector we made of fiber-reinforced plastic (FRP). It is constructed by the three curved surface shape with each different curvature, and they go round while their diameter changes. Figure 3 shows the cross-section of reflector. It has six circular arc with each different radius. The radius of a curved surface changes based on angle of direction θ. Specifically $r_1 = r_{max}$ at $\theta = 0$ rad, the radius is decreasing for the increase of θ, and $r_1 = r_{max} - \Delta r/2$ at $\theta = \pi$ rad. The microphone is located at (0mm, 0mm, 350mm). We use the omnidirectional microphone.

B. Simulation

We simulated of sound field with a reflector by finite difference time domain method (FDTD) using computer to confirm the appearance of reflection. Figure 4 shows the sound pressure changes at the position of microphone and the sound pressure distribution changes. This is 2D simulation on the plane with both microphone and sound source.

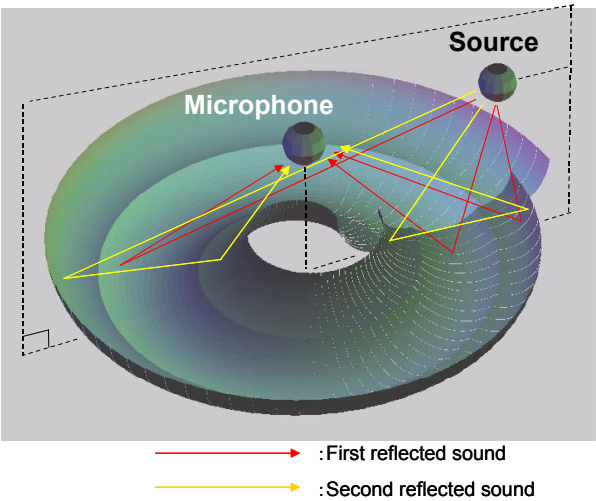


Figure 1: Design of concave curved reflector

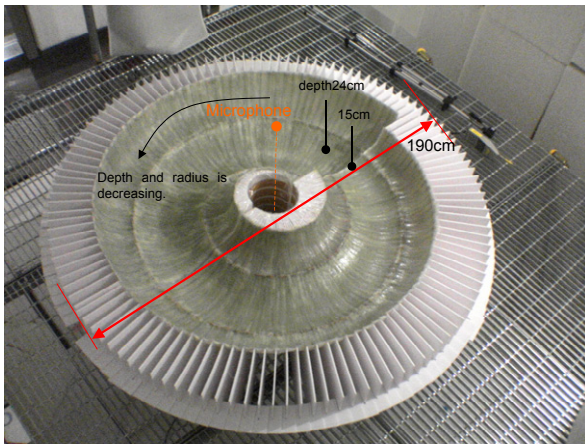
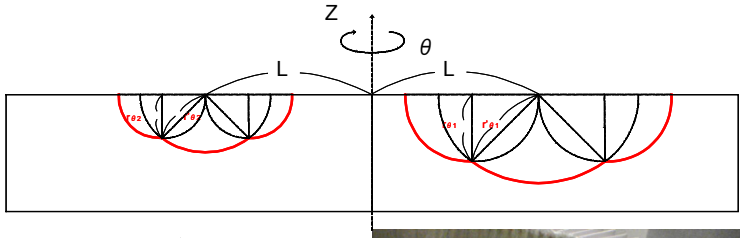


Figure 2: Concave curved reflector



$\theta\,[rad]$: angle of direction $(0 < \theta < \pi)$

r_0 : r_θ at $\theta = 0\,[rad]$ (This is the maxmum of r_θ.)

Δr : Difference between r_0 and $r_{2\pi}$ (It is Decrease of r in a round.)

L : Distance from rotation axis to center of concave surface in cross – section (It is constant for any angle.)

$$L = \sqrt{2} \cdot r_{MAX}$$

$$r_{\theta 1} = r_{MAX} - \theta \cdot \Delta r / 2\pi \qquad r_{\theta 2} = r_{MAX} - (\theta + \pi) \cdot \Delta r / 2\pi$$

$$r'_{\theta 1} = \sqrt{2}/2 \cdot r_{\theta 2} \qquad r'_{\theta 2} = \sqrt{2}/2 \cdot r_{\theta 2}$$

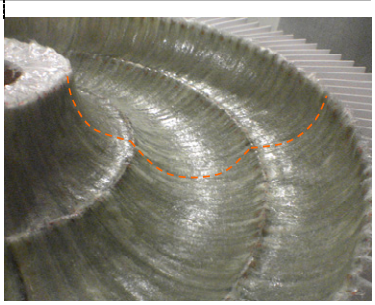


Figure 3: Cross-section of reflector

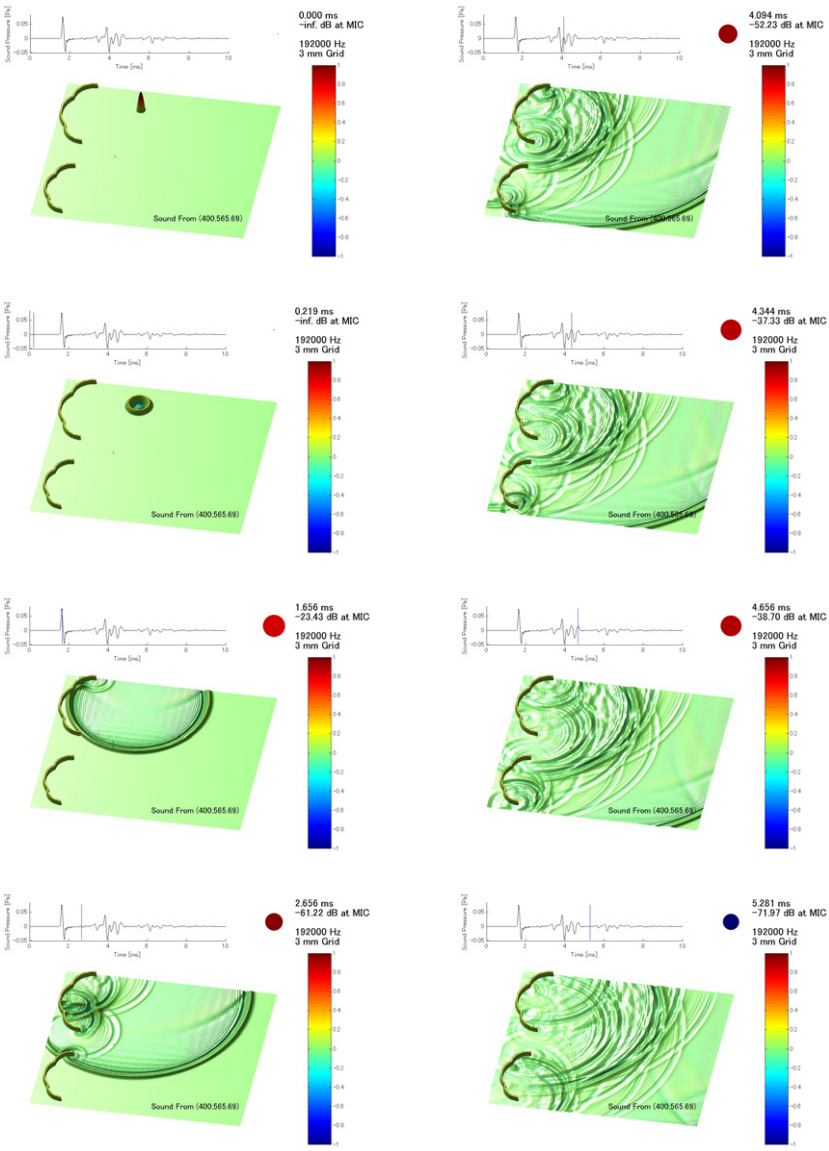
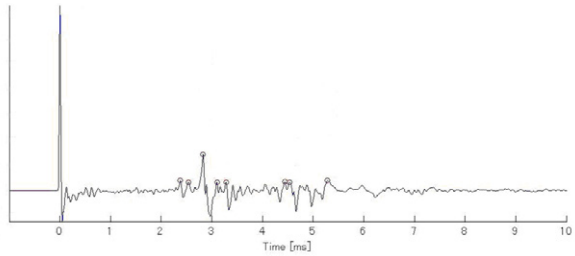


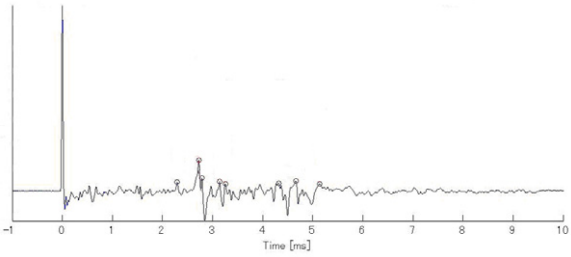
Figure 4: 2D sound field simulation

C. Reflector-Related Transfer Function

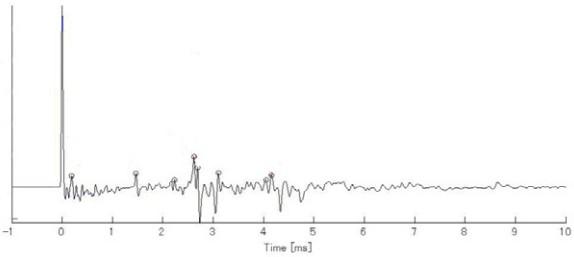
We measured the impulse responses around the reflector, i.e., RRTF. The sound source position was arranged in each 10 degrees of azimuth, and the arrangement of elevation and distance from a microphone was the following three kinds, (30degrees, 1131mm), (45degrees, 1131mm) and (45degrees, 1414mm). So the total number of source position is 108. The measurement source is spark discharge pulse. Figure 5 shows a part of the measurement results. The arrival time of the reflected sound changes slightly by the sound source location.



(a) Azimath is 30 degrees.



(b) Azimath is 90 degrees.



(c) Azimath is 150 degrees.

Figure 5: Impulse response. The distance from microphone is 1131 mm and the elevation is 45 degrees.

3. EXPERIMENTS

A. Experimental Setup

We made a database, component of which is the impulse response around the reflector, i.e., RRTF. They are template profiles. We estimate the sound source location by comparing the impulse response from the unknown source location with template profiles. Comparing is based on cross-correlation between a impulse response and template profiles.

B. Source Location Estimation

When we experimented at the case that the impulse response from unknown source location is corresponding to the component of database, we can find the true source location. Next we experimented at the case that the impulse response is not corresponding to the component of database. We use nine unknown source locations for this. Figure 6 shows a part of results. The red point in Fig.6 shows the location of microphone, the symbol "○" shows the true source location, and the symbol "①" is the estimated source location. The dots in Fig.6 show the locations at which database component was measured.

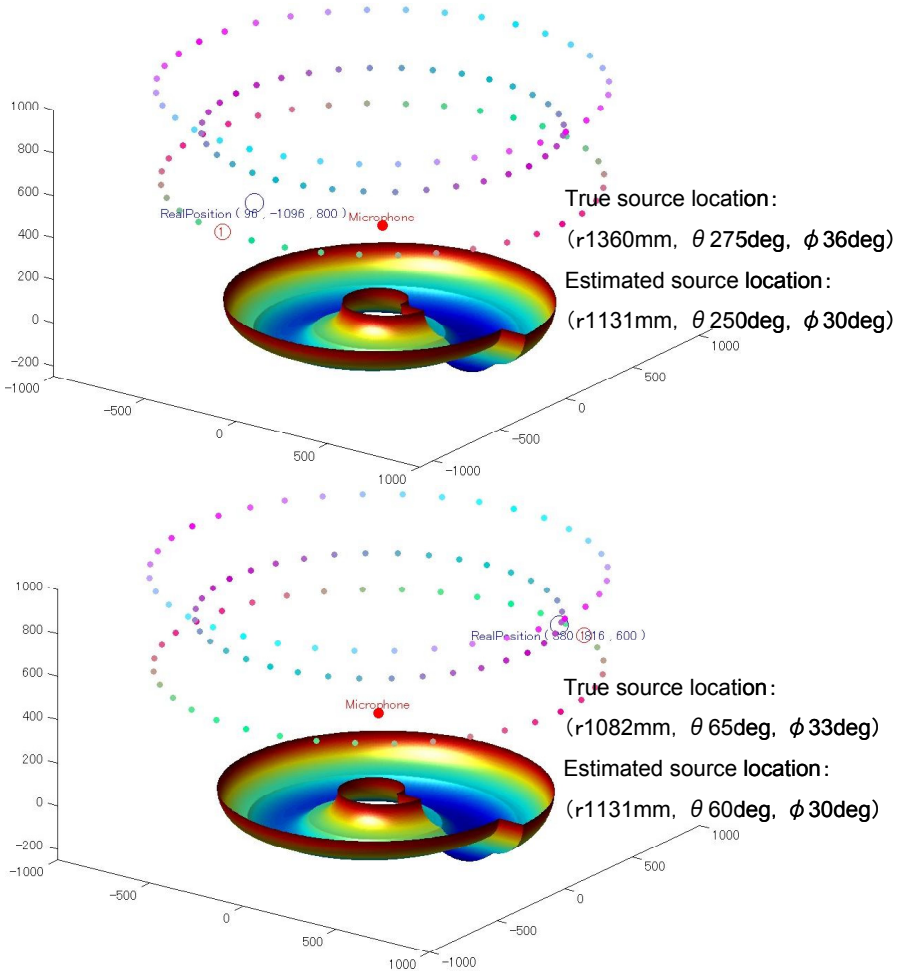


Figure 6: Results of sound source location estimating experiment

4. CONCLUSIONS

We proposed a new method of source location estimation using single microphone with reflector. We designed and made the concave curved reflector that has different impulse responses for each incident angle and distance, and then we made experiments of sound source estimation using single microphone with this reflector. We can estimate a source location for the position of which there is template impulse response in database or for the position near there. In this paper we made template impulse responses by actual measurement. We will make them for any location by numerical calculation, and estimate sound source location using them. We will also

take consideration of a moving microphone method for sound field observation such as DOA estimating or source location estimating.

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