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A Design of Reflective Audio Spot with Reflective Objects

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ABSTRACT

Two reflective objects are proposed to control the reflection and the diffusion in the use of the parametric loudspeaker. Parametric loudspeaker can emit the sound wave to a particular area because it has the sharper radiation characteristic. The area emitted by the parametric loudspeaker is called "audio spot", and the acoustic sound image is perceived on the wall, provided that the emitted sound wave arrives through the wall. The control of the reflection and the diffusion to transmit the sound wave to people through the wall is the main topic in this paper. Two reflective objects are proposed to control the reflection and the diffusion of the sound wave emitted by the parametric loudspeaker. One is the quadrilateral reflector to control the reflection and the other is the hemispherical reflector to diffuse the sound wave in all directions. The hemispherical reflector can transform the radiation pattern of the parametric loudspeaker to that of the general loudspeaker. By using the proposed objects, the listener may perceive the sound image at the position of the hemispherical reflector even if the listener moves. Objective and subjective experiments were conducted to demonstrate the effectiveness of the proposed objects. The subjects were asked whether the source localization at the wall was possible. As a result of these experiments, we confirmed that the quadrilateral reflector can control the reflection and the listener could perceive the sound image at the wall by using the proposed hemispherical reflector.

INTRODUCTION

The corn loudspeaker has been used to emit the sound wave such as the speech and the music. Emitting the sound wave to a particular are is difficult because the sound wave is emitted in all directions. On the other hand, in the museum and the station and so on, the emission to a particular area is required to transmit a person who needs an announcement. However, the interference of the sound wave by reproducing several loudspeakers is one of the problems. A method to emit the sound wave to a particular are is crucial to support these purposes.

The parametric loudspeaker with the ultrasound is useful to emit the sound wave to a particular area [1]. The acoustic sound wave emitted by the parametric loudspeaker has higher directivity such as the light beam "spotlight" and the emitted area is called "audio spot". Furthermore, the sound image is perceived at the wall area by reflecting the sound wave. We have tried to transmit the sound wave to a person by using the reflection of the wall [2]. However, the emission to a particular area is difficult, provided that there is an unwanted object on the emitted area of the acoustic sound wave.

In this paper, we propose two reflective objects to control the reflection and the diffusion of the sound wave emitted by the parametric loudspeaker. One is the quadrilateral reflector to reflect the acoustic sound wave. The other is the hemispherical reflector to diffuse the acoustic sound wave in all directions as well as the corn loudspeaker. The reflective object can transmit the sound wave to the listener through the wall even if there is an unwanted object between the parametric loudspeaker and the listener. Since the hemispherical reflector can diffuse the sound wave emitted by the parametric loudspeaker as well as the corn loudspeaker, the listener can perceive the sound image at the position of the hemispherical reflector.

Objective and subjective experiments were conducted to demonstrate the effectiveness of the proposed objects. The objective experiment was conducted by measuring the directional patterns. The subjective experiment was conducted to verify that whether the sound source localization at the wall was possible by using the proposed objects. As a result of these experiments, we confirmed that the proposed objects can control the reflection and the diffusion. Furthermore, the listener can perceive the audio image at the hemispherical reflector.

PARAMETRIC LOUDSPEAKER

Basic characteristics

The parametric loudspeaker utilizes the ultrasound wave above 30 kHz because it has higher directivity. The sound energy of the parametric loudspeaker is slowly attenuated with distance [3]. The emitted ultrasound wave is demodulated into the audible sound wave based on the nonlinear

interaction between the intense amplitude modulated ultrasound waves in the air [4], [5]. Since the emitted ultrasound wave has the higher directivity, the demodulated audible sound also has the same feature. Figure 1 illustrates the radiation pattern of the parametric loudspeaker and that of the corn loudspeaker.

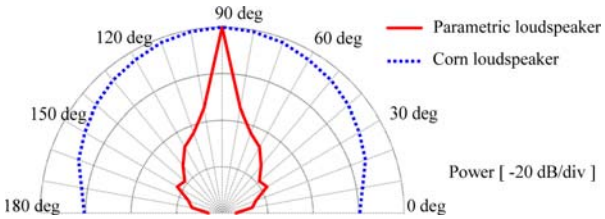

Figure 1. The directional pattern of the parametric loudspeaker and that of the corn loudspeaker.

Furthermore, as the sound wave emitted by the parametric loudspeaker is not diffracted, it provides specular reflective performance. The parametric loudspeaker can transmit the audible sound to the particular area through the wall, and the emitted area is called “audio spot”.

PROPOSED OBJECTS

Problems of the parametric loudspeaker

The parametric loudspeaker has been utilized in various kinds of places for the spoken guidance system. The emission to only the person is essential because sound wave concurrently emitted by several loudspeakers is disagreeable to the ear. Although the parametric loudspeaker can emit the sound wave to a particular area, the person that is at intermediate position between the position of the parametric loudspeaker and that of another person can also hear the sound wave. In this paper, the reflection is utilized to overcome this problem.

The other problem is that the parametric loudspeaker cannot diffuse the sound wave as well as the corn loudspeaker. A lot of parametric loudspeakers are utilized to diffuse the sound in all directions. Therefore, a technology to use the parametric loudspeaker as well as the normal loudspeaker may be useful.

Proposed reflective objects

Two reflective objects shown in Fig. 2 are proposed to control the reflection and diffusion of the sound wave. The left illustrates the quadrilateral reflector to reflect the sound wave, and the right illustrates the hemispherical reflector to diffuse the sound wave. The sound reflects by using the quadrilateral reflector, provided that the incident angle is far from 90 deg. The sound wave diffuses by using it, provided that the incident angle is 90 deg. The hemispherical reflector can diffuse the sound wave without the dependence of the incident angle.

In this paper, the objective and subjective experiments are conducted to verify the effectiveness of the proposed objects.

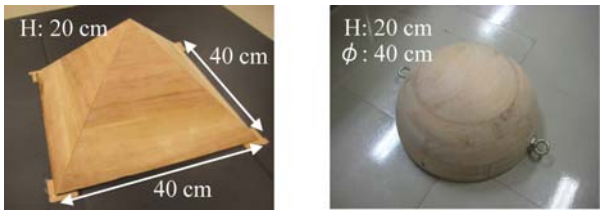

Figure 2. Refective objects. Left: quadrilateral reflector to reflect the sound wave. Right: hemispherical reflector to diffuse the sound wave.

EXPERIMENTS AND REDULTS

The objective experiment is conducted to verify whether the proposed object can control the reflection and the diffusion. The subjective experiment is conducted to verify whether the listener can perceive the sound image at the position of the proposed objects.

Objective experiment

The experimental conditions are shown in Tab. 2. TSP [6] is utilized to observe the reflective sound wave because the direct sound wave interrupts the measurement of the sound energy of the reflective sound wave. The energy of the reflective sound is easily calculated based on the estimated impulse response. The angle of incidence is 90 deg. and 60 deg. as shown in Fig. 3.

Table 1. Conditions for the recording

Parametric loudspeaker	MITSUBISHI, MSP-50E
Microphone	HOSHIDEN, KUC-1333
Loudspeaker amp.	YAMAHA, P2500S
Microphone amp.	YAMAHA, MA-2016
Recording condition	16.0 kHz, 16 bit
Temperature	25 deg C
Ambient noise level	19.0 dBA

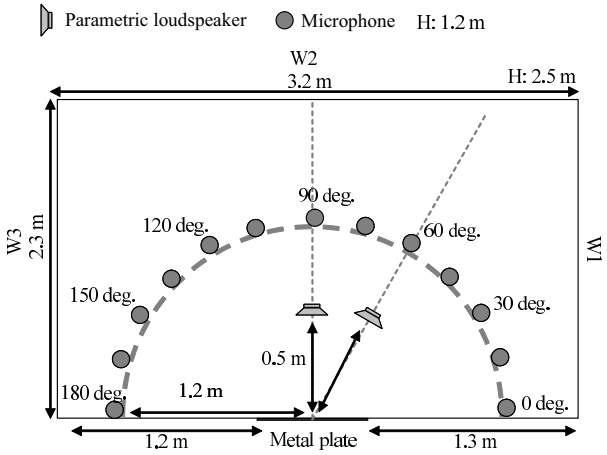

Figure 3. The arrangement of the parametric loudspeaker and the microphones.

Results

The directional pattern is illustrated in the Fig. 4 and 5. The solid lines represent the directional pattern without the proposed objects, the dotted line represents the directional pattern with the quadrilateral reflector and the chained line represents the directional pattern with the hemispherical reflector.

In Fig. 4, the specular reflection is observed by using the parametric loudspeaker. Although the quadrilateral reflector can control the reflection, the spread in the angle around 135 deg. is observed. The hemispherical reflector can diffuse the sound wave in all directions.

Figure 5 suggests that the proposed objects can reflect the sound wave and the diffuse the sound wave. The quadrilateral reflector is more effective than the hemispherical reflector in the case of right and left diffusion, provided that the incident angle is 90 deg. On the other hand, the hemispherical reflec-

tor can evenly diffuse the sound wave in all direction. This result suggests that the proposed objects can partially control the reflection and the diffusion.

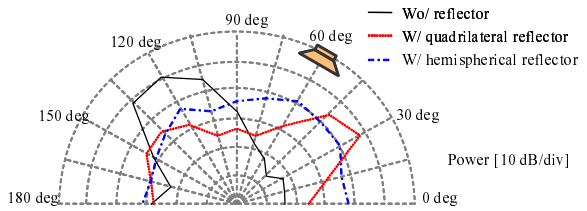

Figure 4. The directional patterns by using the proposed objects (The angle of incidence is 60 deg.)

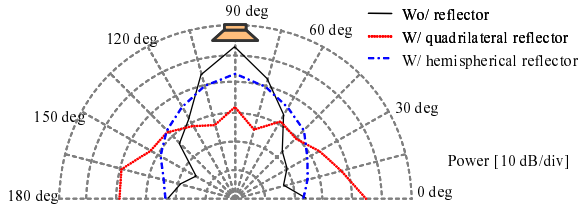

Figure 5. The directional patterns by using the proposed objects (The angle of incidence is 60 deg.)

Subjective experiment

Subjective experiment is conducted to verify the perceptive differences. The assessment points are set as shown in Fig. 6. The subject points at the referencing point. The parametric loudspeaker is set at the 90 deg. and 60 deg. Three conditions (without object, with the quadrilateral reflector and with the hemispherical reflector) are utilized in the experiment. The corn loudspeaker and the parametric loudspeaker are used to compare the perceptive differences. The subject is asked to answer the position at the perceived sound image. In this experiment, the subject should answer that the sound image is 0 deg. because the reflective position is the referencing point and the subject is pointing at it.

The MOS (Mean Opinion Score) is utilized as the evaluation index. Six students are participated in this experiment. The sound wave used for the experiment is the white noise.

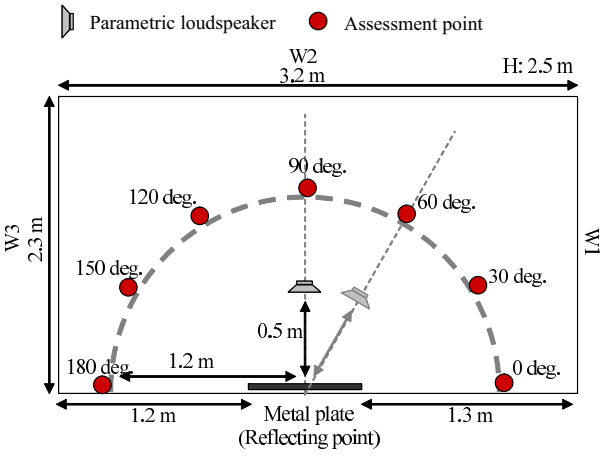

Figure 6. The assessment points for the experiment. The subjects points at the referencing point.

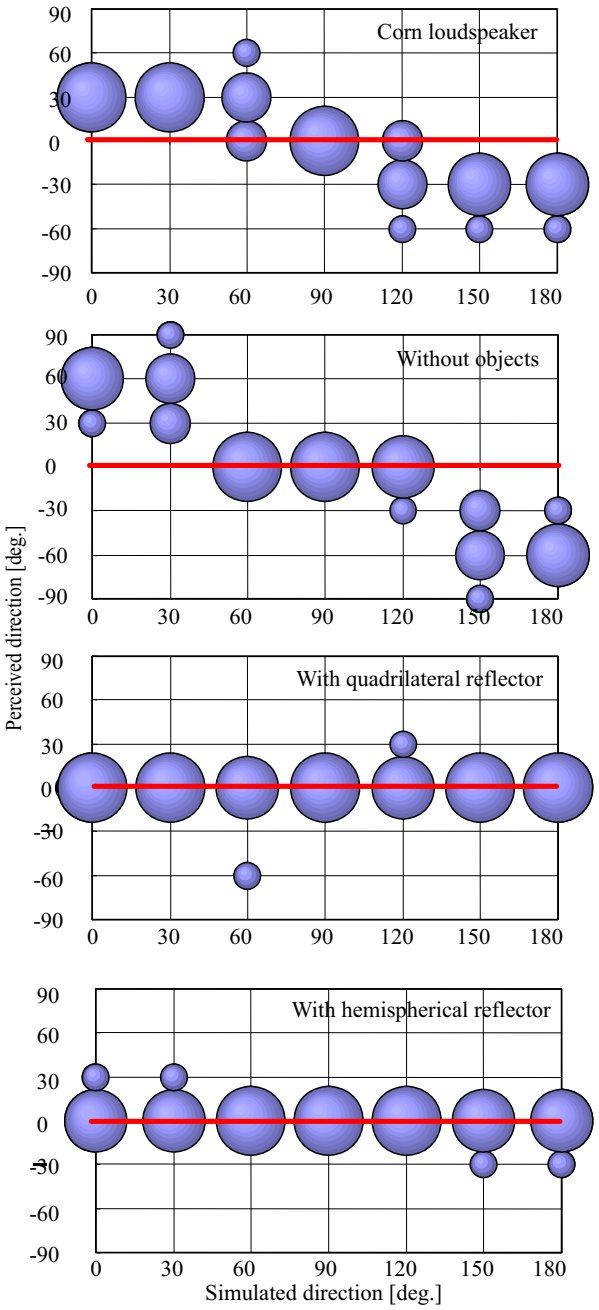

Figure 7. The result in the subjective experiments. Each loudspeaker is set at the 90 deg.

Results

Figure 7 and 8 illustrate the results in the subjective experiment. Figure 7 represents the result that the each loudspeaker is set at the 90 deg. Figure 8 represents the result that the each loudspeaker is set at the 60 deg. The horizontal axis represents the simulated direction [deg.] and the vertical axis represents the perceived direction [deg.]. The solid line illustrates the ideal result because the subject is pointing at the referencing position.

The corn loudspeaker and the parametric loudspeaker without objects cannot create the sound image at the referencing wall as shown in Fig. 8. The loudspeaker position is perceived as the sound image. The parametric loudspeaker with quadrilateral reflector and the hemispherical reflector can create the sound image at the referencing wall. This result suggests that the proposed objects are useful to control the diffusion of the sound wave emitted by the parametric loudspeaker.

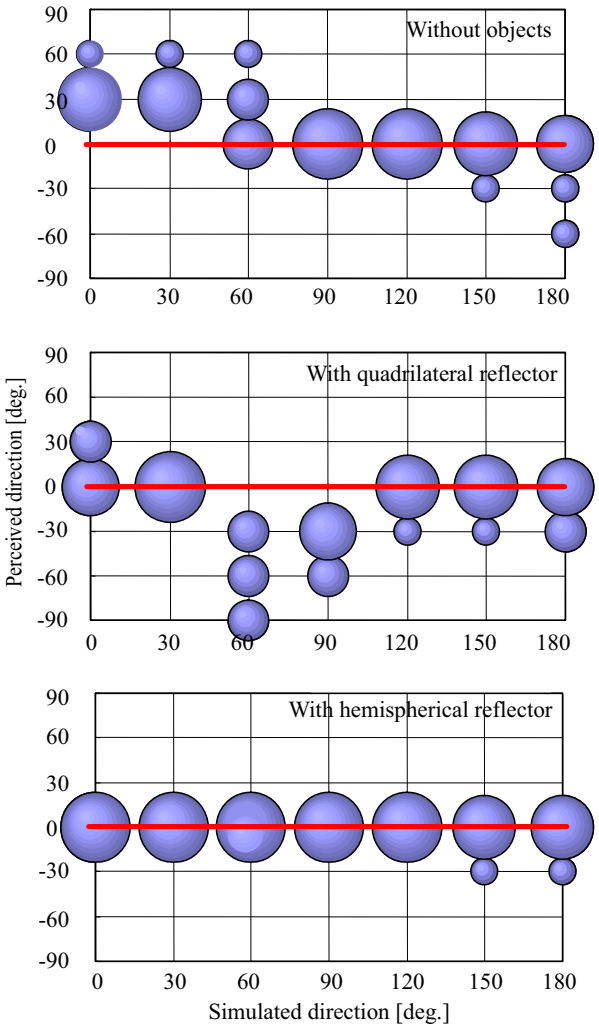

Figure 8. The result in the subjective experiments. Each loudspeaker is set at the 90 deg.

The parametric loudspeaker without objects and that with the quadrilateral reflector cannot create the sound image at the referencing wall as shown in Fig. 8. This is because the quadrilateral reflector reflects the sound wave, provided that the incident angle is far from 90 deg.

The hemispherical reflector can create the sound image at the referencing wall. Therefore, these results suggest that the control of the reflection and the diffusion is achieved by the proposed method.

DISCUSSIONS

Result about the comparison between the corn loudspeaker and the parametric loudspeaker

The sound image position depends on the assessment point in the case of the use of the corn loudspeaker. It suggests that the subject answered the position at the loudspeaker in these conditions. Therefore, the corn loudspeaker cannot create the sound image at the wall. The parametric loudspeaker without objects can create the sound image, provided that the assessment point is the area emitted through the wall. However, the creation of the sound image was difficult because the sound wave emitted by the parametric loudspeaker cannot diffuse.

Result about the parametric loudspeaker

Although the quadrilateral reflector can control the reflection as Fig. 4 and 5, the diffusion of the sound wave was difficult, provided that the incident angle is far from 90 deg. On the other hands, the hemispherical reflector could control the diffusion of the sound wave. The result of the subjective experiment suggested that the subject could perceive the sound image at the wall. Therefore, experimental results suggested that the proposed objects could effectively control the reflection and diffusion

The creation of the sound image at the wall is one of the most important topics in our future research. The other reflective objects are required to cope with the problem. The subjective experiments to perceive the sound image will also be conducted in our future research.

CONCLUSIONS

The reflective objects to control the reflection and the diffusion were proposed in this paper to emit the sound wave through the wall. The parametric loudspeaker cannot emit the sound wave, provided that there is an object that is at intermediate position from the parametric loudspeaker to the listener. The quadrilateral reflector is utilized to overcome this problem by controlling the reflection. Furthermore, although the parametric loudspeaker can emit the sound wave to a particular area, it cannot diffuse the sound wave as well as the conventional loudspeaker. The hemispherical reflector was proposed to diffuse the sound wave in all directions.

The objective and subjective experiments were conducted to verify the effectiveness of the proposed method. The result suggested that the proposed objects can control the reflection and the diffusion.

ACKNOWLEDGEMENTS

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