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ROBUST SOUND-REPRODUCTION-SYSTEM DESIGN AGAINST THE HEAD MOVEMENT

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ABSTRACT

This paper proposes a new sound field reproduction system. Multi-channel sound field reproduction is one of the most promising methods to realize a sound reproduction system robustly against a head movement. Multi-channel sound field reproduction can reproduce the same acoustic field as the recording area by using several controlled points. However, such sound field reproduction systems have not been developed due to poor understanding of the behavior of multiple channel systems. In this paper, we first investigate the accuracy of the reproduced sound of a multi-channel sound reproduction system. In particular we investigate the optimal loudspeaker arrangement and the optimal number of controlled points using computer simulation. We also construct a multi-channel sound field reproduction system which can reproduce the sound within the wide reproduced area around the listener's head. As a result, good sound localization is realized by arranging loudspeakers around the controlled field.

KEYWORDS: sound-reproduciton system, least-norm-solution, inverse filter, source's arrange

INTRODUCTION

Thurlow, 1967, was the first to show that people can localize sound sources better if they can move their heads rather than have their heads fixed[1]. In general, the transaural system, which is one of sound reproduction system, is assumed to be time invariant. Therefore, a conventional transaural system does not allow the listener to change their head position. Accordingly, a transaural system with a fixed head can not produce exact sound localization more than natural listening with head movement. To obtain the exact sound localization, we attempt to construct the acoustical the sound field reproduction system which is equal to the primary sound field around the listeners' heads using many controlled points and loudspeakers. In this paper, we investigate the accuracy of reproduced sound by calculating the difference between the arrangement of loudspeakers for the sound field reproduction system. We also construct a multi-channel sound field reproduction system, to evaluate the horizontal sound localization using subjective tests.

COMPUTER SIMULATIONS

Calculating Conditions. As shown in Fig.1(d), we assume that the primary field is 4.5m

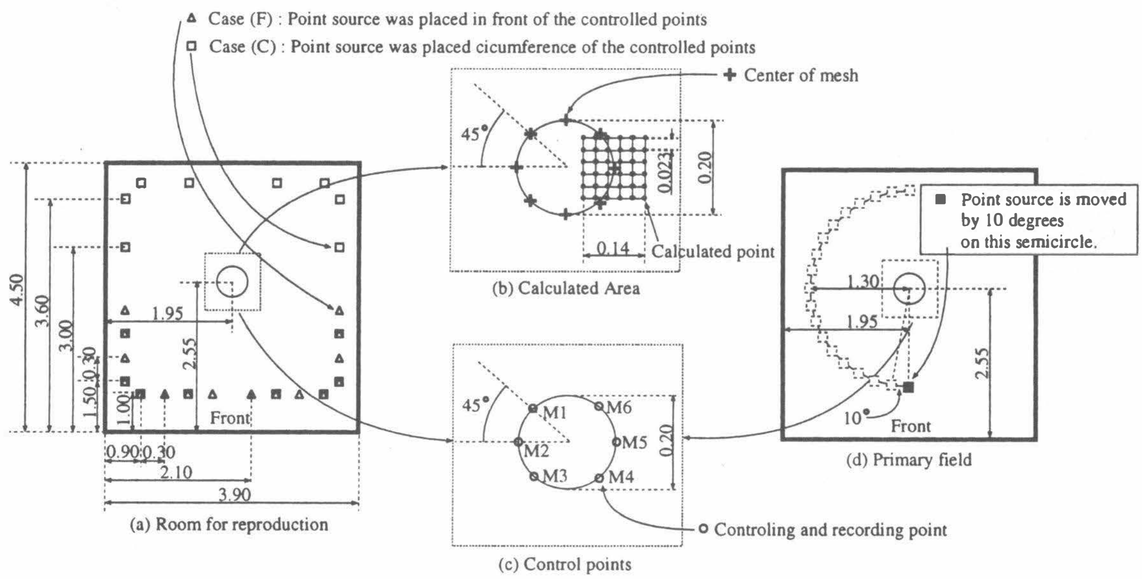


Fig.1 Calculating conditions

long, 3.9m wide and 0.1 reflectivities, using 16 loudspeakers for the reproduction. As Fig.1(c), six recording points of M1 through M6 are placed on a circle of 0.1m radius. Primary sound signals are sound pressure at the recording points in the frequency range of 150Hz to 800Hz when the sound source was set on the primary field. The sound source was moved, 10 degrees at a time from 0 degrees to 180 degrees as shown in Fig.1(d). The controlled points in the room for reproduction were placed in the same position corresponding to the six recording points in primary field as shown in Fig.1(c). We examine the case of 16 reproduction loudspeakers placed in front of the controlled points which were denoted by 16 triangle (Case (F)) in Fig.1(a). We also examine the case of 16 loudspeakers placed in a circumference around the controlled points denoted by 16 squares (Case (C)) in Fig.1(a). We designed the inverse system between the loudspeakers and the controlled points in the frequency domain using the least-norm-solution[2].

Results. As shown in Fig.1(b), the calculation points were on the lattice point of 8 square mesh, which were set on a circle of 0.1m radius in Fig.1(b). Finally, we calculated the accuracy using the follows equation. Fog.2 shows the calculation results for all the loudspeaker arrangements. The horizontal axis shows the angle, and the vertical axis shows the accuracy E_θ. The accuracy lowers, as the azimuth exceed 100 degrees in case (F, 'Front'). In the case (C, 'Circumference'), the accuracy around 22dB was obtained. These results show that not only the sound pressure in the primary field corresponded to the sound pressure in the reproduced field, but also that the wave

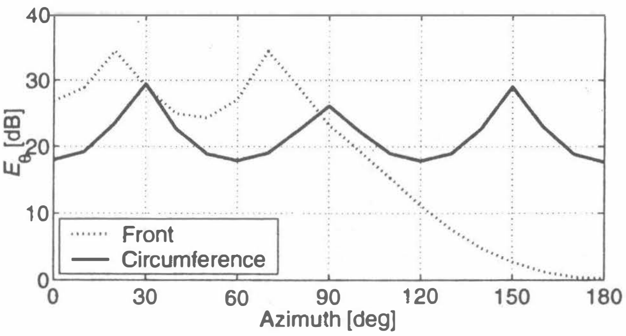


Fig.2 Result of computer simulation

form for the reproduced field, which corresponded to the wave of primary sound signal, could be produced around the controlled points. These results show that the arrived direction of the primary sound signal didn't influence the accuracy of the reproduced sound in the case of the circumference loudspeaker arrangement.

SUBJECTIVE TESTING OF THE HORIZONTAL SOUND LOCALIZATION

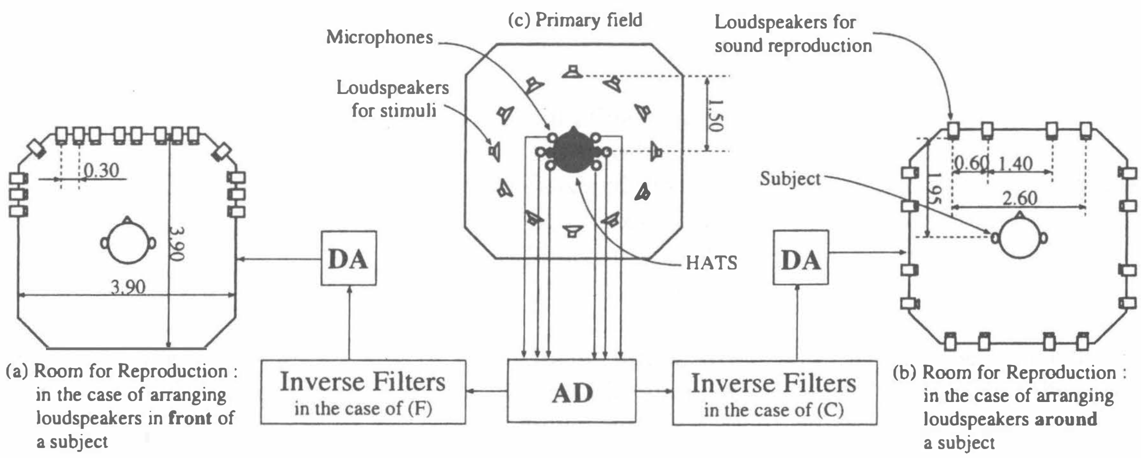
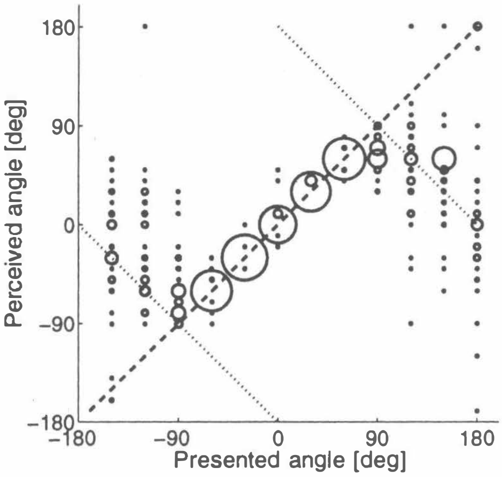


Fig.3 Arrangement of the loudspeakers and microphones

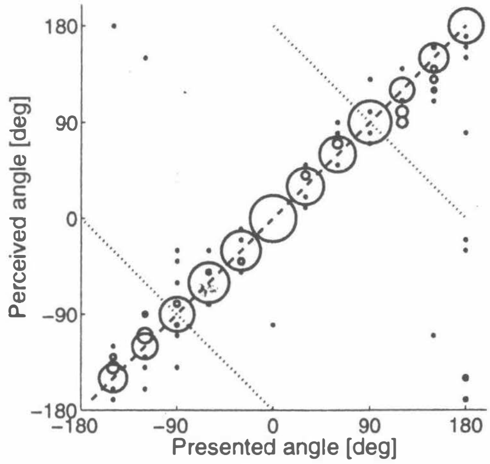
Inverse Filter Design. We measured the impulse response between 16 loudspeakers for reproduction and 6 microphones, that is 6 controlled points, which were put on a surface of the HATS in Fig.3(a) and 3(c). The inverse filters were designed from these impulse responses using the least-norm-solution[2].

Stimuli. Speech of an English male speaker, and an orchestral music which was recorded in anechoic room, were used as primary sources. We assumed these sounds arrived from one of 12 directions within circumference, as shown in Fig.3 Stimuli were made by filtering the primary sound using an inverse filter. The sampling frequency was 48kHz, quantized to 2^{16} levels, and the stimuli were filtered to the range 150-4000Hz using a band pass filter.

Experimental Conditions. Ten male subjects with normal hearing took part in a single half-



Case (F): Front



Case (C): Circumference

Fig.4 Experimental results

an-hour session. Subjects were presented two cases of stimulus sound; the reproduction sounds from 16 loudspeakers for reproduction (Fig.3(a) and 3(b)) and a primary sound output from one of the 12 inside loudspeakers in Fig.3(c). Each stimulus was presented twice. The subjects were allowed moving their heads to confirm the direction. The subjects marked the perceived direction on the testing papers.

Results. Fig.4 shows the experimental results for all the subjects. The horizontal axis shows the presented direction and the vertical axis shows the perceived direction. The center of each circle represents the perceived direction. The circle sizes show the frequencies perceived by all subjects. The circles are plotted against the vertical axis in 10 degree steps. A diagonal dashed line shows the perceived direction, which agrees with the provided sound direction. Two reverse diagonal dotted lines show the cases where the perceived direction can reflect across the median plane. In case (F), subjects couldn't be perceived the sound arriving from backward of subjects. On the other hands, in the case (C), the backward sound localization was reproduced exactly. Moreover, the error of reflecting across the median plane did not exist. These results show that we can make a multi-channel sound field reproduction system which allows moving the listener's head. Moreover, we show that the system had a good localization by placing the loudspeakers circumference of listener.

CONCLUSIONS

A sound field reproduction system design robust against the rotational head movements could be designed using 16 loudspeakers and 6 controlled points by placing the loudspeakers around the controlled fields. In future work, we need to investigate the influence of the spatial arrangement of the controlled points.

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