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NOISE CONTROL FOR A BETTER ENVIRONMENT

Sound field reproduction applicable to noise control engineering

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ABSTRACT

We have conducted examinations about multi-channel sound field reproducing systems using the boundary surface control principle and its simplified versions. In the process of practical development, it is often attempted to evaluate the performance using a demonstration and experiments based on subjective evaluations. In the demonstrations, musical sound recorded in concert halls and the traditional arts-rich sound is often preferred. However, contents such as the road traffic noise or the jet noise showed a high sense of reality and got a good evaluation. These facts suggested that the sound field reproduction is not only reproducing artistic sound field but can be a good simulator of noise field. We currently assume four hypotheses for the higher total performance of the reproducing system; (A) physically assured reproduction; (B) the robustness for external disturbance such as the existence of listener; (C) a space to accept additional direction; (D) a capability to integrate with visual information. For example, the possibility of additional direction (C), would be useful in the simulations of the noise environment. Several examinations about a sense of reality and proposal of noise simulator are shown.

Keywords: Sound Field Reproduction, Multi-channel Reproduction
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

The sound field reproduction system can be roughly classified into two categories. The first is a system that reproduces an arbitrary sound field by using some kind of physical principles and the techniques. The second is creating the desired sound field mostly with artistic manipulations of sound images by using well-established techniques such as amplitude panning or equalizing.

These techniques are often referred to as scientific or engineering, and artistic or aesthetic methods and these are mostly described with different contexts. However, there are many complementary parts between them. The typical example is that the wave-based reproduction methods are good at low-frequency range where the control of the sound image is difficult by panning. The higher performance is therefore expected by the hybrid usage of these different schemes [1].

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Based on these ideas, we are currently seeking the sound field reproduction system with the assumption that the higher performance could be achieved by satisfying the following four hypotheses; (A) the system has some physical background for reproduction; (B) the system is robust against inevitable disturbances due to the existence of listeners, for example; (C) the system can accept the additional directions such as the artificial movement of sound images or changes of frequency characteristics, reverberation and so on; (D) the system can be integrated with visual information.

Particularly, the condition (C), accepting the additional direction, might be useful for noise control-related applications. For example, while playing back a sound field, such as a car cabin, where the noise reduction is aimed, the practical simulation is achieved by changing a position of the main noise, or by changing the distribution of noise level.

Previously, the quantitative and qualitative evaluations were mostly carried out by the environments in which recorded by dummy-head and reproduced with headphones. The simulation with the multi-channel system can revitalize the sound field situations much more realistically by surrounding the listeners from various directions. Practical proposal of the system and the examples of effects of additional direction are shown with several recorded contents, in this report.

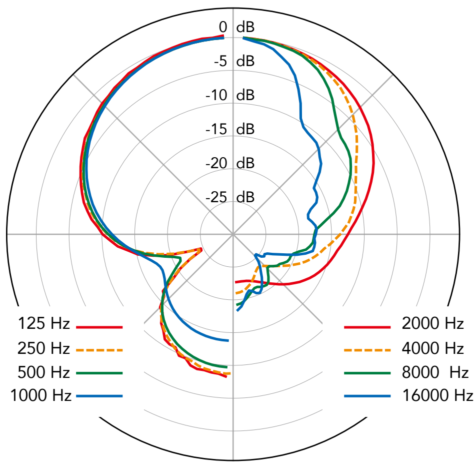
2. PLATFORM FOR EXAMINATION

2.1 Sound field capturing and reproducing devices

The 24-channel narrow directional (shotgun) microphone array is used as sound field capturing device. The appearance of hedgehog-shaped array is shown in Fig. 1 (a). All microphones are arranged at every 45º in azimuth and elevation angles. In Fig. 1 (b), the directional characteristics is shown. The characteristics is broadly uni-directional until 1kHz and the narrower for higher ranges. The minimum distance between adjacent acoustic center of microphones is roughly 0.2m.

As a sound reproducing device, 24-channel loudspeakers are used, in which the loudspeakers are arranged at every 45º in azimuth angle and in three layers in height. This stacked-ring layout system is set in relatively dead space and the appearance is shown in Fig. 2.

(a)



(b)

Fig. 1: *24-channel hedgehog shaped microphone array, (a) the appearance, (b) the directional characteristics.*

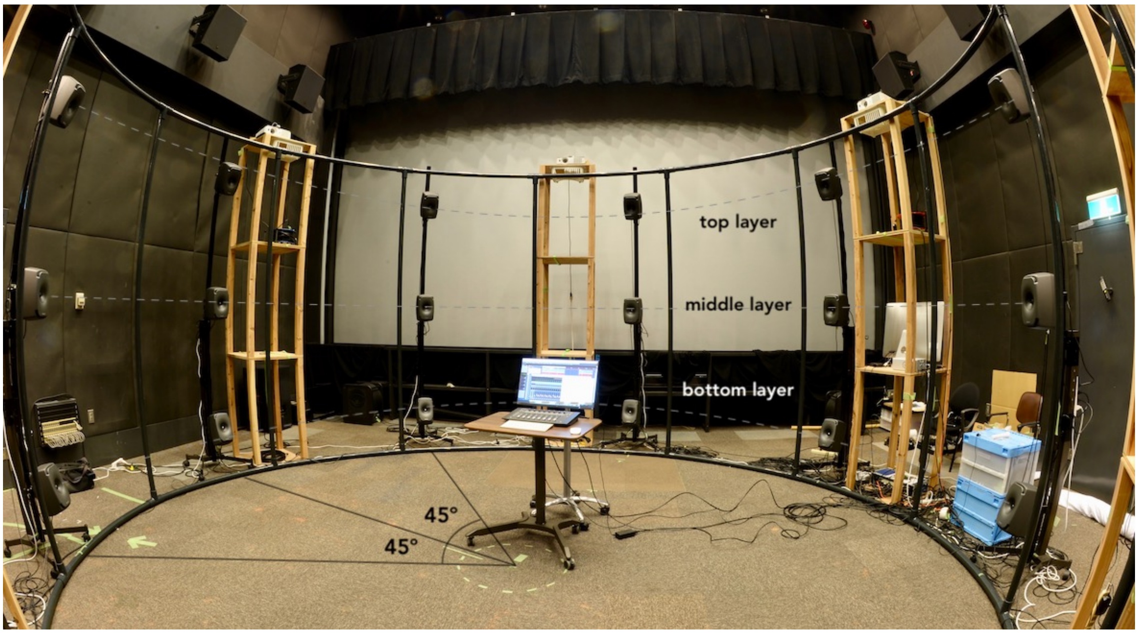


Fig. 2: *24-channel loudspeaker array for reproduction, in which the speakers are arranged at every 45° azimuth angle and stacked-ring layout in three layers.*

Signals are usually recorded and reproduced by using Digital Audio Workstation (DAW) software and AD/DA devices connected with MADI. The common plug-in software can, therefore, be applied to each signal for appropriate modification.

2.2 Reproduction methods

Several methods are usually used for reproduction. The first one is based on the boundary surface control principle [2] (BoSC hereafter). The distribution of sound pressure at the surface of the microphone array captured in the recording (primary) field would be reproduced by the signals emitted by the loudspeakers. The transfer characteristics in the reproducing (secondary) field must be cancelled by the inverse filtering. Although this principle works as theoretically expected by reproducing the distribution of sound pressure captured by omnidirectional microphones, the practical validity of using directional microphone is known [3].

The second reproduction method is a simple and direct one (Direct hereafter). The signals recorded by each directional microphone is reproduced from the loudspeaker located at almost corresponding direction. No specific processing such as inverse filtering is applied for reproduction, except for the time alignment for each loudspeaker and microphone combination. This method reproduces the directional information owing to the directivity of the microphones. This can be interpreted as an extension of a previously proposed six-channel system [4] and the simplified version of a series of the reproducing method using the directional information and the amplitude panning [5-10].

The BoSC can reproduce the wave information as much as possible especially for low frequency. Since the minimum microphone distance of microphone is around 0.2m, the upper limiting frequency for special aliasing is around 850Hz at which the wavelength is 0.4m. At the higher region, accurate reproduction cannot be assured. Also, the reproduction area would be restricted to the size of the microphone array, and the final performance would strongly depend on the design method of the inverse filter.

On the other hand, the second method, the Direct, reproduce the directional information moderately and does not have severe restrictions. The relatively broad directional characteristics at low frequency might limit the effective frequency to the higher range. However, the simplicity of the reproduction structure is attractive for the additional direction, since it does not adjust the sensitive relationship between signals emitted from plural loudspeakers. We, therefore, adopt this Direct reproduction for further examination of additional direction in this manuscript.

We currently assume that the above mentioned two methods would be suitable for the sound field reproduction especially for the applications of noise control. As for the other applications, there is an alternative method, which utilizes the directional impulse responses (i.e., including the information of reflections from certain direction) to generate sound signals emitted by each loudspeaker. The directional impulse responses can be measured in the desired primary sound field by using the hedgehog microphone array. These responses would include the information of the reflections mainly coming from the directions of the axis of each microphone. These are convoluted with a monaural or conventional stereo source signals and simulate the primary field. This is also simple and effective method. However, the detailed examination is not shown here.

3. ADDITIONAL DIRECTION IN REPRODUCTION

By using the above-mentioned system, several kinds of sound contents were recorded. The effect of additional direction on the listener's impression was then examined by subjective evaluation.

If the additional direction that improves (or worsen) the impressions of the sound and sound field becomes clear, it might be easier to design the countermeasures to cope with them. This might be an important and effective usage of the sound field reproduction for noise control engineering.

3.1 Example of additional direction

An example of the rock music performance by student's band is shown here. The sound field of the small-sized auditorium (in the university campus) was captured for 30 seconds during their play. Since the auditorium was not originally designed for playing music, the frequency characteristics and the structures of reflections were insufficient. These drawbacks might be complemented by the directions.

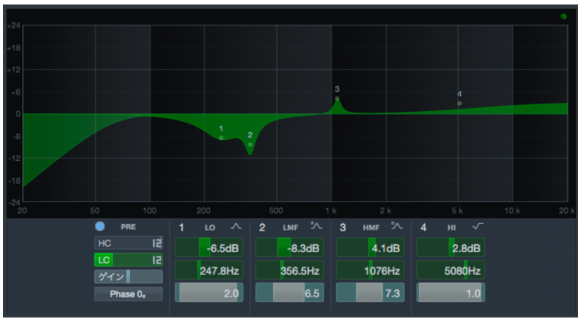


Fig. 3: *Snapshot of equalizer used for modification.*

As the practical examples of additional directions, the equalization using parametric equalizer plugin, and the alternation of the balance of sounds coming from the front, were attempted. Fig. 3 shows the snapshot of equalizer. The levels of sounds emitted from the three front loudspeakers, located in the middle layers and the front and ± 45º, were boosted 10 dB for altering the balance.

3.2 Subjective test

The subjective evaluations based on MUSHRA (Multiple Stimuli with Hidden Reference and Anchors) were carried out. In our evaluation, the originally recorded signals were used as the reference, instead of the anchor sound that usually assumed in the normal MUSHRA. Total 17 subjects were asked to evaluate the following terms within 0 to 100 score range;

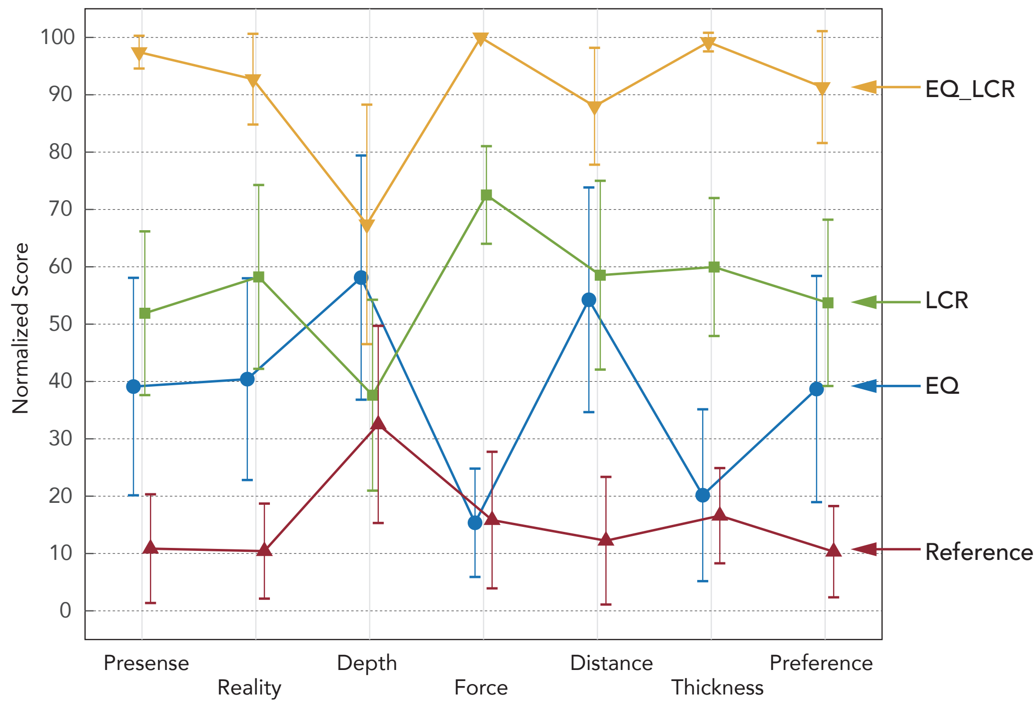


Fig. 4: *Normalized score obtained in the subjective evaluation.*

- Presence (as if you are at the venue)
- Reality (as if the object exists in front of you)
- Depth (can recognize the field as three-dimensional or not)
- Force (strength of sounds)
- Distance (can recognize the distance to the sound source or not)
- Thickness (thickness of sounds)
- Preference (overall preference)

Figure 4 indicates the results. The equalization (EQ in the figure) applied to compensate the insufficient frequency characteristics were effective to improve the Presence, Reality and Distance. The altering the level (LCR in the figure) were also effective for all terms except for the Depth. Using both operation (EQ_LCR) was most effective and the highest scores were obtained for all terms.

Fig. 5: Hedgehog microphone in a car cabin

3.3 Another example

As described above, even in a system whose basic objective is to reproduce a sound field, the impression of the listener could be actively changed by adding some effects during playback. This function includes possibilities applicable to various noise control applications. Also, this might be effective for acoustic design. Especially the advantages of using a multichannel system is the possibility of manipulating the spatial information. In the experiment shown in this manuscript, the manipulation was limited to simple level amplification of the front sound.

As another example, there is a simulation of noise in the passenger compartment of a car. As shown in Fig. 5, the noise was recorded by 24 channel microphone in the passenger compartment of a car. While reproducing that sound by the Direct method, sounds caused by various reason, such as noise due to the vibration or wind noise near the pillars, and recorded separately can be mixed to the arbitrary loudspeakers. A very simple demonstration to reproduce such situation was carried out for the engineer of the carmaker and the effectiveness was confirmed by the interviews.

4. CONCLUSIONS

This report introduced the example which used a sound field reproducing system for noise control. By using the reproduction technique that is not too strict and also by using appropriate numbers of acquiring and reproducing devices, a sound field reproducing system can be used as a tool for noise control effectively. As for such applications, examination is carried out sequentially.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. H. Kashiwazaki, A. Omoto, "*Sound field reproduction system using narrow directivity microphones and boundary surface control principle*," Acoust. Sci. & Tech. **39**, pp.295-304 (2018).
2. S. Ise, "*A principle of sound field control based on the Kirchhoff-Helmholtz integral equation and the theory of inverse systems*," Acta Acoust. Acustica, **85**, pp.78-87 (1999)
3. T. Kimura, K. Kakehi, "*Effects of Microphone and Loudspeaker Directivity on Accuracy of Synthesized Wave Fronts in Sound Field Reproduction with Wave Field Synthesis*," Trans. Virtual Reality Soc. Jpn, **12**, pp. 191-198 (2007), (in Japanese).
4. S. Yokoyama, K. Ueno, S. Sakamoto and H. Tachibana, "*6-channel recording/reproduction system for 3-dimensional auralization of sound fields*," Acoust. Sci. & Tech., **23**, 97– 103 (2002).
5. J. Merimaa and V. Pulkki, "*Spatial impulse response rendering I: Analysis and synthesis*," J. Audio Eng. Soc., **53**, 1115–1127 (2005).
6. V. Pulkki and J. Merimaa, "*Spatial impulse response rendering II: Reproduction of diffuse sound and listening tests*,"J. Audio Eng. Soc., **54**, 3–20 (2006).
7. V. Pulkki, "*Spatial sound reproduction with directional audio coding*," J. Audio Eng. Soc., **55**, 503–516 (2007).
8. J. Vilkamo, J. Vilkamo, T. Lokki and V. Pulkki, "*Directional audio coding: Virtual microphone-based synthesis and sub- jective evaluation,*" J. Audio Eng. Soc., **57**, 709–724 (2009).
9. S. Tervo, J. Patynen and T. Lokki, "*Acoustic reflection localization from room impulse responses*," Acta Acust. united Ac., **98**, 418–440 (2012).
10. S. Tervo, J. Patynen, A. Kuusinen and T. Lokki, "*Spatial decomposition method for room impulse responses*," J. Audio Eng. Soc., 61, 17–28 (2013).