Acoust. Sci. & Tech. **27**, 3 (2006)

ACOUSTICAL LETTER

Visualization of reflected sound in enclosed space by sound intensity measurement

Yoshinari Fukushima*, Hisaharu Suzuki† and Akira Omoto‡

Faculty of Design, Kyushu University,
Shiobaru 4–9–1, Minami-ku, Fukuoka, 815–8540 Japan

(*Received 15 December 2005, Accepted for publication 27 December 2005*)

Keywords: Physical parameters, Room acoustics, Sound intensity, Visualization
PACS number: 43.55.Mc, 43.58.Fm [DOI: 10.1250/ast.27.187]

1. Introduction

There are many physical parameters in examining the quality of a large sound field such as a concert hall. Some of them have already been adopted in the annex of ISO [1]. There are some discussions also on small enclosures such as recording studios [2–6]. However, the widely used 'common parameters,' such as C_{80} and EDT, have not been established yet. On the other hand, the several early reflections have great importance in a small enclosure when determining the special impression and the timbre, as reported in references [3–5]. We believe, a detailed examination of the structure of early reflections may reveal the effective parameters. In reference [7], the use of the echo diagram of instantaneous and envelope intensities was introduced for such purposes. Our report can be categorized as a proposal of a processing method of the measurement results shown in [7]; that is the visualization of the dominant reflections using sound intensity.

There are well-developed methods, proposed more than ten-years ago, which indicate the structures of the reflections [8,9]. However, the method of visualization is still a subject of current discussion [10,11]. In our previous reports [12,13], the arrival direction of large reflection sounds were projected onto a wire-frame rectangular enclosure model of a real enclosure. In this report, a more intelligible method of using photos of the enclosure is introduced.

2. Sound intensity measurement system

As introduced in our previous report [12], the sound intensity is calculated using the measured impulse responses at four closely located points. Figure 1 shows the constructed microphone holder in which the microphone is attached at the position of origin. The particle velocities for each direction needed for the calculation of intensities are obtained by taking the differences in the sound pressures between the origin and the other positions. Only one microphone (SONY ECM-77B) is used in the practical process and four impulse responses are obtained by sequential measurement.

The envelope intensities in each direction are then calculated using the Hilbert transform of the instantaneous intensity. The dominant peaks in the envelope intensities are recognized as the important reflections. The arrival angles of these reflections are then calculated. Detailed discussions on the calculation of the instantaneous and envelope intensities are given in [7,12].

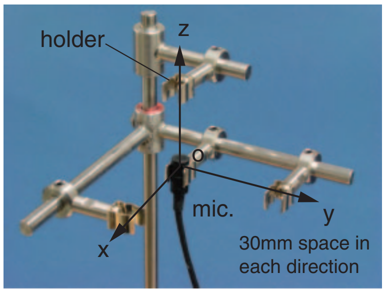

Fig. 1 The constructed microphone holder used in the sound intensity measurement.

3. Visualization of dominant reflections

One method that we previously proposed is the projection of the arrival angle of reflections onto the surface of a rectangular wire-frame box. In the example shown in Fig. 2, the large reflections are shown as circles on each surface of the enclosure. Since successively reflected sound can be seen by animation, this method is useful for grasping the structure of the early reflections, provided the measured enclosed space can be modeled by a rectangular shape.

In the method proposed in this report, we use photographs of the enclosure. The combination of images of the sound field and the measurement results, which is often used in noise source identification systems [14,15], is essentially an intuitive method. The procedures of our method are shown in Fig. 3.

Firstly, two or three photos which cover all directions (4π steradian) are taken using a digital camera with a fish-eye lens having a picture angle of 180 degrees. The position of the camera was made to coincide with the measurement point of the sound intensity. An exclusive *rotator* was used to generate a reliable panorama photo. These photos were then stitched to create a one-sheet panorama photo (Fig. 3(b)). This stitching is performed using software available on the market. The generated photo (in JPEG format) was then pasted onto the surface of a transparent (imaginary) sphere. Although the practical program for generating this sphere was coded in C-language, a similar process can be expressed in MATLAB code as

*Currently with D&M Holdings Inc.
†e-mail: hisaha@mcn.ne.jp
‡e-mail: omoto@design.kyushu-u.ac.jp

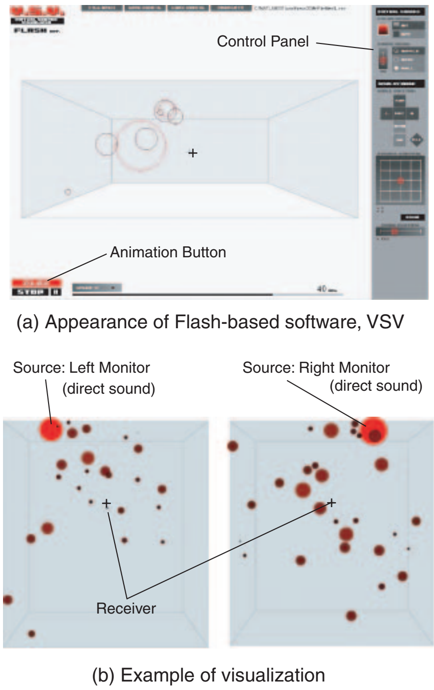

Fig. 2 Previously proposed method of displaying reflection sound in which the angles of the arriving reflections are shown by the locations of the circles with radii proportional to the levels of reflection [12].

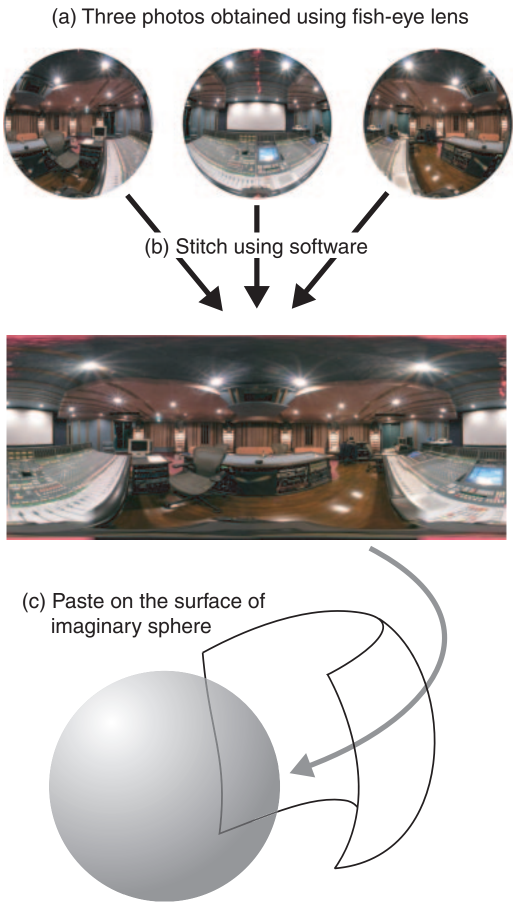

Fig. 3 Procedures for creating the imaginary sphere having an image of the practical enclosure.

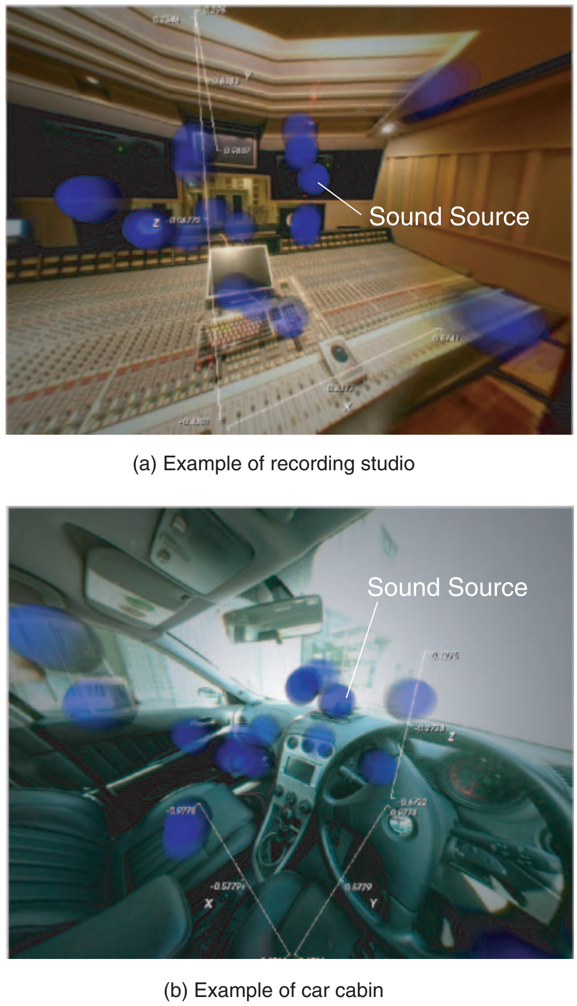

Fig. 4 Examples of the proposed visualization method adopted in a recording studio and a car cabin.

```
>> sphere
>> photo=imread('RoomPhoto.jpg');
>> h = findobj('Type','surface');
>> set(h,'CData',photo,'FaceColor','texturemap');
>> axis equal;
```

where `RoomPhoto.jpg` is the stitched JPEG file.

The viewpoint was then set at the center of the sphere to view the surface. The reflections are then projected onto the surface of the sphere at corresponding directions. Examples are shown in Fig. 4, in which the photos and the results of measurements in a recording studio and a car cabin are shown. The circles in these figures correspond to the directions of the arriving reflection sound. The radii of the circles can be varied to be proportional to the levels of the reflections. In the PC program, the viewing angle can be easily changed by manipulating the cursor keys, and the time histories of the reflection can be expressed as animations.

We must beware that these marks indicate only the *arrival directions* of the reflections. The walls behind the marks do not necessarily contribute to the real reflections directly, e.g., the arriving reflection may be due to scattering by the edges of the walls or may be bent by an inhomogeneous medium. Although it is easy to imagine strong relationships between marks and the walls at corresponding directions in the small enclosure, a detailed examination must be carried out to clarify the strength of such relationships.

4. Concluding remarks

A visualization method of dominant reflections in an enclosure is proposed. The envelope intensities in each direction, which were calculated from the measured impulse responses, were used to recognize the timings and the levels of the dominant reflections. A panorama photo was pasted onto the surface of an imaginary sphere and the reflections were expressed as circular marks on the surface. This method could improve the intelligibility of the direction of arrival of the reflections.

There is no guarantee that the arriving reflections are actually 'reflected' at the surface positions indicated by the circles. Further examination is needed using a more simply shaped enclosure, such as a rectangular parallelepiped, to elucidate the relationships. Additionally, a method of decoding further information from the generated figures is another subject of our current research.

Acknowledgement

The authors would like to thank Dr. M. Nakahara, SONA Corp. and studio engineers who provide kind support during the measurements. This study was supported in part by a Grant-in-Aid for the 21st Century COE Program.

References

[1] ISO 3382, Acoustics — Measurement of the reverberation time of rooms with reference to other acoustical parameters (1997).

[2] R. Walker, "A new approach to the design of control room acoustics for stereophony," *AES 94th Convention Berlin*, Preprint 3543 (1993).

[3] S. Bech, "Timbral aspects of reproduced sound in small rooms. I," *J. Acoust. Soc. Am.*, **97**, 1717–1725 (1995).

[4] S. Bech, "Timbral aspects of reproduced sound in small rooms. II," *J. Acoust. Soc. Am.*, **99**, 3539–3548 (1996).

[5] S. Bech, "Spatial aspects of reproduced sound in small rooms," *J. Acoust. Soc. Am.*, **103**, 434–445 (1998).

[6] A. T. Furjes, A. Arato-Borsi and F. Augusztinovicz, "Evaluation and design of small rooms," *Build. Acoust.*, **7**, 277–296 (2000).

[7] R. W. Guy and A. Abdou, "A measurement system and method to investigate the directional characteristics of sound fields in enclosures," *Noise Control Eng. J.*, **41**, 8–18 (1994).

[8] Y. Yamasaki and T. Itow, "Measurement of spatial information in sound field by closely located four point microphone method," *J. Acoust. Soc. Jpn.* (*E*), **10**, 101–110 (1989).

[9] K. Sekiguchi, S. Kimura and T. Hanyuu, "Analysis of sound field on spatial information using a four-channel microphone system based on regular tetrahedron peak method," *Appl. Acoust.*, **37**, 305–323 (1992).

[10] Y. Tokita and Y. Yamasaki, "Visualization of 3-dimensional Sound Fields by Numerical Solutions and Measured Data," *Proc. Int. Symp. Room Acoustics: Design and Science 2004*, 058 (2004).

[11] R. Yokota, K. Oki and Y. Yamasaki, "3-dimensional visualization of the sound field by four-point microphone method," *Proc. Autumn Meet. Acoust. Soc. Jpn.*, 1-3-15, pp. 581–582 (2004).

[12] A. Omoto and H. Uchida, "Evaluation method of artificial acoustical environment: Visualization of sound intensity," *J. Physiol. Anthropol. Appl. Hum. Sci.*, **23**, 249–253 (2004).

[13] Y. Fukushima, S. Shimada, C. Koga, H. Uchida and A. Omoto, "Visualization of reflections in small enclosures," *AES Regional Convention Tokyo*, Preprints (2005).

[14] H. Nogami, N. Kamiakito, Y. Tamashita, T. Zaima and M. Owaki, "Development of the system for identification of sound sources combined the picture: Development of system with the 5 microphones," *Proc. Autumn Meet. Acoust. Soc. Jpn.*, 2-P-1, pp. 857–858 (2001).

[15] K. Takashima, "Sound source identification technique for audible sound," *J. Acoust. Soc. Jpn.* (*J*), **61**, 659–664 (2005).