The 10th Western Pacific Acoustics Conference
第十届西太平洋声学会议
WESPAC X 2009
21-23 September 2009, Beijing, China

Development of Real System in Near 3D Sound Field Reproduction System Using Directional Loudspeakers and Wave Field Synthesis

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ABSTRACT

It is very important to develop near 3D sound field reproduction techniques in order to realize the ultra-realistic communications such as 3D television and 3D tele-conference. In this paper, the near 3D sound field reproduction system using directional loudspeakers and wave field synthesis is developed by constructing the surrounding microphone array, where 157 microphones are attached on the 5 planes of the rectangular room, and the radiated loudspeaker array, where 157 loudspeakers are directly attached to the 5 planes of the rectangular enclosure. The performance of the developed system is evaluated by displaying the developed system to general public at the exhibition.

1 INTRODUCTION

We have been investigating ultra-realistic communications techniques [1]. As shown in Figure 1, if 3D video and audio realistically reproduced pops up in a 3D space by applying these techniques and several people can view the object anywhere in its vicinity without having to wear equipment such as glasses, more realistic forms of communication (e.g. 3D television, 3D teleconferencing, etc.) will be possible than those currently provided by conventional video and audio techniques (HD video and 5.1-channel audio). In this paper, we focus on wave field synthesis [2-4], which is one of 3D sound field reproduction techniques, and propose a 3D sound field reproduction system based on this technique.

Wave field synthesis is a 3D sound field reproduction technique for reproducing wave fronts of a control area in a listening area based on Huygens' principle [5]. Microphones placed on the boundary of a control area record the original sound and loudspeakers placed on the boundary of the listening area then play the recorded sound. The position of the loudspeakers is the same as that of the microphones. Multiple listeners can listen to the sound anywhere in the listening area without having to wear a device such as headphones because

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this technique reproduces the sound field of a 3D space rather than the sound field of binaural positions.

In order to realize the 3D sound field reproduction system that multiple listeners can listen to a sound anywhere in its vicinity without having to wear equipment such as headphones, we proposed the near 3D sound field reproduction systems using directional loudspeakers and wave field synthesis and evaluated the condition reproducing wave fronts by the computer simulation [6]. In this paper, we develop the proposed system by constructing the surrounding microphone array and the radiated loudspeaker array. In order to evaluate the performance of the developed system, the sound of the string quartet was generated and the developed system was displayed at an exhibition.

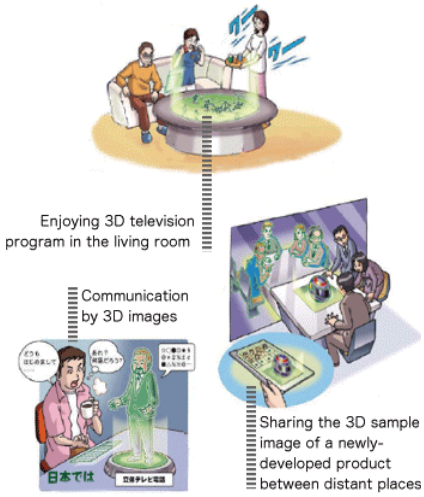

Figure 1: Future image of ultra-realistic communications [1].

2 DIAGRAM OF DEVELOPED SYSTEM

A diagram of the developed system is shown in Figure 2. First, the surrounding microphone array, which consists of *M* omni-directional microphones, is placed around the sound sources in the original sound field and *M* audio signals, $x_i(t)$, are recorded. The positions of the microphones are on the boundary surface. Second, the radiated loudspeaker array, which consists of *M* directional loudspeaker units, is placed in the reproduced sound field and the *M* recorded audio signals, $x_i(t)$, are played. The positions of the loudspeaker units are the same as those of the microphones. The directivity of the loudspeaker units is toward the outside of the boundary surface. As a result, because wave fronts were are accurately reproduced on the outside of the radiated loudspeaker array, listeners on the outside of the radiated loudspeaker array can feel that the sound sources are being played on the inside of the radiated loudspeaker array. In the case of Figure 2, listeners who are close to the piano can feel that they listen to the sound near the piano and listeners who are close to the violin can feel that they listen to the sound near the violin.

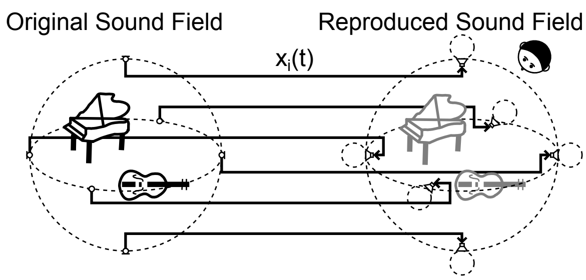

Figure 2: Near 3D sound field reproduction system using directional loudspeakers and wave field synthesis [6].

3 DEVELOPED SYSTEM

3.1 Surrounding microphone array

As the surrounding microphone array, we used a surrounding microphone array room equipped in the Research Institute of Electrical Communication, Tohoku University [7]. The reverberation time of the room was approximately 150 ms. 157 omni-directional microphones (Brüel & Kjær: Type 4951) were attached to the 5 planes of the room as shown in Figure 3. These microphones record mainly the direct sound from sound sources placed in the room because sound absorption panels are also attached to all planes of the room.

Figure 3: Image of surrounding microphone array room [7].

The arrangement of microphones is shown in Figure 4. On the two narrow sidewall planes (Wall A), 20 (= 5×4) microphones are attached to each plane. On the two wide sidewall planes (Wall B), 36 (= 9×4) microphones are attached to each plane. On the ceiling plane, 45 (= 9×5) microphones are attached. The interval between the microphones is 0.5 m. These microphones are connected to 10 microphone preamplifiers of 16 channels (Brüel & Kjær: Type 2694)

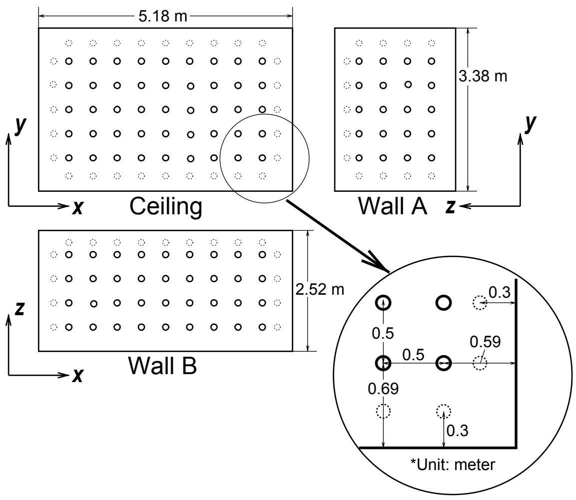

Figure 4: Arrangement of microphones in the surrounding microphone array [7].

3.2 Radiated loudspeaker array

As the radiated loudspeaker array, we newly manufactured the loudspeaker shown in Figure 5. The size of the radiated loudspeaker array is one-fourth of that of the surrounding microphone array. This radiated loudspeaker array has a rectangular enclosure, 157 loudspeaker units, and a stand. The size of the rectangular enclosure is 1.145 m (width) ×

0.695 m (depth) × 0.555 m (height). The materials used for the rectangular enclosure are plywood and aluminum panels. The 157 loudspeaker units with a size of 1 inch (AURASOUND: NSW1-205-8A suitable) are directly attached to the five planes of the rectangular enclosure. The directivity of each loudspeaker unit is toward the outside of the rectangular enclosure because the sound radiated from each loudspeaker unit to the inside of the rectangular enclosure does not leak to the outside of the rectangular enclosure.

Figure 5: Image of radiated loudspeaker array.

The arrangement of the loudspeaker units is shown in Figure 6. On the two narrow sidewall planes (Wall A), 20 (= 5×4) loudspeaker units are attached to each plane. On the two wide sidewall planes (Wall B), 36 (= 9×4) loudspeaker units are attached to each plane. On the ceiling plane, 45 (= 9×5) loudspeaker units are attached. The interval between the loudspeaker units is 0.125 m. These loudspeaker units are connected to the preamplifier with 157 channels (custom-made). The radiated loudspeaker array is elevated by 0.7 m by the stand.

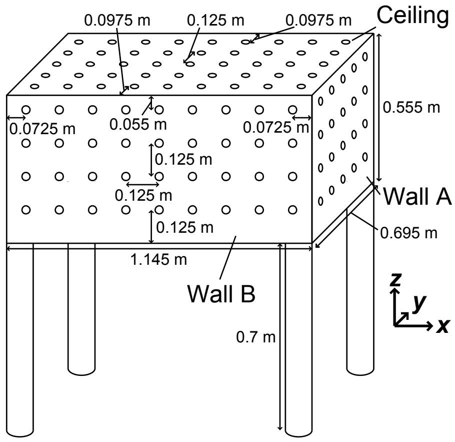

Figure 6: Arrangement of loudspeaker units in the radiated loudspeaker array.

4 EVALUATION OF DEVELOPED SYSTEM

4.1 Recording of string quartet

The performance of the string quartet was recorded in a surrounding microphone array room described in section 3.1. As shown in Figure 7, four musical players, which consist of two violinists, one violist, and one cellist, entered the room and played the first movement of Mozart's thirteenth serenade (also known as ‘‘Eine kleine Nachtmusik’’) together. The performance was captured by 157 microphones, amplified by 10 microphone preamplifiers, and recorded using the recording equipment that consisted of 14 audio devices (Mark Of The

Unicorn: HD192). The recording software (Steinberg: Nuendo 3) was installed on four PCs (Apple: Power Mac G5). As a result, 157-channel audio signals (sampling frequency: 48 kHz, quantization bit: 16 bits) were obtained.

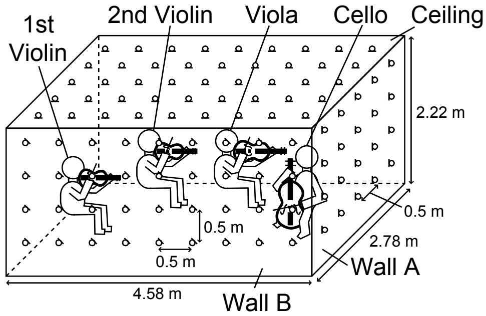

Figure 7: Arrangement of string quartet in the surrounding microphone array room.

4.2 Playing of 157-channel audio signals

The radiated loudspeaker array described in section 3.2 directly played the recorded 157-channel audio signals by using the playing equipment (Digidesign: ProTools HD). The playing software (Digidesign: ProTools HD) was installed on a PC (Apple: Mac Pro). The channels were assigned such that the azimuth and elevation angles of each loudspeaker unit were same to those of each microphone. Because the size of the radiated loudspeaker array is not same as that of the microphone array used in section 4.1, wave fronts produced by the string quartet are not accurately reproduced on the outside of the radiated loudspeaker array. However, because the position of the loudspeaker units is similar to that of microphones, wave fronts, which are similar to those produced by the string quartet, are generated on the outside of the radiated loudspeaker array. Consequently, as shown in Figure 8, several listeners on the outside of the radiated loudspeaker array felt as that the string quartet was being played on the inside of the radiated loudspeaker array.

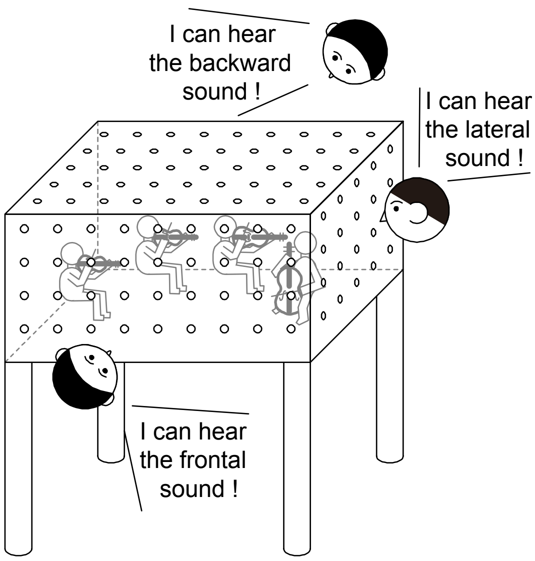

Figure 8: Image of string quartet in the radiated loudspeaker array.

4.3 Display of developed system

In order to evaluate the response of general public to the developed system, the radiated loudspeaker array was displayed at the exhibition (CEATEC JAPAN 2008 [8]). In this exhibition, a great number of visitors (about several tens of thousands) listened to the sound of the string quartet generated by the radiated loudspeaker array. Most of them felt that there were four musical players in the radiated loudspeaker array and that the string quartet was being played in the radiated loudspeaker array. As a result, it was suggested that the performance of the developed system was enough in order to realize the ultra-realistic communications system although the developed system does not reproduce accurate wave fronts.

5 CONCLUSIONS

In this paper, we developed the proposed system, which used directional loudspeakers and wave field synthesis, by constructing the surrounding microphone array and the radiated loudspeaker array. The sound field of the string quartet was generated on the outside of the radiated loudspeaker array by recording the performance of the string quartet in the surrounding microphone array and playing the 157-channel audio signals by the radiated loudspeaker array. The developed system was displayed at the exhibition in order to evaluate the performance of the developed system.

In the display of the developed system, because the size of the radiated loudspeaker array is not same as that of the surrounding microphone array, wave fronts are not accurately reproduced on the outside of the radiated loudspeaker array. However, general public felt that the performance of the developed system was enough. Thus, it needs to study the accuracy of wave fronts generated by the developed system and to evaluate the effect of the accuracy on the sound field perception when the size of the radiated loudspeaker array is not same as that of the surrounding microphone array.

6 REFERENCES

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