Mixed Reality Visualization of Instantaneous Sound Intensity with Moving 4-ch Microphone Array

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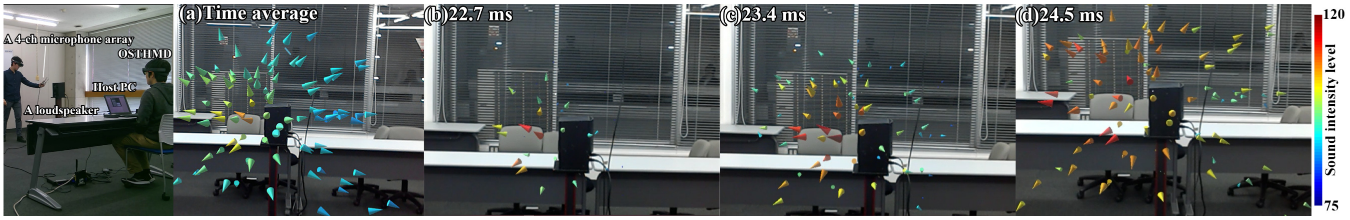

Figure 1: MR Visualization of instantaneous sound intensity with the time change. Leftmost figure shows the view of measurement with the proposed system. (a) shows the time-averaged result of the sound intensity distribution. (b)-(d) show the snapshots of the instantaneous sound intensity distribution at 22.7, 23.4 and 24.5 ms.

ABSTRACT

To understand the sound propagation in a real space, we propose the mixed reality (MR) visualization system of instantaneous sound intensity, which can be measured at each measurement point with moving a handy microphone array in synchronization with sound reproduction. By visualizing the measured instantaneous sound intensities with an MR animation, we can observe the temporal flow of sound energy in the real space to understand the propagation of sound wave and acoustic properties, such as sound reflection.

CCS CONCEPTS

• **Human-centered computing → Mixed/augmented reality**.

KEYWORDS

scientific visualization, acoustic imaging, sound intensity, mixed reality, augmented reality.

ACM Reference Format:
Yuta Kataoka, Yasuhiro Oikawa, Yasuaki Watanabe, and Yusuke Ikeda. 2020. Mixed Reality Visualization of Instantaneous Sound Intensity with Moving 4-ch Microphone Array. In *Special Interest Group on Computer Graphics and Interactive Techniques Conference Posters (SIGGRAPH '20 Posters), August 17, 2020.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3388770.3407401

1 INTRODUCTION

Visualization of sound field enables us to understand the invisible physical phenomena of sound propagation. Sound visualization technologies have been utilized for estimating a noise source, checking a sound energy flow, room acoustic design, etc. In particular, the visualization of sound propagation is essential for understanding the spatial characteristics of the sound environment. The visualization methods of sound propagation have been studied in the field of simulations using numerical calculations such as ray tracing or the finite-difference time-domain method (FDTD). In most cases, the calculated sound propagation was visualized only in the virtual space, because the propagation speed is very high and the sound broadly spreads in 3D space.

In recent years, a real-time visualization system of sound field using optical see-through head mounted displays (OSTHMDs) has been proposed [Inoue et al. 2019]. In this system, it is assumed that the sound field is stationary since a handy 4-ch microphone array is moved to scan the real space. Thus, this previous system cannot visualize the temporal sound propagation.

In this work, we propose a visualization system for instantaneous sound intensity to observe the spatial temporal acoustic properties, such as sound propagation and reflection. By synchronizing the recording of the 4-ch microphone array signals with the playback of the sound source, the instantaneous sound intensity at each measurement point is measured for the transient and reproducible sound field. After the measurement, the instantaneous sound intensity for each time bin can be visualized as an MR animation.

2 PROPOSED SYSTEM

In this system, the combination of two approaches is taken to measure the nonstationary sound field using a handy 4-ch microphone array. One is the synchronous measurement with audio playback. Another is that MR animation is used to visualize transient sound propagation.

2.1 System Overview

The overview of our proposed system is shown in Fig. 2. For the measurement, OSTHMDs and a host PC with a 4-ch microphone

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SIGGRAPH '20 Posters, August 17, 2020, Virtual Event, USA

ACM ISBN 978-1-4503-7973-1/20/08.
https://doi.org/10.1145/3388770.3407401

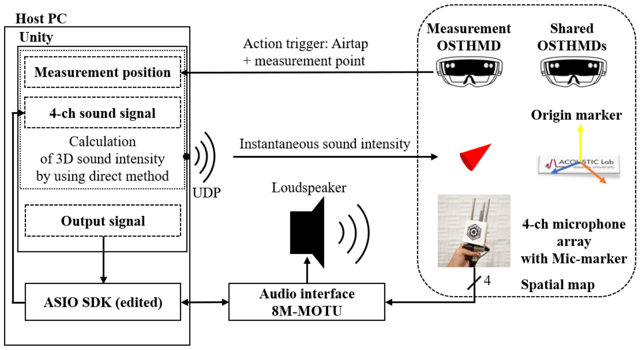

Figure 2: System overview. We use an air tap as a trigger to record and play back simultaneously in this system. The instantaneous sound intensity for each time sample is calculated by the direct method and visualized on OSTHMDs.

array and a loudspeaker through an audio interface are used. Microsoft HoloLens is used as OSTHMD.

At the first step of measurement, the locations of the loudspeaker and the AR marker (Origin-marker), which decides the reference position in the real space to be measured, are determined. The playback and recording are synchronized at each measurement point while scanning the space. In this proposed system, the air tap, which is a motion for operating HoloLens, is the trigger to start each measurement. The recorded signals from the microphones are calculated into the sound intensity using the method described in Sec. 2.2. Then, the data is immediately sent to OSTHMDs via UDP protocol. The coordinate of measurement point in the spatial map generated by OSTHMD is obtained from the position of the AR marker (Mic-marker) attached on the microphone array. Then each measurement result is superimposed as a cone-type 3D computer graphics (3DCG) object indicating that the sound energy is flowing toward the tip of the cone. The color of the cone indicates the sound intensity level. The sound intensity data can be plotted in the real space with sharing in multiple OSTHMDs, since the reference position in the individual spatial maps of OSTHMDs is shared by the Origin-marker.

From the measured signals with time synchronization, the time-averaged sound intensity is not only obtained but also the instantaneous sound intensity. Thus, we can observe the temporal variation of the sound propagation by changing the display data at each time.

2.2 Calculating Instantaneous Sound Intensity

The direct method is used to compute the sound intensity in the time domain [Fahy and Salmon 1990]. The N samples signal obtained from each microphone is filtered based on the inverse characteristics of each channel which includes microphone amplifier, cable and microphone [Kotus and Szwoch 2018]. A second-order band-pass filter is adapted to narrow down the target frequency. The instantaneous sound intensity is calculated for each sample of the measured signal. For time-averaged sound intensity, they are averaged during the period of measurement. The sound intensity is immediately displayed on OSTHMDs.

Figure 3: Visualization of instantaneous sound intensity. Upper figures show the reflection by the whiteboard. The lower figures show the reflection by the sound-absorbing material. As shown in the red mark, no reflection is caused by the sound-absorbing material.

3 VISUALIZATION EXPERIMENT

We conducted a visualization experiment with the proposed system. The absorption effect of the sound-absorbing material was visualized in the two experimental conditions: with and without the sound-absorbing material in front of the whiteboard. A loudspeaker which radiates 4 periods of 1 kHz sine wave was placed at the 3.0 m away position from the whiteboard. The experimental conditions were as follows: sampling frequency was 44100 Hz and $N = 4096$.

The results of the measurements are shown in Fig. 3. In the experiment, sound intensities were measured at 134 points within half an hour of measurement time. Time-averaged results show that the sound intensities were directed towards the sound-absorbing material when putting a sound-absorbing material. It is because the energy of reflected sound waves was small enough to vanish in the visualization.

The instantaneous sound intensities measured through OSTHMD were visualized as an animation for each time bin. The sound waves emitted from the loudspeaker propagated as spherical waves towards the wall and were reflected or absorbed. Then, it was visualized as the temporal flow of sound energy. We compare the temporal changes in instantaneous sound intensity. It is confirmed that the intensity level on the trajectory around the center of the sound-absorbing material was reduced by about 10 dB compared to a non absorbing material case.

From the animation of instantaneous sound intensity, we were able to observe the sound propagating through the room and the reflection. Thus, further development of acoustic design can be expected in the future by measuring the acoustic characteristics of more complicated sound fields.

ACKNOWLEDGMENTS

This work was supported by JSPS KAKENHI Grant Number 19K12049.

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