Visualization of 3D Sound Field using See-Through Head Mounted Display

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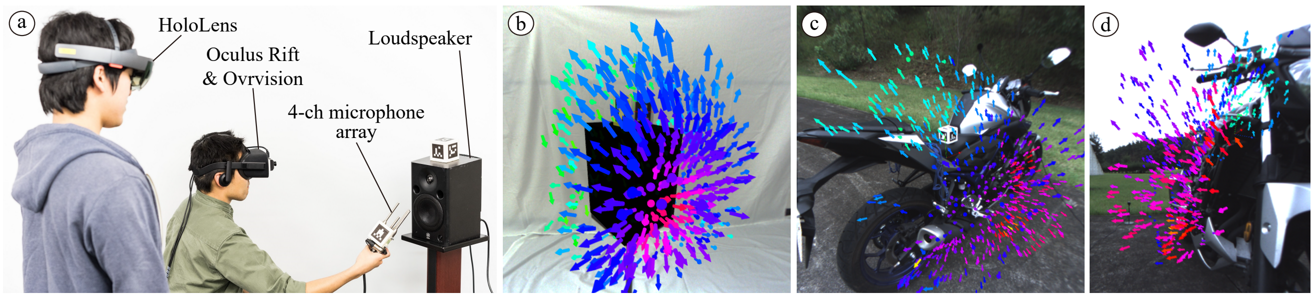

Figure 1: (a) Proposed measurement and visualization system applying to a loudspeaker. (b) Visualized sound intensity around a loudspeaker (the arrows represent the direction of the sound intensity, and their color represents its level). (c) Sound intensity around a motorbike. (d) Another view of (c).

ABSTRACT

We propose a visualization system of three-dimensional (3D) sound information using video and optical see-through head mounted displays (ST-HMDs). The Mixed Reality (MR) displays enable intuitive understanding of 3D information of a sound field which is quite difficult to project onto an ordinary two-dimensional (2D) display in an easily understandable way. As examples of the visualization, the sound intensity (a stationary vector field representing the energy flow of sound) around a speaker and a motor engine is shown.

CCS CONCEPTS

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

KEYWORDS

Scientific visualization, acoustic imaging, sound intensity, video and optical ST-HMD.

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1 INTRODUCTION

Sound is one of the most important sources of information in our daily life as it tells us the states of an object, a machine, and surrounding environment. Deeper understanding of sound enables us to design a comfortable life. Therefore, sound measurement has been studied in its long history, and the standard measurement method is well-established.

However, intuitive display of the measured quantities of sound is quite difficult owing to its three-dimensional (3D) nature. Since sound is the phenomenon widely spreading around the 3D space, its measured quantities are also a 3D scalar/vector field. Such 3D information cannot be illustrated in a straightforward manner by the ordinary two-dimensional (2D) display.

In this work, we propose a visualization system of a 3D sound field using a see-through head mounted display (ST-HMD). The system superimposes the 3D quantities of sound at the measured points so that the positional relation between the quantities and object can be easily understood. ST-HMD enables intuitive visualization of the field thanks to the ability of moving freely around it. In this paper, we chose *sound intensity* (a stationary vector field representing the energy flow of sound) as the quantity to be visualized, and for ST-HMDs, *Oculus Rift* combined with a stereoscopic camera (*Ovrvision Pro*) and *Microsoft HoloLens* were used (Fig. 1).

1.1 Previous Works

Sound fields have been visualized by superimposing to an image, an omnidirectional camera, or a 3D model of the object. However, these methods only use the ordinary 2D displays which are not intuitive enough to understand the field [Oikawa et al. 2016].

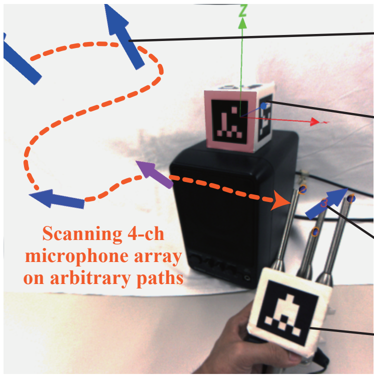

Figure 2: Illustration of the sound intensity measurement using our system. The user continuously moves the microphone array with Mic-marker by hand. The sound intensity objects are placed at points where the user specified.

2 MEASURING 3D SOUND INTENSITY

The sound intensity $\boldsymbol{I}(x,y,z) = [I_x(x,y,z), I_y(x,y,z), I_z(x,y,z)]^T$ (W/m^2) is a vector field on the 3D space which represents time average of the net flow of sound energy per unit area,

$$\boldsymbol{I}(x,y,z) = \frac{1}{T_2 - T_1}\int_{T_1}^{T_2} p(x,y,z,t)\, \boldsymbol{u}(x,y,z,t)\, dt,$$

where p is the sound pressure, $\boldsymbol{u}$ is the acoustic particle velocity, and $[T_1, T_2]$ is the interval of averaging which should be long enough comparing to the period of the sound. It is often measured by a microphone array (a set of microphones), which can measure the sound pressure, in order to calculate the spatial derivative associated with the particle velocity by the finite difference approximation [Fahy 2002]. Note that, in this formulation, the measured sound field is assumed to be *stationary*, that is, the characteristics of the sound does not change within the measurement. This assumption holds (or is a reasonable approximation) in many practical applications of sound measurement, for example, measurement of continuous noise emitted from a machine.

As the sound field is assumed to be stationary, the sound intensity at each point can be measured asynchronously. Therefore, scanning the microphone array through the field can provides $\boldsymbol{I}(x,y,z)$ at each point. In this work, we combined a marker detection system [Fiala 2005] (implemented by using ArUco [Munoz-Salinas 2012]) with the microphone array to automatically acquire the positional relationship among multiple measurements in real time. The markers are printed on a cubic object (placed on the measured object) and the microphone array for identifying their positions, as illustrated in Fig. 2. The measured points on the scanning path can be interactively chosen by the user.

3 VISUALIZATION

We implemented two visualization systems using two kinds of ST-HMDs: a video ST-HMD, Oculus Rift + Ovrvision Pro (stereoscopic camera), and an optical ST-HMD, Microsoft HoloLens.

In the system using the video ST-HMD, the measured sound intensity is superimposed to the stereoscopic video according to

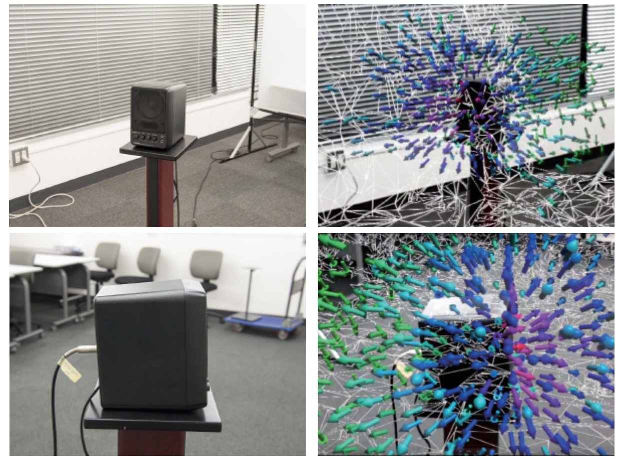

Figure 3: Visualized sound intensity around a loudspeaker using optical ST-HMD (Microsoft HoloLens). The 3D sound intensity objects are placed according to the spatial map which is robust to the movement of the user. Its spatial recognition feature enables us to visualize the information from a distant position. The wireframe is shown in these figures to illustrate the spatial map constructed by HoloLens.

the position of Cube-marker [Inoue et al. 2016]. Some visual examples of measured sound intensity are shown in Fig. 1. It can be seen from the figures that the energy of sound of the loudspeaker propagates mainly in front of the loudspeaker, while that of the motorbike propagates mainly in side of the motorbike. Such directional information of a 3D sound field can be intuitively interpreted by our system, which is difficult by the ordinary 2D display.

In the system using the optical ST-HMD, the measured sound intensity is placed and fixed to the spatial map of observing location as in Fig. 3. This system has very low latency because no processing related to a video camera is required for visualizing enviromental scene. In addition, the spatial map enables us to step away from the measured object, which is an advantage of HoloLens over the marker detection based system. Another advantage is that the spatial map can occlude the sound information behind the object, which helps us to recognize which intensity arrows are on which side of the object.

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