Visualization of Spatial Impulse Responses using Mixed Reality and Moving Microphone

Yasuaki Watanabe
20fmi26@ms.dendai.ac.jp
Tokyo Denki University
Adachi-ku, Tokyo, Japan

Yusuke Ikeda
yusuke.ikeda@mail.dendai.ac.jp
Tokyo Denki University
Adachi-ku, Tokyo, Japan

Yuta Kataoka
kataoka8894@akane.waseda.jp
Waseda University
Shinjuku-ku, Tokyo, Japan

Yasuhiro Oikawa
yoikawa@waseda.jp
Waseda University
Shinjuku-ku, Tokyo, Japan

Naotoshi Osaka
osaka@mail.dendai.ac.jp
Tokyo Denki University
Adachi-ku, Tokyo, Japan

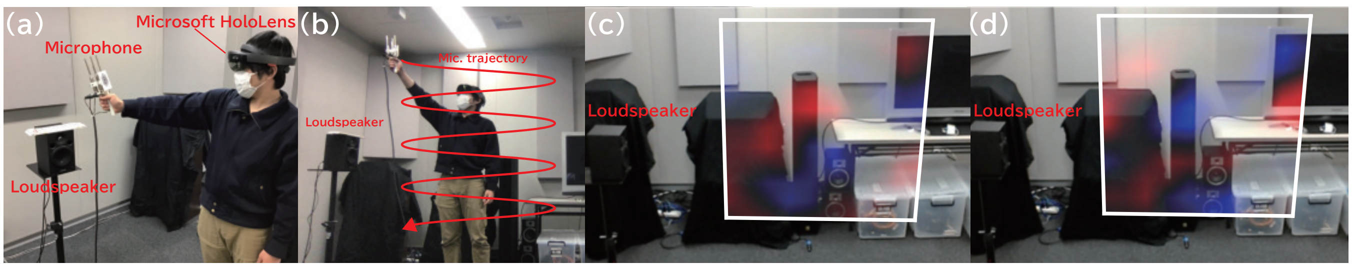

Figure 1: Overview of measurement and visualization system for the spatial impulse responses. (a) System configuration. An measurer wearing Microsoft HoloLens moves a handy microphone using an AR marker. (b) The microphone is moved to scan the 2D plane. (c), (d) Examples of MR visualization of impulse responses at 1.67 and 2 ms, respectively.

ABSTRACT

In this paper, we propose a measurement and visualization system for spatial impulse responses that utilizes a moving handy microphone and Mixed Reality (MR). By enhancing the existing visualization system of sound intensity using MR, the proposed system aids in the visualization of spatial impulse responses using the estimation based on the signal measured by a moving microphone. As the visualization of the sound field varies with time, it is effective to understand the relationship between a complicated sound field, including the reflected sounds, and the reflecting objects in a room.

CCS CONCEPTS

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

KEYWORDS

Mixed Reality, Spatial mapping, Dynamic sound-field measurement, Interpolation, Loudspeaker, Sound Propagation

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1 INTRODUCTION

Mixed Reality (MR) is useful in the visualization of sound fields as it clearly estimates the relationship between sound-reflecting objects and the measured sound data. Previously, the sound intensity visualization systems with MR and handy microphones was proposed[Inoue et al. 2019; Kataoka et al. 2018]. In such systems, the sound intensities at multiple points are measured by scanning a stationary sound field using handy microphones, which demonstrate the flow of sound energy. Using these data, the measured results are immediately plotted in the actual room via MR. However, visualization of the time variation of the sound field is necessary to understand complicated sound fields like sound-reflective rooms.

In this paper, by enhancing the conventional system[Inoue et al. 2019; Kataoka et al. 2018], we propose a system to measure and visualize spatial impulse response via MR. In this system, an measurer continuously measures a sound signal using the moving microphone, and reconstructs the spatial impulse responses (IRs) based on the estimated path of microphone movement via Simultaneous Localization and Mapping (SLAM) and Augmented Reality (AR).

2 OVERVIEW OF PROPOSED SYSTEM

Figure 2 depicts the overview of the proposed system. The measurer scans the objective space by moving a handy microphone while

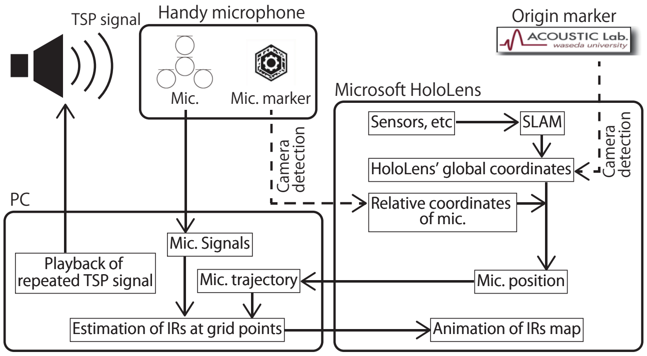

Figure 2: Overview of propose system. Microsoft HoloLens is used to track the position of microphone and visualize the result of estimated IRs at the grid points.

a loudspeaker emits a measurement signal. To visualize the time variation of the sound field, the spatial IRs at the grid points are estimated based on the measurement data along any microphone trajectory obtained by using Microsoft HoloLens and Mic. marker.

3 ESTIMATION METHOD FOR IMPULSE RESPONSES AT GRID POINTS

In [Katzbeg et al. 2018], an estimation method for IRs from the measured signal along any trajectory was proposed. Based on the IRs, $h(\partial, n)$, at the grid points, $\partial (\in G)$, the IR with any trajectory of the microphone is interpolated using the following equation.

$$h(y(n), n) = \sum_{\partial \in G} \varphi(\partial, y(n)) h(\partial, n), \tag{1}$$

where $y(n)$ denotes the position of microphone at time n, $\varphi(\partial, y(n))$ denotes the interpolation function between the grid point ∂ and the microphone position $y(n)$. By repeating a measurement signal R times, Eq.(1) is expressed in matrix form as follows,

$$h_{\mathrm{m}} = A h_{\mathrm{g}}, \tag{2}$$

where

$$h_{\mathrm{m}} = [h(y(1,1), 1), \ldots, h(y(L, R), LR)]^{\mathrm{T}}, \tag{3}$$

$$A = \begin{bmatrix} \Phi_{1,1} & \cdots & \Phi_{N,1} \\ \vdots & \ddots & \vdots \\ \Phi_{1,R} & \cdots & \Phi_{N,R} \end{bmatrix},$$

$$\Phi_{u,r} = \mathrm{diag}(\phi(\partial_u, y(1, r)), \ldots, \phi(\partial_u, y(L, r))),$$

$$h_{\mathrm{g}} = [h(\partial_1, 1), \ldots, h(\partial_N, L)]^{\mathrm{T}},$$

where $u (= 1, \ldots, N)$ is the index of grid point. Then, using Fourier Transform (FT), Eq.(2) is expressed as follows,

$$h_{\mathrm{m}} = A(\Psi_{\mathrm{X}} \otimes \Psi_{\mathrm{Y}} \otimes \Psi_L) c, \tag{4}$$

where $\otimes$ denotes the Kronecker product, Ψ_L denotes the inverse of the discrete-time FT matrix, Ψ_{X} and Ψ_{Y} denote the inverse matrices of FT matrices corresponding to the X and Y axes, respectively.

As it is well known that the sparsity of a spectrum of the sound in the spatial time-frequency domain, the coefficient vector c can be derived from the following optimization problem.

$$\underset{c \in \mathbb{C}^{(L \times N)}}{\mathrm{argmin}} \; \|c\|_{\ell_1} \quad \text{s.t.} \quad \|h_{\mathrm{m}} - A(\Psi_{\mathrm{X}} \otimes \Psi_{\mathrm{Y}} \otimes \Psi_L) c\|_{\ell_2} \leq \epsilon, \tag{5}$$

By using the estimated c and Eq.(4) with a spatial time-frequency filter, the IRs at the grid points are calculated to visualize the animation of the sound field.

4 EXPERIMENTS

4.1 Condition

We conducted the measurement and visualization experiments for 2D spatial IRs. As shown in Fig.1(b), the microphone was manually moved during the scan of the 2D plane. The total of measurement time is approximately 5 minutes. The length of each measurement signal was 0.17 ms and the sampling rate was 6 kHz.

4.2 Results

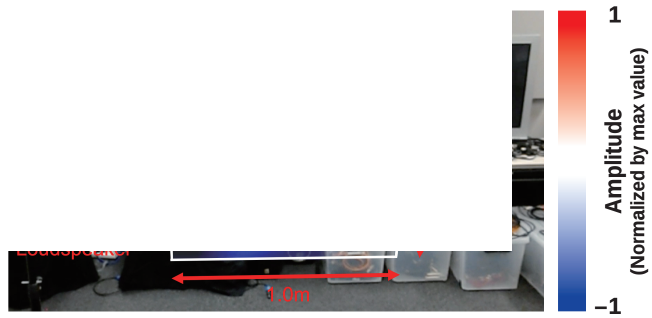

Figure 3: Visualization of 2D-Spatial IRs with MR. The size of visualized sound field is 1.0 m × 0.9 m. Red and blue colors indicate positive and negative values, respectively.

Figures 1(c)(d) and 3 show the estimated spatial IRs which were represented in the real space by using HoloLens. The amplitude of the IRs was colorized and the colored IRs map was attached to the texture of 3DCG plane. It is evident from the figure, the sound emitted from the loudspeaker propagated to the other direction.

ACKNOWLEDGMENTS

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REFERENCES

A. Inoue, Y. Ikeda, K. Yatabe, and Y. Oikawa. 2019. Visualization system for sound field using see-through head mounted display. In *Acoust Sci.& Tech.*, Vol. 40. 1–11.

Yuta Kataoka, Wataru Teraoka, Yasuhiro Oikawa, and Yusuke Ikeda. 2018. Real-Time Measurement and Display System of 3D Sound Intensity Map Using Optical See-through Head Mounted Display. In *SIGGRAPH Asia 2018 Posters* (Tokyo, Japan) *(SA '18)*. Association for Computing Machinery, New York, NY, USA, Article 71, 2 pages. https://doi.org/10.1145/3283289.3283358

Fabrice Katzberg, Radoslaw Mazur, Marco Maass, Philipp Koch, and Alfred Mertins. 2018. A Compressed Sensing Framework for Dynamic Sound-Field Measurements. In *IEEE/ACM Trans. Audio, Speech, Lang. Process.*, Vol. 26. 1962–1975.