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Sound field visualization and analysis by acousto-optic sensing

Seeing sound by light

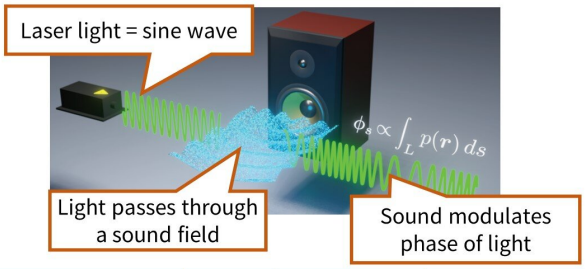
Abstract

Sound travels through the air as waves, much like ripples on the water's surface, but its propagation cannot be directly observed. In this study, we use optical technologies to visualize sound waves in high resolution, providing a detailed analysis of how sound is generated and transmitted. Unlike conventional microphones that only measure the waveform at the positions where the microphones are installed, we capture sound waves as images using optical technology and high-speed cameras. Furthermore, we have developed a deep learning-based noise reduction technique for sound field images, achieving highly accurate visualization of sound. Although sound is vital to our daily lives, many research questions still need to be answered, such as what constitutes ideal sound and how it should be evaluated. Through our research into new optical sound measurement technologies, we aim to contribute to scientific research and manufacturing related to sound and to create a comfortable acoustic environment.

Optical sound measurement (OSM)

What is OSM?

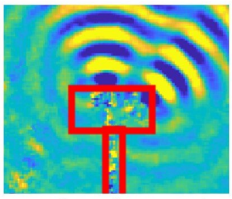
- Sound is measured by light
- Camera captures sound with high-resolution
- Visualizing sound wave is helpful for acoustic research



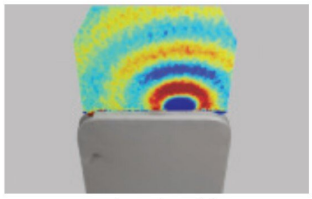
	Noise amount	Spatial resolution	Number of channels
Microphone array	◎	△ Depends on mic interval	△ # of mic (10^0~10^2)
OSM	△	◎ < 1mm is achievable	◎ Camera pixel (10^4~10^7)

Visualization examples

Using a high-speed camera enables to directly capture sound waves. By mapping the sound pressure at each pixel to a color, we visualized the wavefront of sound emitted from a speaker.



40kHz ultrasound



Sound emitted from a smartphone

Noise removal by deep learning

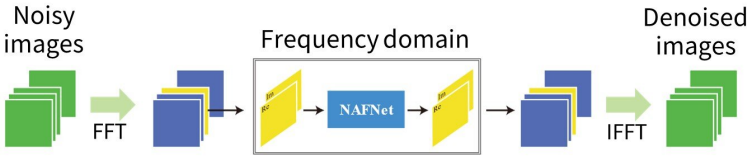
Challenges of OSM

OSM is sensitive to measurement noise

Proposed method：Deep sound-field denoiser

- Deep learning method for denoising of OSM data
- Dedicated sound field image dataset is created

Processing



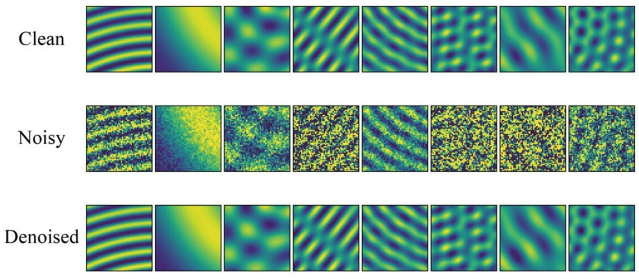
Step1 Fourier transform the data along time direction

Step2 Convert a complex-valued sound field into a two-channel image and denoised by DNN

Step3 Obtain denoised data by inverse Fourier transform

Results

By training on a sound field dataset generated by simulations considering wave equation and various noise conditions, we have demonstrated that effective noise reduction can be achieved even from heavily noisy images.



References

[1] S. A. Verburg, K. Ishikawa, E. Fernandez-Grande, Y. Oikawa, “A century of Acousto-optics: from early discoveries to modern sensing of sound with light,” *Acoustics Today*, Vol. 19, pp. 54-62, 2023.

[2] K. Ishikawa, “Imaging and Precise Measurement of Sound by Light,” J. IEICE, Vol. 106, No. 9, pp. 849-854, 2023.

[3] K. Ishikawa, D. Takeuchi, N. Harada, T. Moriya, “Deep sound-field denoiser: optically-measured sound-field denoising using deep neural network,” *Optics Express*, Vol. 31, No. 20, pp. 33405-33420, 2023.

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