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Guided-spatio-temporal filtering for extracting sound from optically measured images containing occluding objects

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Introduction

- We have proposed a novel measurement method of flow-induced sound including air-flow using parallel phase-shifting interferometry (PPSI).
- For detailed investigation of the flow-induced sound, separation of flow and sound is required.

Problem An ordinal physical-model-based spatio-temporal filter cannot extract the sound near occluding objects and image boundaries.

Objective A method for extracting the sound near occluding objects and image boundaries.

Proposal A guided filter is combined with the physical-model-based spatio-temporal filter for extracting sound from optically measured images.

Optical measurement of sound

- Optical method can capture sound field without setting any measuring device inside the field.
  ➡ it is effective for measuring near the source of aerodynamic sound.

<PPSI>

- Multiple interference fringes can be obtained by a high-speed polarization camera.
- It can measure a time-varying sound field up to 750 kHz, in theory.

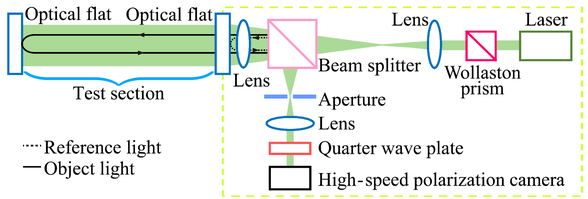

Fig. 1: Schematic of the PPSI system used in our research.

Physical-model-based spatio-temporal filtering

- By considering the Helmholtz equation, the solution can be approximated arbitrarily well by the plane wave.
- The spatial spectrum of a plane wave has only on the circle whose radius is $k = \omega/c$.
  k: wavenumber ω: angular frequency c: speed of sound
- The spatio-temporal filterbank passes the spectrum related to sound and stop other parts.

<Problem>

- The performance of the spatio-temporal filterbank is degraded around the occluding objects and image boundaries because such artificial boundary is not considered in the conventional model.

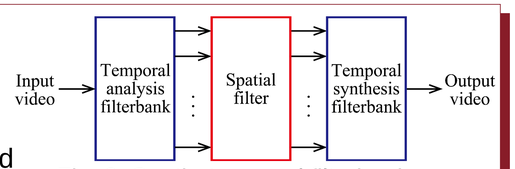

Fig. 2: Spatio-temporal filterbank.

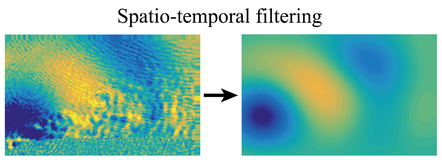

Fig. 3: Spatio-temporal filtered data.

Proposed method

- A guided filter is integrated into the spatio-temporal filterbank.
- To do so, we consider the weighted least squares method:

$$\arg\min_{a_m, b_m} \sum_{n \in \mathcal{W}_m} w_{n,m} \big((\, a_m\, G(n) + b_m - I_{\mathrm{in}}(n)\,)^2 + \lambda\, a_m^2 \big).$$

$a_m,\ b_m$: some coefficients for the mth region n: index of the image pixel
$\mathcal{W}_m$: mth region of a sliding window G: guidance image
$w_{n,m}$: weight I_{in}: input image λ: regularization parameter

- The weight is decided according to the frequency of sound.
- The guidance image is a binary mask of the occluding objects.

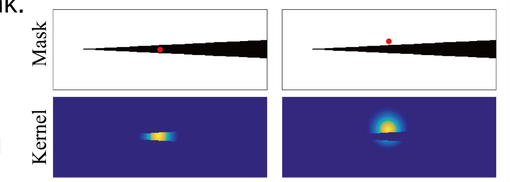

Fig. 4: Filter kernel of the guided filter. Smoothing does not occur because the kernel does not stretched over the edge of the mask.

Experiments

<Simulation>

- Simulated noisy sound fields, with and without occluding objects, were spatially filtered by the proposed guided filter and conventional linear filter with four boundary conditions for comparison.

Table 1: Conditions of the simulation.

Filters	Ordinary liner filters (zero padding, symmetric copy, replication, circular copy)
	Proposed guided filter
SNRs of input images [dB]	-20, -10, 0, 10, 20

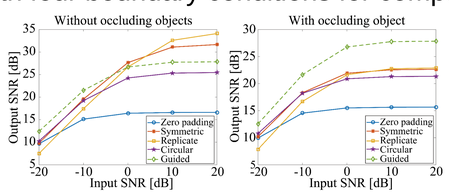

Fig. 5: SNRs of guided filtered images.

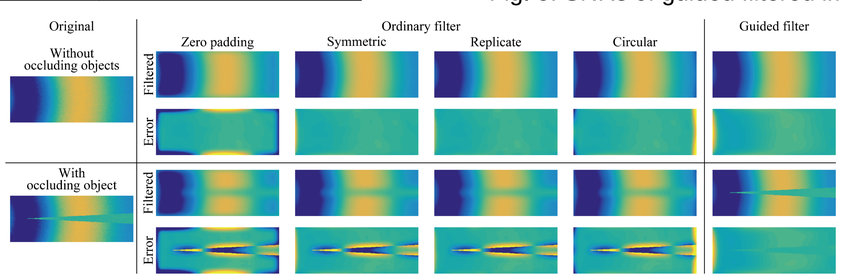

Fig. 6: Filtered results of the simulated data (SNR: 20 dB).

<Application to data measured by PPSI>

- The proposed method was applied to three types of measured data (Fig. 6).

(i) Speaker+hose: A sound field generated from a loudspeaker and a flow field blown from a hose.
(ii) Whistle: A sound and flow field emitted from a whistle.
(iii) Edge-tone: A sound and flow field generated by an edge-tone phenomenon.

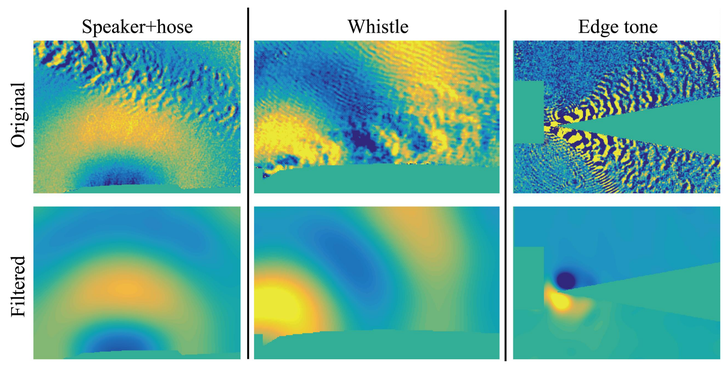

Fig. 7: Guided filtered images of experimental data.

Conclusions

- A guided-spatio-temporal filter is effective for extracting sound field with occluding objects captured by optical method.
- Future work includes application of the proposed method for physical investigation.