Near field Acoustic Holography on arbitrary shapes using Convolutional Neural Network

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Abstract

Near-field Acoustic Holography (NAH) is a well-known problem aimed at estimating the vibrational velocity field of a structure by means of acoustic measurements. In this paper, we propose a NAH technique based on Convolutional Neural Network (CNN). The devised CNN predicts the vibrational field on the surface of arbitrary shaped plates (violin plates) with orthotropic material properties from a limited number of measurements. In particular, the architecture, named Super Resolution CNN (SRCNN), is able to estimate the vibrational field with a higher spatial resolution compared to the input pressure. The pressure and velocity datasets have been generated through Finite Element Method simulations. We validate the proposed method by comparing the estimates with the synthesized ground truth and with a state-of-the-art technique. Moreover, we evaluate the robustness of the devised network against noisy input data.

1. Problem Formulation

- Kirchhoff-Helmholtz (KH) *[1]* integral models the exterior acoustic radiation a vibrating surface $\mathcal{S}$

$$p(\boldsymbol{r},\omega) = \int_{\mathcal{S}} p(\boldsymbol{s},\omega)\frac{\partial}{\partial \boldsymbol{n}} g_\omega(\boldsymbol{r},\boldsymbol{s})d\boldsymbol{s} - j\omega\rho_0 \int_{\mathcal{S}} v_n(\boldsymbol{s},\omega) g_\omega(\boldsymbol{r},\boldsymbol{s})d\boldsymbol{s}$$

- Discretization of KH evaluated at the holographic plane $\mathcal{H}$ with the introduction of the discrete estimator F

$$\mathbf{p}_{\mathcal{H}}(\omega) \approx \mathcal{F}(\mathbf{p}_{\mathcal{S}}, \mathbf{v}, \omega)$$

NAH GOAL:
recover the velocity on the surface from the pressure measured at the holographic plane

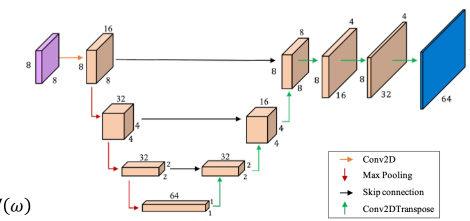
$$\boxed{\hat{\mathbf{v}}(\omega) \approx \mathcal{F}^{-1}(\mathbf{p}_{\mathcal{H}}(\omega))}$$

2. Proposed Solution with SRCNN *(https://github.com/polimi-ispl/nah-srcnn)*

Learn the function $\mathcal{F}^{-1}$ by means of Convolutional Neural Network

Network:
- UNet style architecture
- Input pressure magnitude $\mathbf{P}_{\mathcal{H}}(\omega) \in \mathbb{R}^{8\times 8}$
- Output velocity magnitude $\hat{\mathbf{V}}(\omega) \in \mathbb{R}^{16\times 64}$

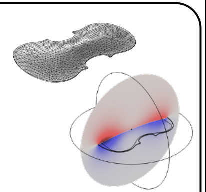
Training:
- Training - Validation - Test set
  80% - 10% - 10%
- Weights trained on the MSE between $\hat{\mathrm{V}}(\omega)$ and $\mathrm{V}(\omega)$



3. Dataset & Validation description

Dataset

- Violin top plates with parametric outlines *[2]*
- FEM simulations with COMSOL Multiphysics®
- Total pressure and velocity images $\quad Dataset = 72\,323$

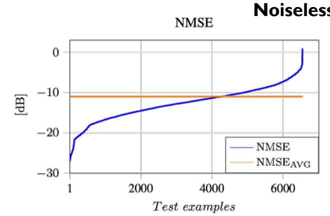


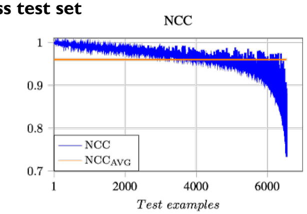
Validation

- Normalized Cross Correlation $\mathrm{NCC} = \dfrac{|\hat{\mathbf{v}}(\omega)^T \mathbf{v}(\omega)|}{||\hat{\mathbf{v}}(\omega)||_2 \cdot ||\mathbf{v}(\omega)||_2}$
- Normalized Mean Square Error $\mathrm{NMSE} = 10\log_{10}\left(\dfrac{||\hat{\mathbf{v}}(\omega) - \mathbf{v}(\omega)||_2^2}{||\mathbf{v}(\omega)||_2^2}\right)$
- Comparison with Dictionary-based ESM (DESM) *[3]*

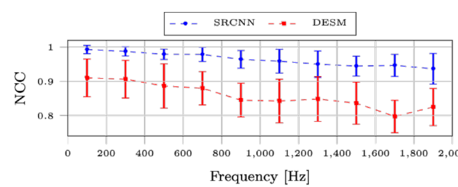
4. Results

Noiseless test set

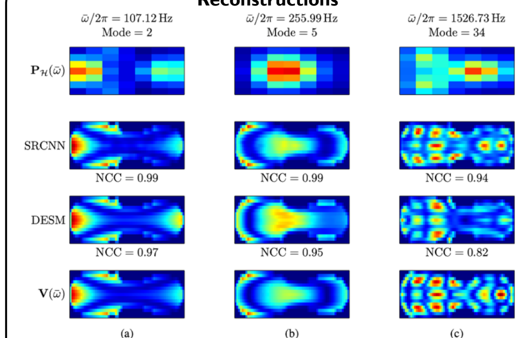




- $\mathrm{NMSE}_{\mathrm{AVG}}$ = -10.96 dB
- $\mathrm{NCC}_{\mathrm{AVG}}$ = 0.96 (96%)
- SRCNN outperformed DESM for the whole frequency range



Reconstructions



- SRCNN provides robustness against noisy input data up to SNR = 10 dB

References

[1] E. G. Williams, "Fourier acoustics: sound radiation and nearfield acoustical holography", Elsevier, 1999
[2] S. Gonzalez, D. Salvi, D. Baeza, F. Antonacci, and A. Sarti, "A data-driven approach to violin making," Scientific Reports, vol. 11, no. 1, pp. 1–9, 2021
[3] A. Canclini, M. Varini, F. Antonacci, and A. Sarti, "Dictionary-based equivalent source method for near-field acoustic holography" in 2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), pp. 166–170, IEEE, 2017.

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