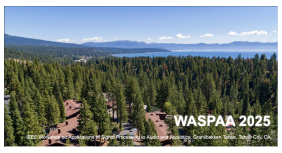

14 Oct. 2025

SFC-L1:

Sound Field Control With Least Absolute Deviation Regression

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1. Introduction

- **Sound field control with multiple loudspeakers and control points**
  - Pressure matching, mode-matching …
  - Least squares (LS) regression
    -> Maximum-likelihood estimation
    = Error is assumed to be Gaussian distribution

- **Proposed method: SFC-L1**
  - Pressure matching with least absolute value (LAD) regression
    -> Error is assumed to be Laplace distribution

- **Torch-SFC**
  - Pytorch-based sound field control toolkit

2. Conventional LS-based methods

- **Simple and weighted pressure matching methods**
  - Synthesized sound field

$$p_{\mathrm{syn}}(\boldsymbol{r}) = \sum_{l=1}^{L} d_l(\boldsymbol{r}_l) G(\boldsymbol{r}|\boldsymbol{r}_l) = \boldsymbol{g}(\boldsymbol{r})^{\top}\boldsymbol{d}$$

  - Cost function for simple pressure matching

$$\underset{\boldsymbol{d}}{\text{minimize}}\ \mathcal{J} = \int_{\boldsymbol{r}\in V} \left|\boldsymbol{g}(\boldsymbol{r})^{\top}\boldsymbol{d} - p_{\mathrm{des}}(\boldsymbol{r})\right|^2 \mathrm{d}\boldsymbol{r}$$

  - Cost function for weighted pressure matching

$$\underset{\boldsymbol{d}}{\text{minimize}}\ (\boldsymbol{G}\boldsymbol{d} - \boldsymbol{p}_{\mathrm{des}})^{\mathsf{H}}\boldsymbol{W}_{\mathrm{PM}}(\boldsymbol{G}\boldsymbol{d} - \boldsymbol{p}_{\mathrm{des}}) + \lambda_{\mathrm{WPM}}||\boldsymbol{d}||_2$$

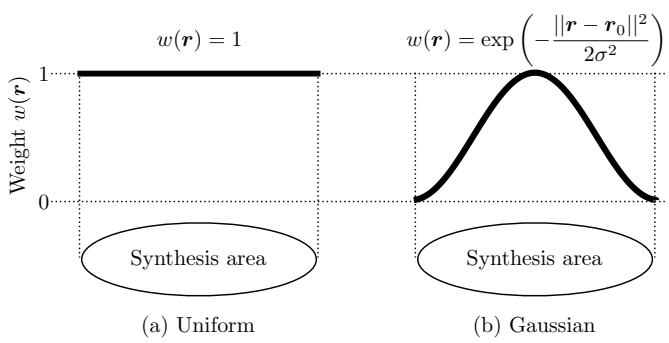
  - Driving signals solved as a closed-form

$$\boldsymbol{d}_{\mathrm{WPM}} = \left(\boldsymbol{G}^{\mathsf{H}}\boldsymbol{W}_{\mathrm{PM}}\boldsymbol{G} + \lambda_{\mathrm{PM}}\boldsymbol{I}\right)^{-1}\boldsymbol{G}^{\mathsf{H}}\boldsymbol{W}_{\mathrm{PM}}\boldsymbol{p}_{\mathrm{des}}$$

3. Proposed method

- **Pressure matching with LAD regression**
  - Cost function with spatial weighting function

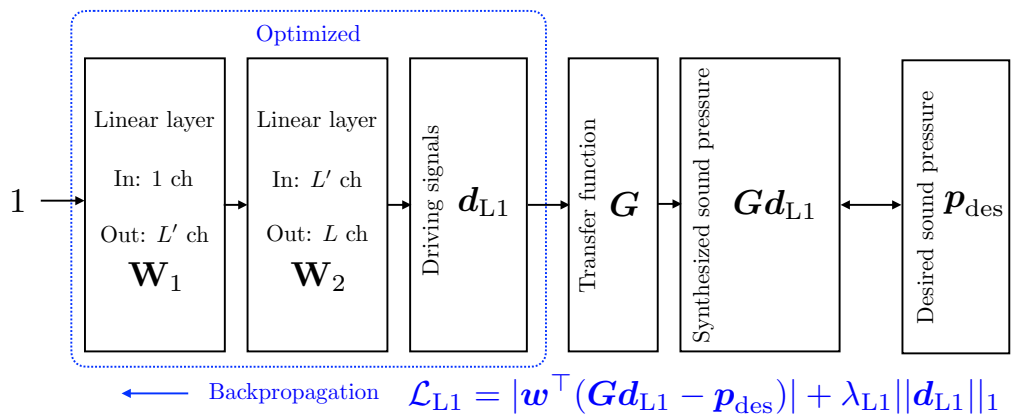
$$\underset{\boldsymbol{d}}{\text{minimize}}\ \mathcal{J} = \int_{\boldsymbol{r}\in V} \left|w(\boldsymbol{r})\left(\boldsymbol{g}(\boldsymbol{r})^{\top}\boldsymbol{d} - p_{\mathrm{des}}(\boldsymbol{r})\right)\right| \mathrm{d}\boldsymbol{r}$$



- **LAD regression with Pytorch**
  - LAD regression is not a closed form
  - Loss function minimized by backpropagation with Adam optimizer

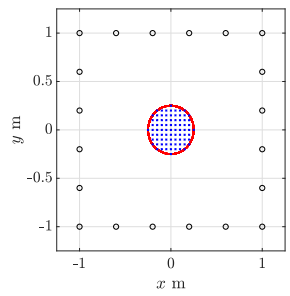
$$\mathcal{L}_{\mathrm{L1}} = |\boldsymbol{w}^{\top}(\boldsymbol{G}\boldsymbol{d}_{\mathrm{L1}} - \boldsymbol{p}_{\mathrm{des}})| + \lambda_{\mathrm{L1}}||\boldsymbol{d}_{\mathrm{L1}}||_1$$

  - Driving signals solved by optimizing weighting matrices

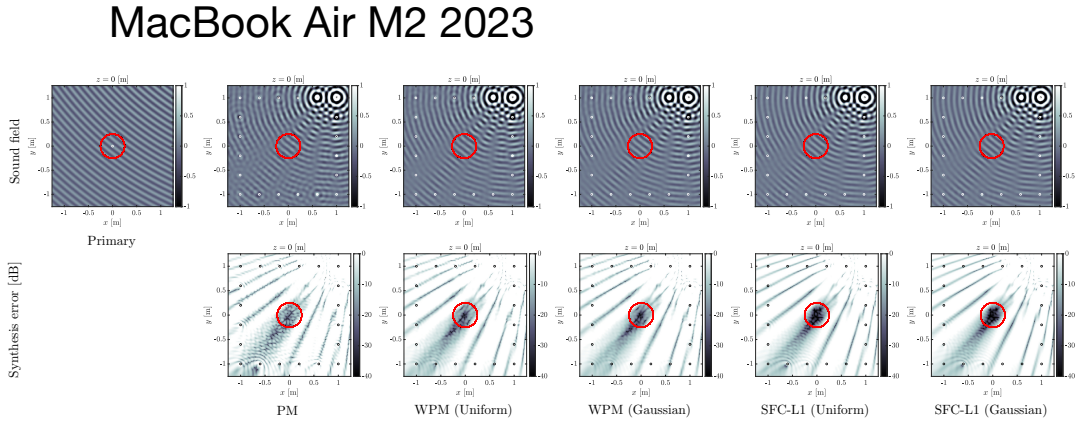


3. Computer simulations

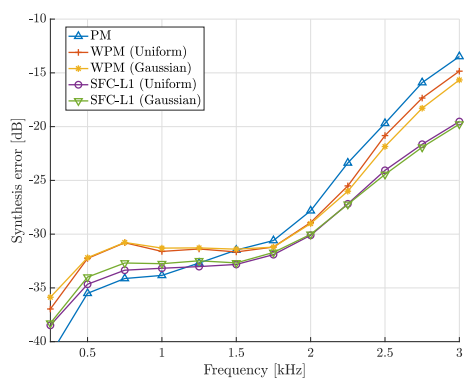
- **2.5-dimensional sound field control**
  - 3-dimensional free-field
  - 20 loudspeakers and 81 control points

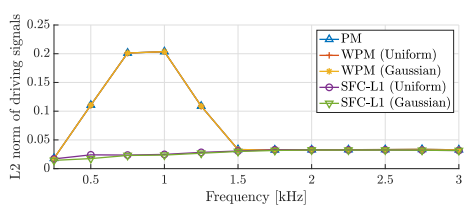


- **Results**
  - Calculation time of proposed method: 0.6 seconds with 4,000 iterations by using Apple MacBook Air M2 2023



Synthesis error for 3 kHz





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