EUSIPCO 2024

LISTENER ACOUSTIC PERSONALISATION (LAP) CHALLENGE

Task-1

HRTF Normalization for Merging Different HRTF Datasets

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2024-08-29

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Introduction

- **Differences between HRTF datasets**
  - Measurement setup
  - Postprocessing
  - ...

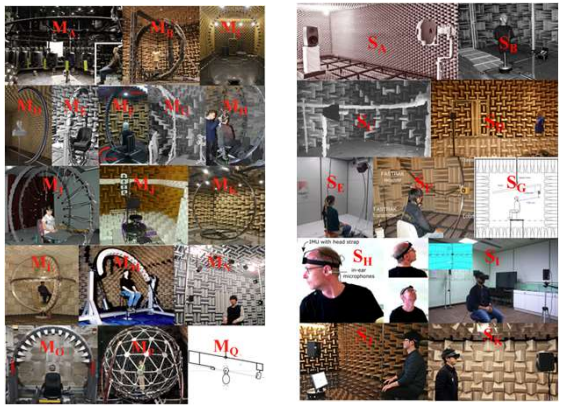


Fig. 8 & Fig. 9 in Li S et al. (2020)

- **Data-driven HRTF modeling**
  - SONICOM, HUTUBS, ...
  - Single dataset → limited performance
  - **Merging datasets**

Task-1

HRTF Normalization for Merging Different HRTF Datasets

- Li S, Peissig J. Measurement of head-related transfer functions: A review[J]. Applied Sciences, 2020, 10(14): 5014.

Introduction

- **Task-1 Constraints**

- **Stage-1**
  - Evaluation with thresholds over different localization metrics computed using an auditory model (*Barumerli et al., 2023*)
  - Differences in localization metrics must be below the threshold for at least 64 of 80 harmonized HRTF datasets (i.e. 80%).

Maintain
Localization Performance

- **Stage-2**
  - The evaluation employs a classifier (*Pauwels and Picinali, 2023*) to test to what extent different collections can be distinguished from each other after harmonization, affirming the removal of measurement setup-induced biases.

Eliminate
Dataset Characteristics

- Barumerli R, Majdak P, Geronazzo M, et al. A Bayesian model for human directional localization of broadband static sound sources[J]. Acta Acustica, 2023, 7: 12.
- Pauwels J, Picinali L. On the relevance of the differences between HRTF measurement setups for machine learning[C]//ICASSP 2023-2023 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP). IEEE, 2023: 1-5.

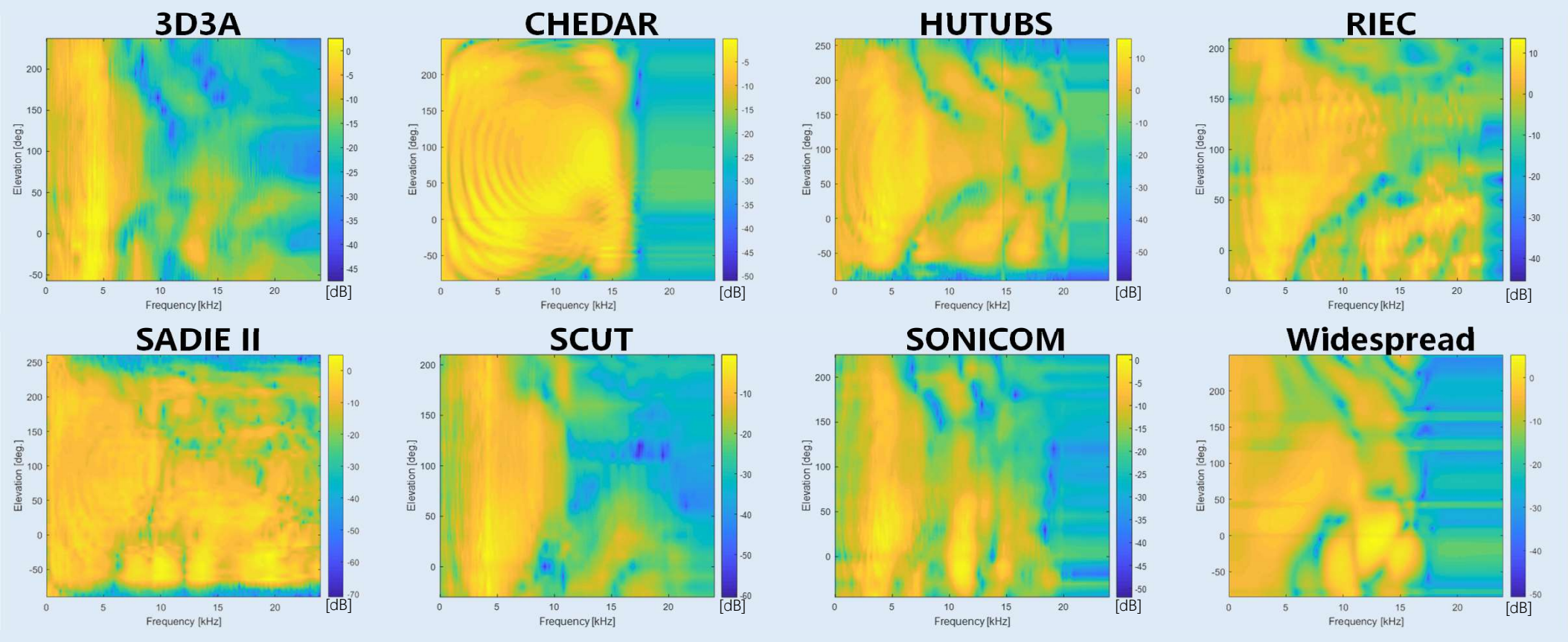
Introduction

- **Dataset Characteristics**

Dataset	Sample Rate	Duration	Radius	Positions	Method	Subjects
3D3A	96 kHz	21.3 ms	0.76 m	648	measured	10
CHEDAR	48 kHz	10 ms	2 m	2522	simulated	10
HUTUBS	44.1 kHz	5.8 ms	1.47 m	440	measured	10
RIEC	48 kHz	10.7 ms	1.5 m	865	measured	10
SADIE II	96 kHz	5.3 ms	1.2 m	2114	measured	10
SCUT	96 kHz	5.3 ms	1 m	864	measured	10
SONICOM	96 kHz	5.3 ms	1.7 m	828	measured	10
Widespread	48 kHz	10 ms	1 m	2522	simulated	10

Introduction

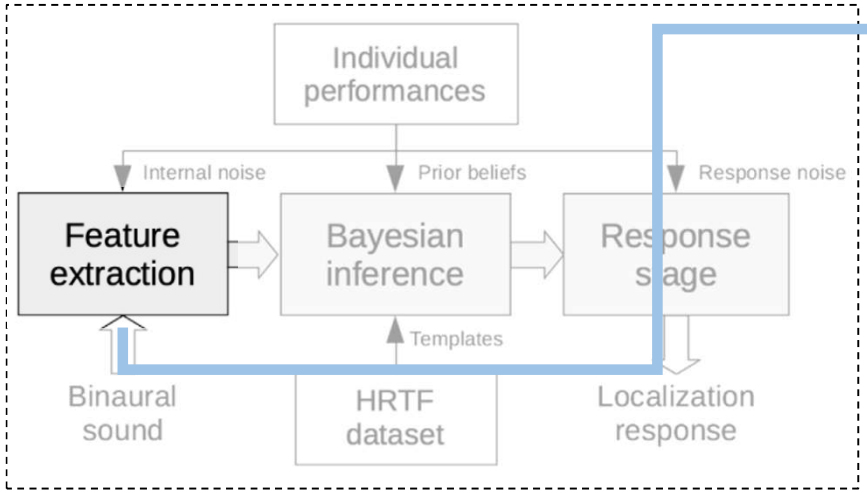
- **Dataset Characteristics**



Contour maps of HRTF spectra on the sagittal plane

Method

- **Maintain Localization Performance**

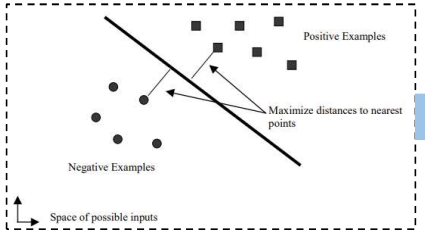


$$\bar{t} = [x_{\mathrm{itd}}, x_{\mathrm{ild}}, \boldsymbol{x}_{\mathrm{L,mon}}, \boldsymbol{x}_{\mathrm{R,mon}}]$$

- **Localization Basis**
  - Interaural Time Difference
  - Interaural Level Difference
  - Binaural gammatone features

Fig. 1 & Eq. 1 in Barumerli et al., 2023

- **Reduce Classification Accuracy**



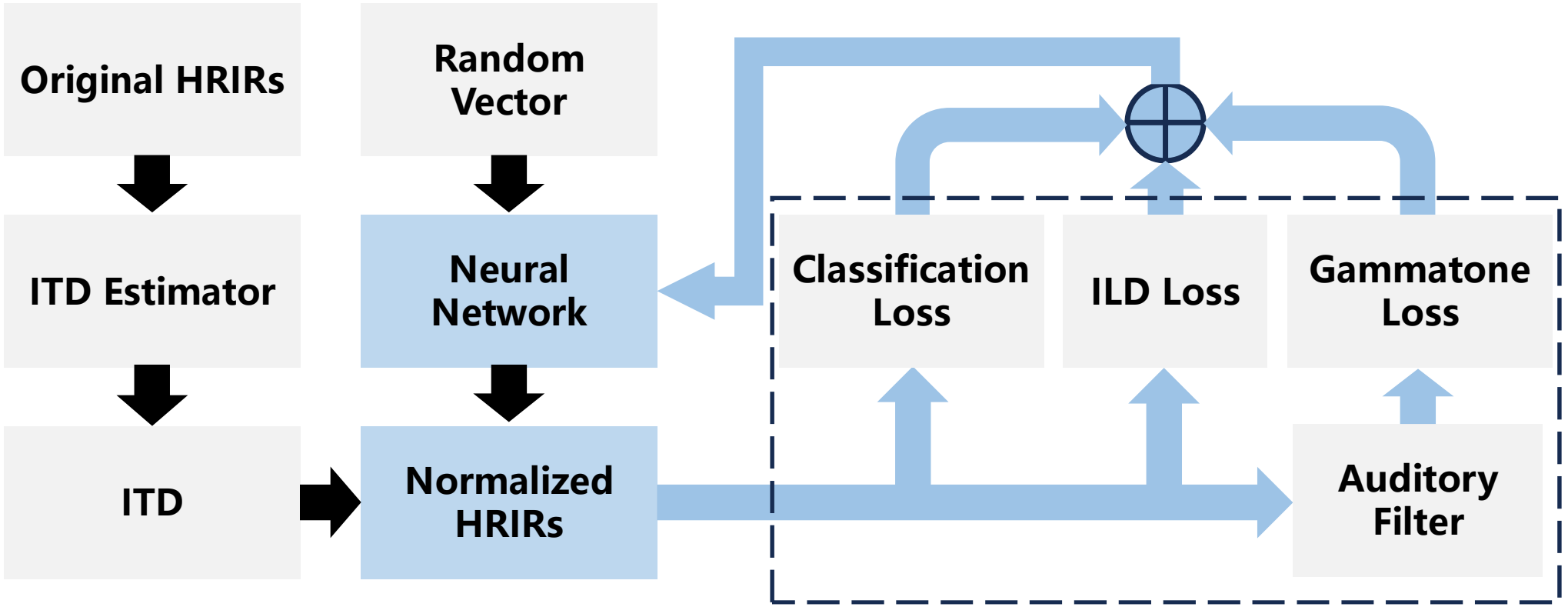
- **Classification Basis**
  - Reduce the distance between classes

Fig. 1 in Platt J, 1998

- Barumerli R, Majdak P, Geronazzo M, et al. A Bayesian model for human directional localization of broadband static sound sources[J]. Acta Acustica, 2023, 7: 12.
- Pauwels J, Picinali L. On the relevance of the differences between HRTF measurement setups for machine learning[C]//ICASSP 2023-2023 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP). IEEE, 2023: 1-5.
- Platt J. Sequential minimal optimization: A fast algorithm for training support vector machines[J]. 1998.

Method

- Flowchart



Method

- **Localization Loss Function**

$$Loss = Loss_{ILD} + \alpha Loss_{gammatone} + \beta Loss_{class}$$

α is 1 and β is 0.01

$$Loss_{ILD} = \left(\sqrt{\frac{\sum_{i=1}^{N} HRIR_i^{\,2}}{N}} - \sqrt{\frac{\sum_{i=1}^{N} \widehat{HRIR}_i^{\,2}}{N}}\right)^2$$

$HRIR$ is binaural
N is the number of samples

$$Loss_{gammatone} = \left(\mathcal{F}(HRIR) - \mathcal{F}\left(\widehat{HRIR}\right)\right)^2$$

$\mathcal{F}$ → Auditory Model in Stage 1

$$Loss_{class} = \sum_{i=1}^{8} \sum_{j=1}^{i} \left\| c_i - c_j \right\|^2$$

c is class center

Maintain
Localization Performance

Eliminate
Dataset Characteristics

Experiments

- **Preprocessing**
  - **HRIR Resampling:** {44100, 48000, 96000} Hz → 48000 Hz, with 512 samples
  - **ITD estimator:** interaural cross-correlation (IACC)

- **Network Training**
  - **Three blocks:** Fully Connected Layer, Batch Normalization, and ReLU activation in each block
  - **Input & Output:** 512x2 samples
  - **One model for one sampling position:** 126 models in total
  - **Training time:** 600 epochs, Nvidia A40 → 2 hours and 40 minutes

Results

- **Stage-1: Localization Performance**

	Lateral Accuracy [deg.]	Polar Accuracy [deg.]	Lateral RMS error [deg.]	Polar RMS error [deg.]	Quadrant error	Polar gain [1/deg.]
Threshold	5.86	12.67	20.71	5.90	34.56%	0.33
Proposed	**0.64**	**3.45**	**15.13**	**2.60**	**17.54%**	**0.08**

Pass Rate: 76/80=95%

- **Stage-2: Classification Accuracy**

1	2	3	4	5	6	7	8	9	10
28.75%	23.13%	24.38%	25.63%	25.00%	27.50%	25.00%	28.75%	25.63%	25.63%

10 validation runs

Mean: 25.94%

Future Work

- **Perceptual Performance**
  - The perceptual evaluation of normalized HRTFs
  - A perceptually similar localization loss function

Ideal loss function:

1. Input: Target position, Binaural HRTFs — Output: Localization Error
2. Input: Binaural HRTFs — Output: Timbre Error

- **Validation of the Normalized HRTF Dataset**
  - A further investigation whether existing HRTF modeling methods demonstrate improved performance with merged datasets.
  - By comparing the performance across small datasets, large datasets, and merged datasets, the effectiveness of the normalization method could be better confirmed..

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Thank you

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Code: https://github.com/IOA3Daudio/LAP-Task-1

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