Paper Number 9892

A method for efficiently calculating head-related transfer functions (HRTFs) directly from head scan point clouds

Presented at the 143rd AES Convention
October 21, 2017, New York, NY, USA

Rahulram Sridhar (presenter)
Edgar Y. Choueiri

3D Audio and Applied Acoustics (3D3A) Laboratory
Princeton University, Princeton, NJ, USA
www.princeton.edu/3D3A

Paper Number 9892

Outline

- Introduction
- Motivation
- Method Formulation
- Application
- Validation
- Conclusions
- Future Work

Paper Number 9892

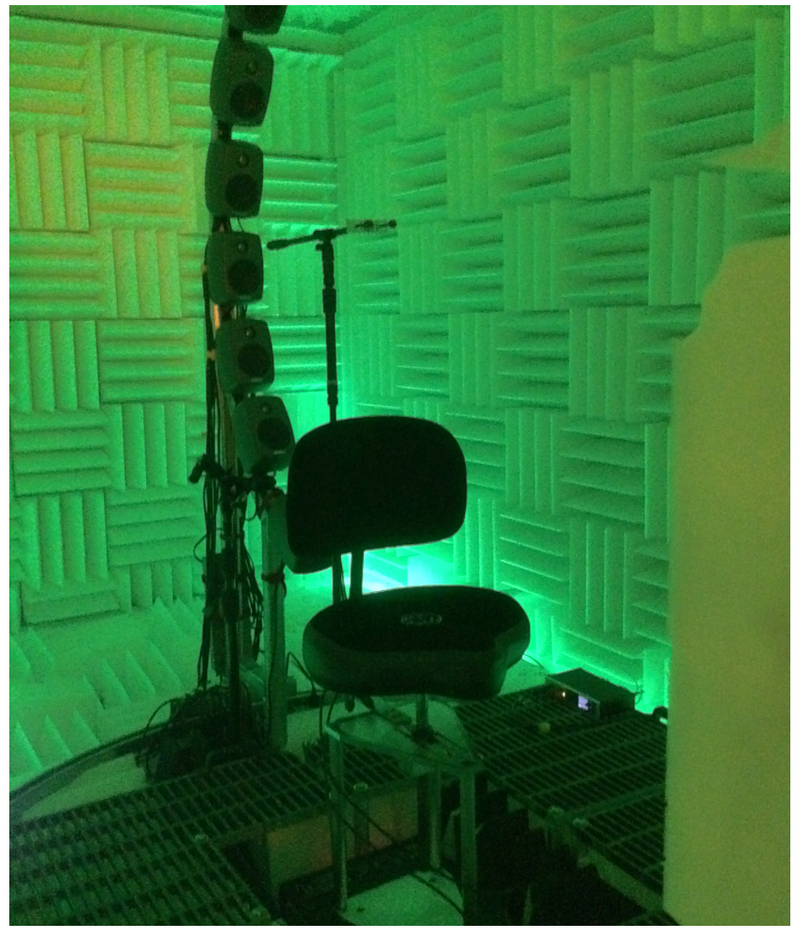
Outline

- **Introduction**
- Motivation
- Method Formulation
- Application
- Validation
- Conclusions
- Future Work

Introduction

HRTFs from acoustical measurements

- Currently most accurate
- Benchmarks for comparing computed HRTFs
- Requires anechoic chamber
- Cumbersome to set up
- Can be tiresome for subject
- Not ideal for commercial implementation



HRTF measurement setup at 3D3A lab

Outline

- Introduction - Acoustically-measured HRTFs are accurate but not ideal for commercial use.
- **Motivation**
- Method Formulation
- Application
- Validation
- Conclusions
- Future Work

Motivation

HRTFs from morphological data: Existing methods

I.
Refs: [3 - 6]

- Computationally expensive.
- Inaccurate without an accurate 3D mesh.

All reference numbers correspond to those in the associated convention paper.

Motivation

HRTFs from morphological data: Existing methods

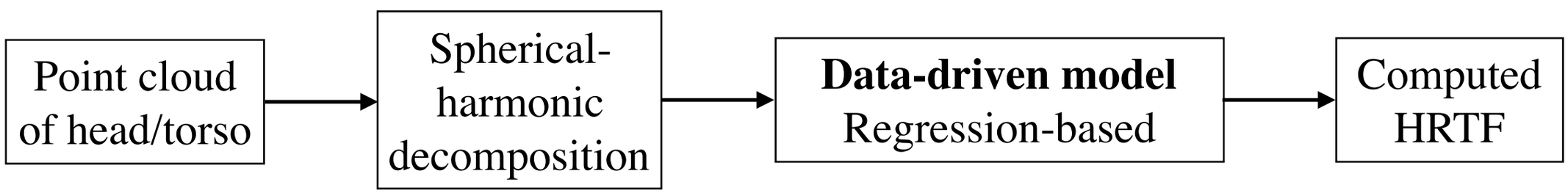
II.
Ref: [2]

Requires explicit identification and measurement of anthropometric features.

All reference numbers correspond to those in the associated convention paper.

Motivation

HRTFs from morphological data: Proposed method



- Requires only point cloud data.
- Computationally inexpensive.
- Does not require explicit identification and measurement of anthropometric features.

Paper Number 9892

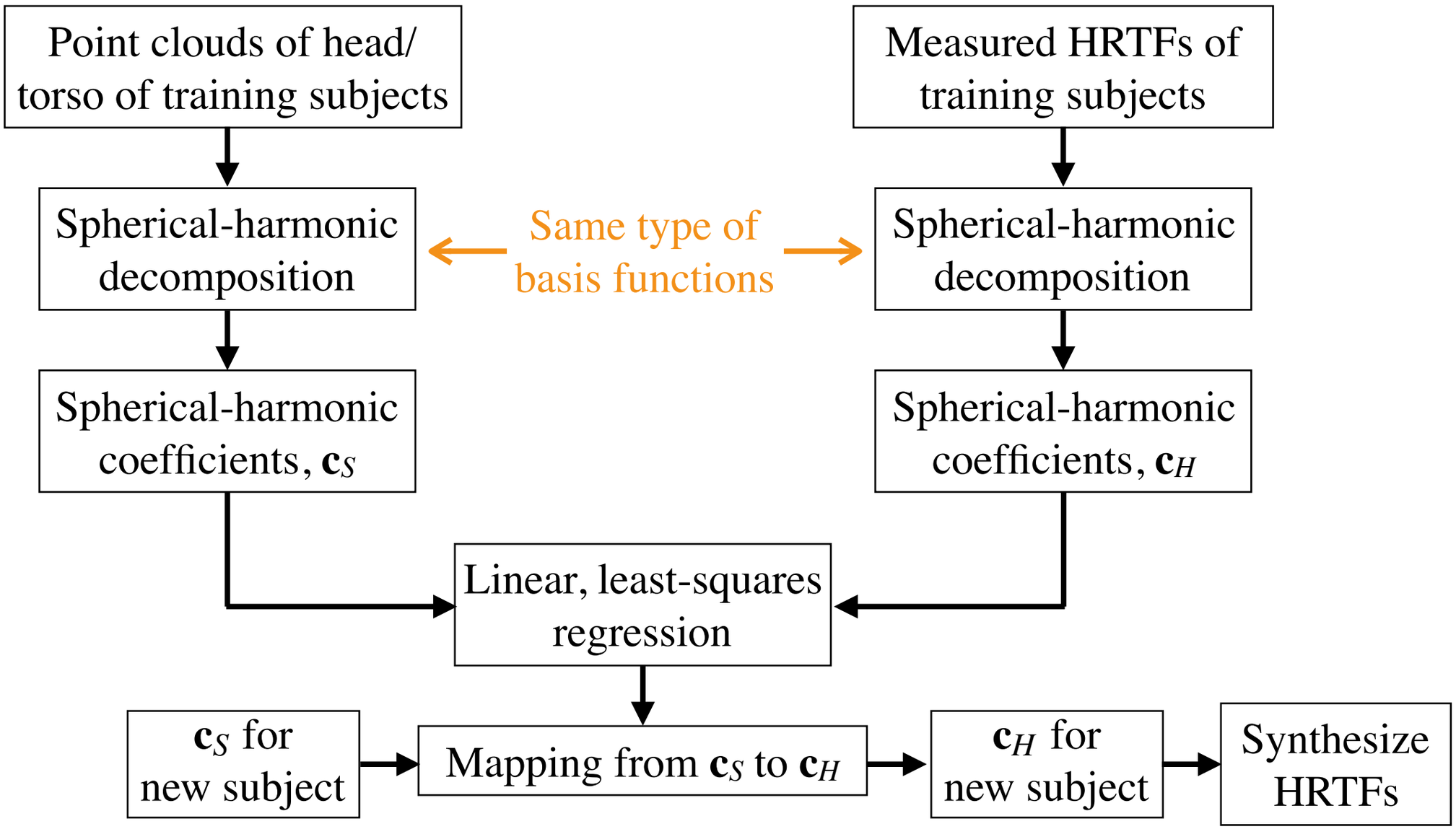
Outline

- Introduction - Acoustically-measured HRTFs are accurate but not ideal for commercial use.
- Motivation - Meshed scans and anthropometric features for computing HRTFs using existing methods are difficult to obtain with required accuracy.
- **Method Formulation**
- Application
- Validation
- Conclusions
- Future Work

Paper Number 9892

Method Formulation

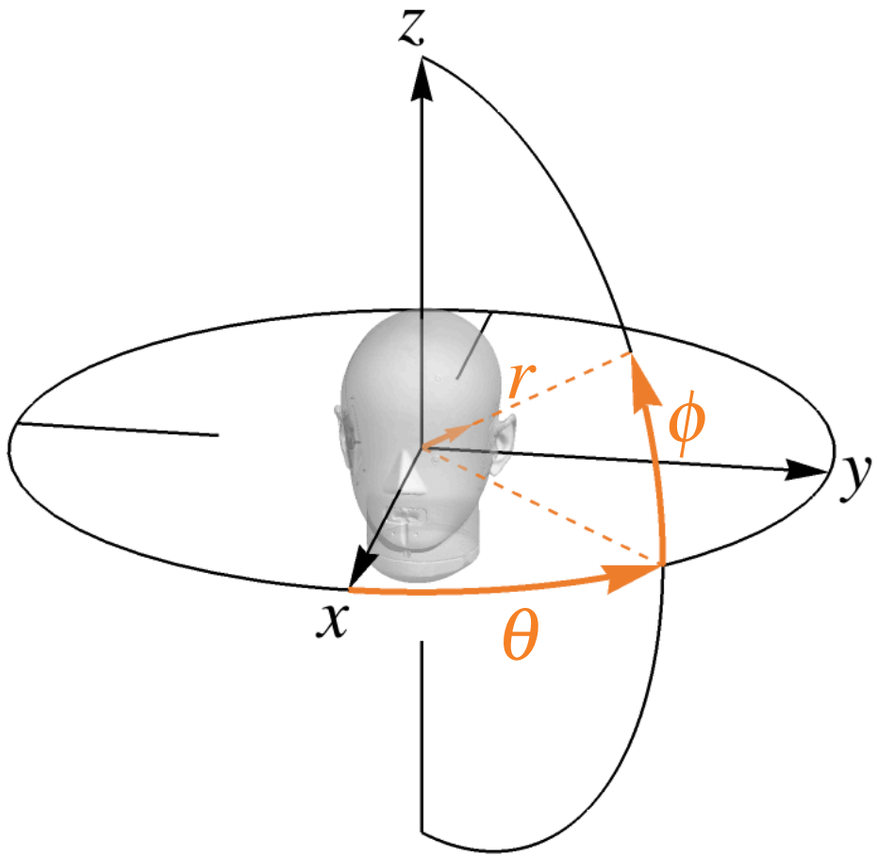
Basic idea



Paper Number 9892

Method Formulation

Spherical harmonic representation of point cloud data



Represent $r(\theta, \phi)$ using spherical harmonics

Assumption: Scan is already aligned as shown above.

Paper Number 9892

Method Formulation

Spherical harmonic representation of HRTF data

Choose HRTF feature and represent as spatial function, $H(\theta, \phi)$

↓

Represent $H(\theta, \phi)$ using spherical harmonics

Example features:

(1) ITDs
(2) HRTF frequency responses
(3) HRTF magnitude responses

Outline

- Introduction - Acoustically-measured HRTFs are accurate but not ideal for commercial use.
- Motivation - Meshed scans and anthropometric features for computing HRTFs using existing methods are difficult to obtain with required accuracy.
- Method Formulation - Point clouds → Spherical harmonics → Matrix multiplications → HRTFs
- **Application**
- Validation
- Conclusions
- Future Work

Paper Number 9892

Application

Data acquisition

Measured HRTF and head scan database	RIEC* [12]
Number of “training” subjects, U	23
HRTF features	(1) HRTF magnitude spectra in dB (cf. [10]) (2) ITD computed by thresholding (cf. [13])

*http://www.riec.tohoku.ac.jp/pub/hrtf/index.html

All reference numbers correspond to those in the associated convention paper.

Application

Data pre-processing

- Make measured HRIRs minimum-phase and truncate to 5.8 ms [10].

- Align head scan such that *y*-axis = interaural axis and *x*-axis lies in both horizontal and median planes.

All reference numbers correspond to those in the associated convention paper.

Paper Number 9892

Application

Spherical harmonic representation of point cloud data

Maximum possible degree = 3

Mapping to	Degree used
HRTF magnitudes	2
ITDs	1

“Degree” corresponds to degree of spherical harmonic expansion of point cloud data

Paper Number 9892

Application

Spherical harmonic representation of HRTF feature data

Maximum possible degree = 14

HRTF feature	Degree used
HRTF magnitudes in dB	6 (cf. [10])
ITDs	3

Paper Number 9892

Outline

- Introduction - Acoustically-measured HRTFs are accurate but not ideal for commercial use.
- Motivation - Meshed scans and anthropometric features for computing HRTFs using existing methods are difficult to obtain with required accuracy.
- Method Formulation - Point clouds → Spherical harmonics → Matrix multiplications → HRTFs
- Application - Derive mappings from spherical harmonic representations of point clouds to those of (1) HRTF magnitudes in dB and (2) ITDs.
- **Validation**
- Conclusions
- Future Work

Paper Number 9892

Validation

Approach and Metrics

- Number of “test” subjects = 2

- Metric to validate computed HRTF magnitudes: log-weighted average spectral distortion in dB.

- Metric to validate computed ITDs: absolute ITD error.

Paper Number 9892

Validation

Providing Perceptual Context

Approx. perceptibility threshold for rms average spectral distortion

Frequency range (kHz)	Perceptibility threshold (dB)
0 to 2	1
2 to 8	2
8 to 16	3

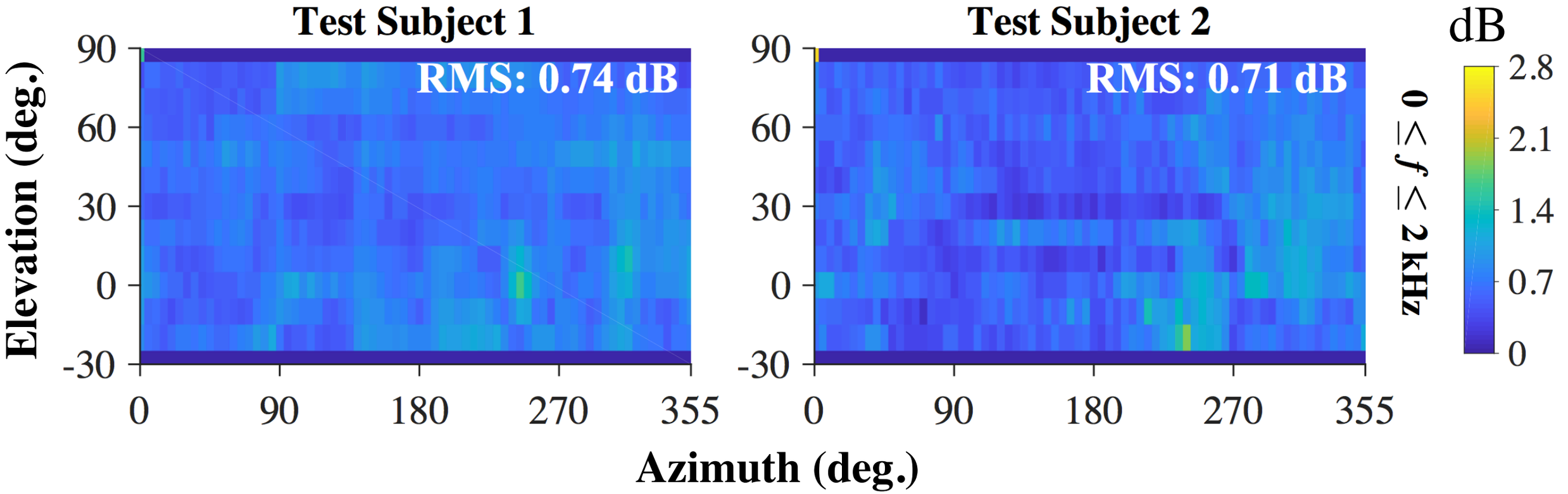
Approx. perceptibility threshold for absolute ITD error = $30\,\mu$s

Paper Number 9892

Validation

Computed HRTF magnitudes

Log-weighted average spectral distortion in dB



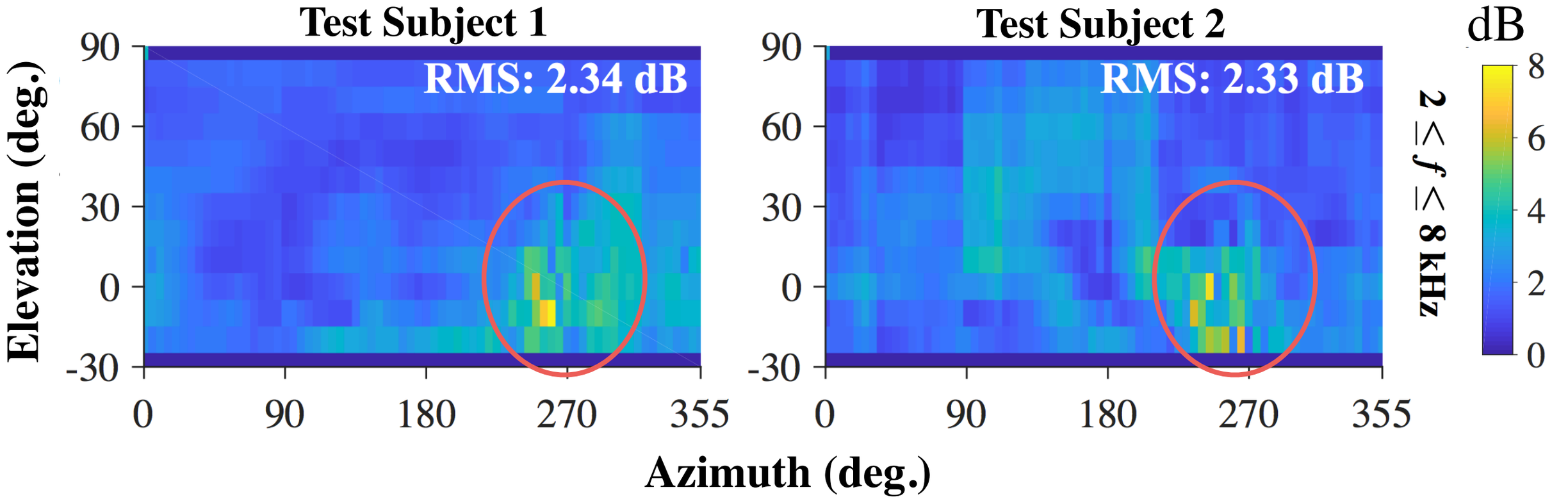
Approx. rms perceptibility threshold = 1 dB

Paper Number 9892

Validation

Computed HRTF magnitudes

Log-weighted average spectral distortion in dB



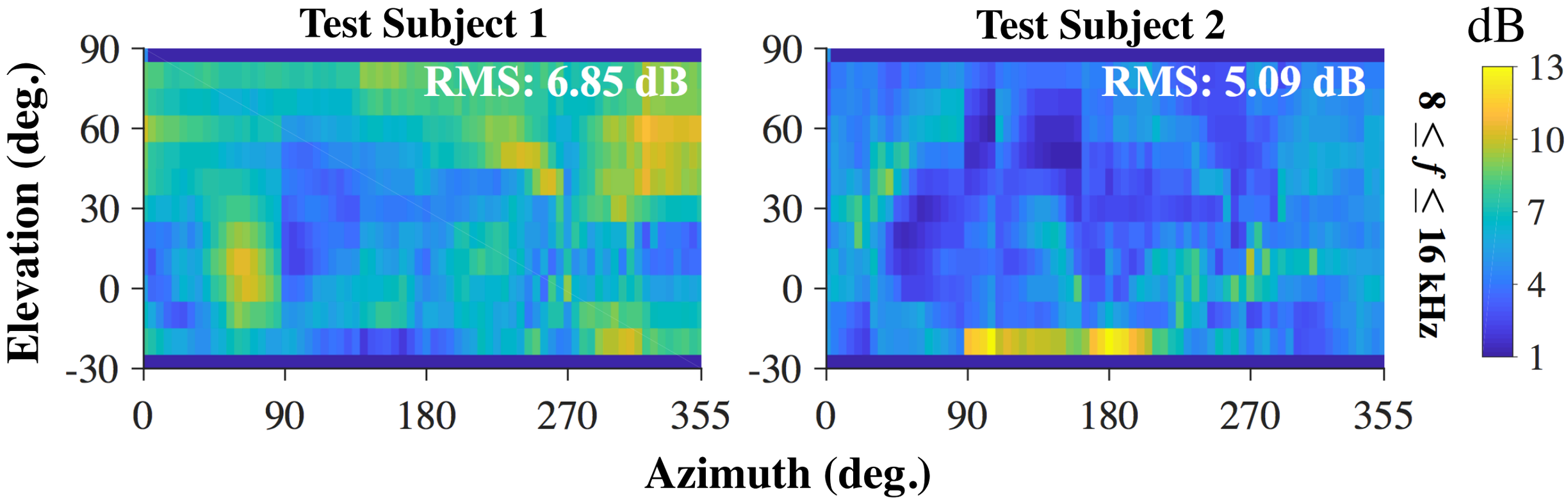
Approx. rms perceptibility threshold = 2 dB

Paper Number 9892

Validation

Computed HRTF magnitudes

Log-weighted average spectral distortion in dB



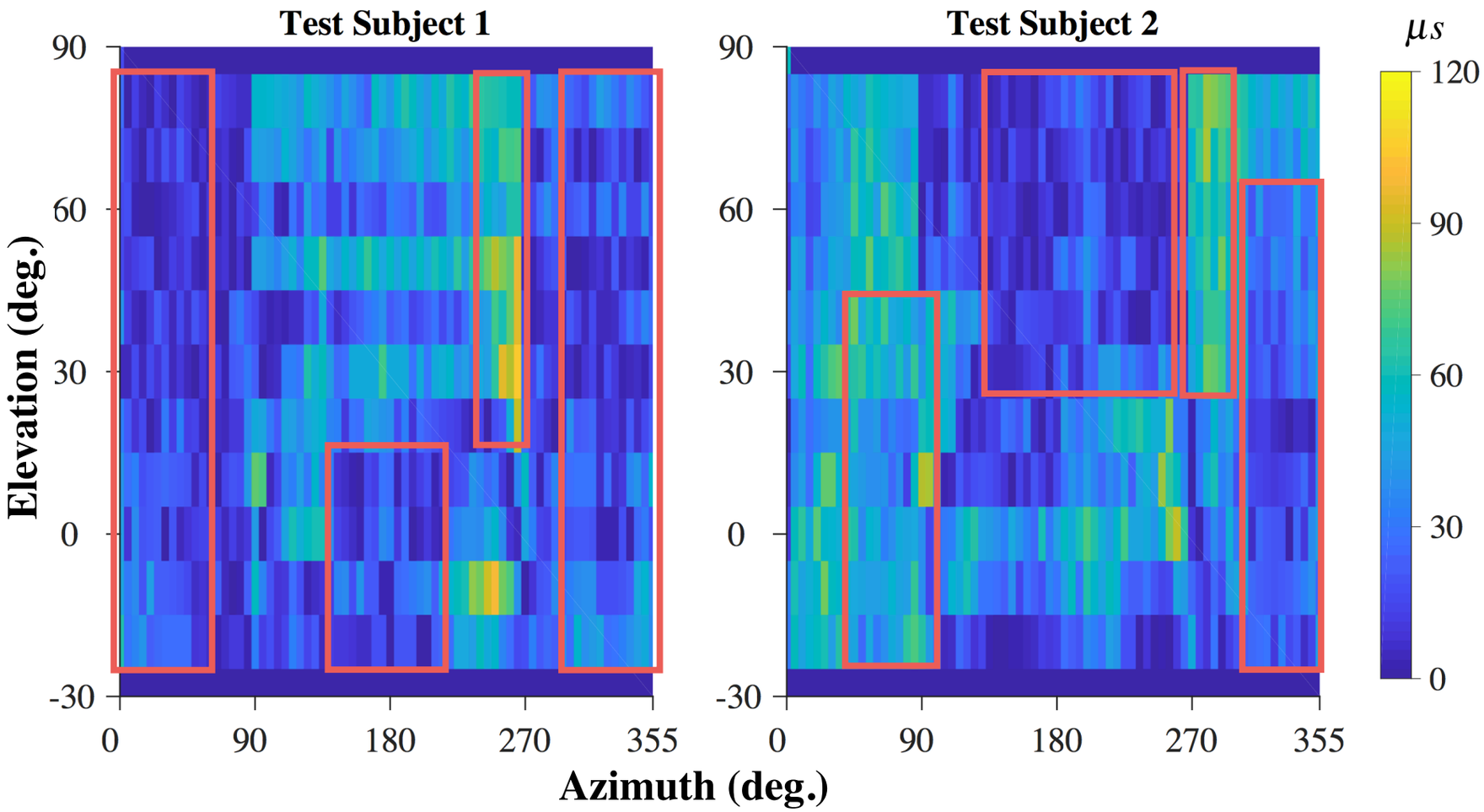
Approx. rms perceptibility threshold = 3 dB

Paper Number 9892

Validation

Computed ITDs

Absolute ITD error in μs



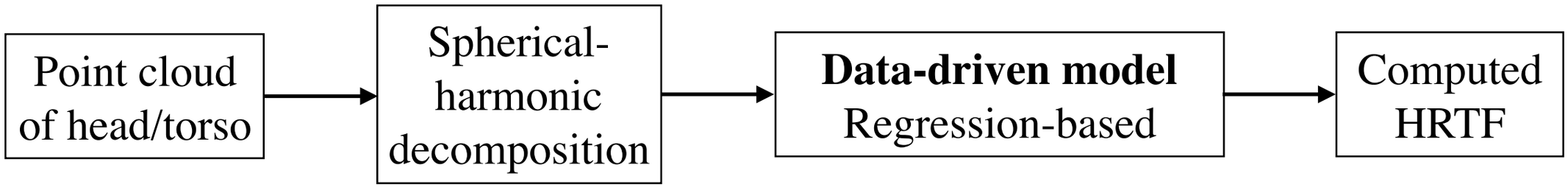
Paper Number 9892

Outline

- Introduction - Acoustically-measured HRTFs are accurate but not ideal for commercial use.
- Motivation - Meshed scans and anthropometric features for computing HRTFs using existing methods are difficult to obtain with required accuracy.
- Method Formulation - Point clouds → Spherical harmonics → Matrix multiplications → HRTFs
- Application - Derived mappings from spherical harmonic representations of point clouds to those of (1) HRTF magnitudes in dB and (2) ITDs.
- Validation - Used two test subjects to objectively show (with perceptual context) that computed HRTFs are accurate up to approx. 6 kHz.
- **Conclusions**
- Future Work

Conclusions

- Presented the following method to compute HRTFs from point cloud data of an individual's morphology:



- HRTFs directly from point clouds and no need to identify anthropometric features. This makes it suitable for commercial implementation.

- The current implementation of our method may be used to compute HRTFs that are likely indistinguishable from measured HRTFs for $f < 6$ kHz.

- More data is required to determine how the method performs at higher frequencies. So the 6 kHz limit above may **not** be a limitation of the method.

Outline

- Introduction - Acoustically-measured HRTFs are accurate but not ideal for commercial use.
- Motivation - Meshed scans and anthropometric features for computing HRTFs using existing methods are difficult to obtain with required accuracy.
- Method Formulation - Point clouds → Spherical harmonics → Matrix multiplications → HRTFs
- Application - Derived mappings from spherical harmonic representations of point clouds to those of (1) HRTF magnitudes in dB and (2) ITDs.
- Validation - Used two test subjects to objectively show (with perceptual context) that computed HRTFs are accurate up to approx. 6 kHz.
- Conclusions - Our method is suitable to implement commercially, and shows promise for computing HRTFs accurately, but more data is needed.
- **Future Work**

Future Work

- Applying method to larger dataset.
- Trying different types of HRTF features to represent using spherical harmonics.
- Trying different mapping techniques.
- Trying to account for the fact that the head with pinnae is a non-star-shaped object.
- Validation using subjective listening tests.

Paper Number 9892

A method for efficiently calculating head-related transfer functions (HRTFs) directly from head scan point clouds

Presented at the 143rd AES Convention
October 21, 2017, New York, NY, USA

Rahulram Sridhar (presenter)
Edgar Y. Choueiri

3D Audio and Applied Acoustics (3D3A) Laboratory
Princeton University, Princeton, NJ, USA
www.princeton.edu/3D3A