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HRTF Measurements and their Improvements with Time-Frequency Methods

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Signal Processing Workshop 2011; Brno, 28.10.2011

Overview:

Overview:

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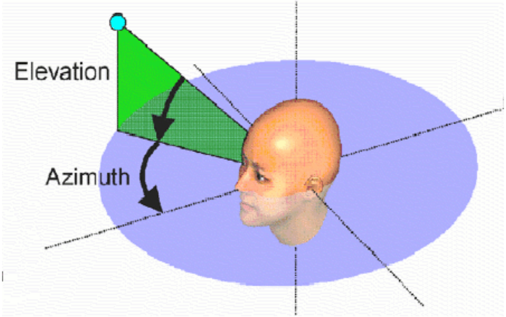
Overview:

Spatial Hearing

Spatial Hearing

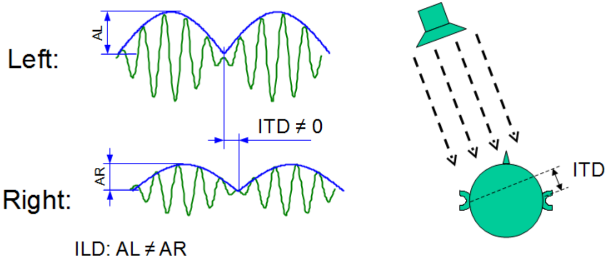
How can humans localize sounds ?



Signals from two receivers (=ears) available!

Spatial Hearing

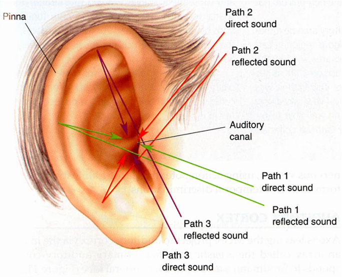
- Interaural level differences (ILDs)
- Interaural time differences (ITDs)



Important for Left-Right Localization!

Spatial Hearing

- Asymmetries in the geometry of the individual receivers lead to
  - Direction-dependent spectral change of incoming sound.
  - Important for Up-Down and Front-Back Localization!



- Head-related transfer functions (HRTFs):
  - Describe the filtering effect of the head, torso, pinna.
  - Depend on the position of the sound source.
  - Unique for every person.

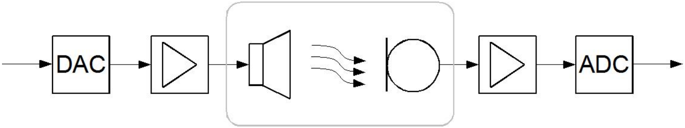
Acoustic System Estimation and HRTF Measurements

Acoustic System Estimation

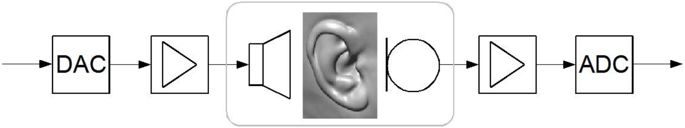
Measurement of Head Related Transfer Functions (HRTFs)

Acoustic System Estimation

Electro-acoustic signal path:
weakly non-linear, time invariant systems (PA, Speakers)



with head-movement weakly non-linear, time variant system
But the interesting part is the HRTF: an LTI system!



(Non-blind) System identification :

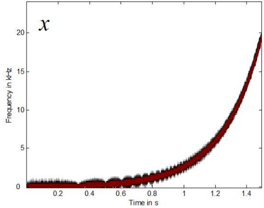
Choice of Excitation signals:

- Impulse
- white noise
- binary pseudo random sequences
- frequency sweeps
  - linear
  - exponential

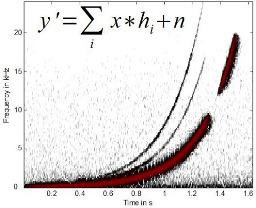
We choose Exponential Sweeps: small crest factor, monofrequent, non-linearities well separable, ...

Acoustic System Estimation

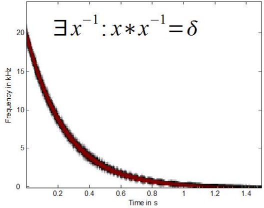
Input

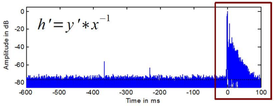


Output



Deconvolution





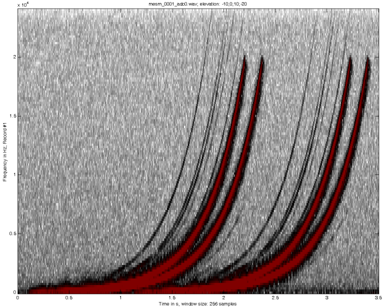
Improvement of Head-Related-Transfer-Function-Measurements

HRTF measurements

Peter Balazs

- Spatial Hearing
- Acoustic System Estimation and HRTF Measurements
- **MESM**
- HRTF Modeling
- Future and Current Projects
- Conclusion

Improvement of the Measurement by the Multiple Exponential Sweeps Method (MESM) [Majdak et al., 2007]



Optimized parameter for overlapping and interleaving the sweeps in the time-frequency domain.
Speed up measurement by **factor of four**.

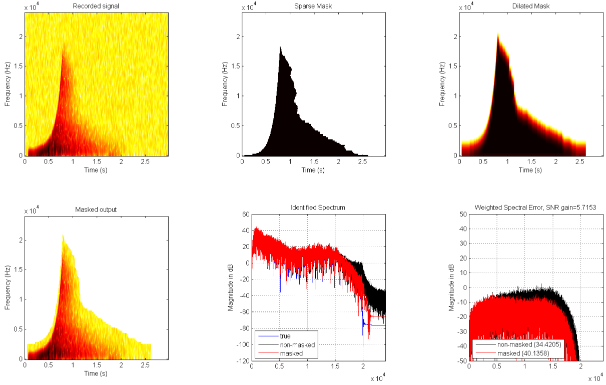
Improvement of Head-Related-Transfer-Function-Measurements

Time-Frequency Denoising [Majdak et al., 2011]:
Measurement is diluted by noise, which in this case is often frequency-dependent. Standard-methods need assumption of white noise or produce artifacts.
We propose a method using a time-frequency multiplier.
Advantages:

- Takes redundant representation into account.
- Uses a-priori knowledge of input signal.
- Noise can have any spectral shape.
- It improves the measurement significantly for long IRs and low SNR.
- It *doesn't* introduce artifacts, also not in the case of high SNR.

Improvement of Head-Related-Transfer-Function-Measurements

Time-Frequency Denoising [Majdak et al., 2011]:



Application to concrete HRTF measurements and determination of exact advantages is current research!

HRTF Modeling by BEM

Helmholtz equation

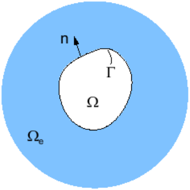
- Helmholtz equation

$$L(\Phi(x)) = \nabla^2\Phi(x)+k\Phi(x) = 0$$

- Boundary conditions

$$\Phi(x) = p(x), x \in \Gamma_D, \frac{\partial\Phi(x)}{\partial n} =$$

$$\left|\frac{\partial\Phi}{\partial r} - \mathrm{i}k\Phi\right| \leq$$



- Fundamental solution

$$L(G(x,y)) = \delta(x-y) \quad G(x,y) = \frac{e^{\mathrm{i}k||x-y||}}{4\pi||x-y||}.$$

Integral Equation

With Green's Theorem restriction to boundary!

Representation formula

$$\alpha\Phi(x) = -\int_\Gamma G(x,y)\Psi(y)ds_y + \int_\Gamma \frac{\partial G(x,y)}{\partial n_y}\Phi(y)ds_y$$

Discretization $\Longrightarrow$ Boundary Element Method (BEM).

Galerkin

To solve operator equation

$$Bu = f$$

it is projected on finite-dimensional subspace:

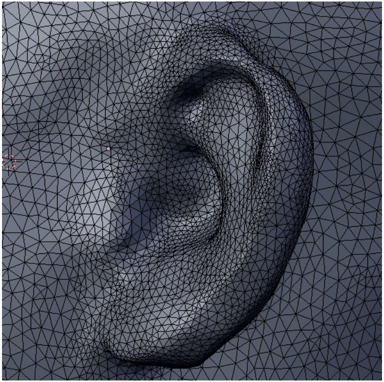
$$\boldsymbol{B}\boldsymbol{u} = \boldsymbol{f} \text{ with } \boldsymbol{B}_{ij} = \langle B\phi_i, \phi_j \rangle$$

Standard choices: (ϕ_i) Orthonormal basis [Sauter and Schwab, 2004] or Riesz basis [Dahlke et al., 2005].

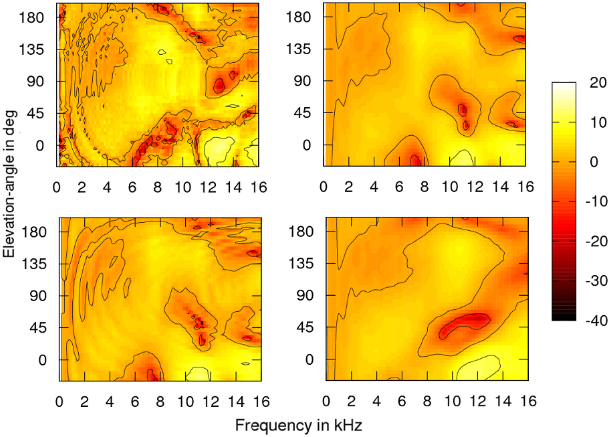
BEM-Model of HRTFs

Fast Multipole BEM-Model of HRTFs

[Kreuzer et al., 2009]:



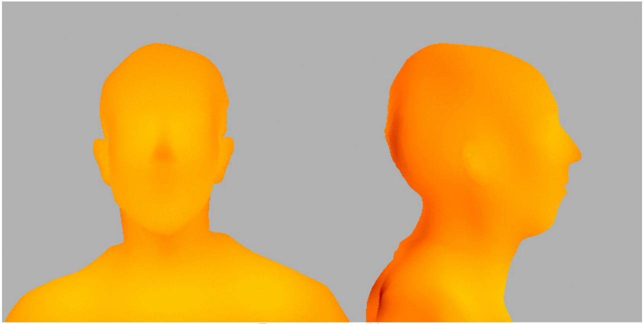
BEM-Model of HRTFs



Different frequencies

Acoustic pressure distribution for different frequencies. The source is positioned 1.2m in front of the person.

Different frequencies



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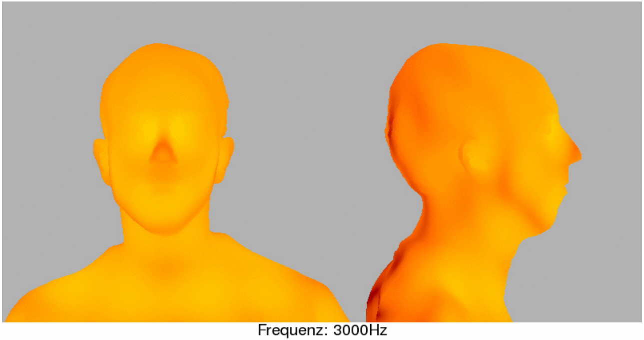

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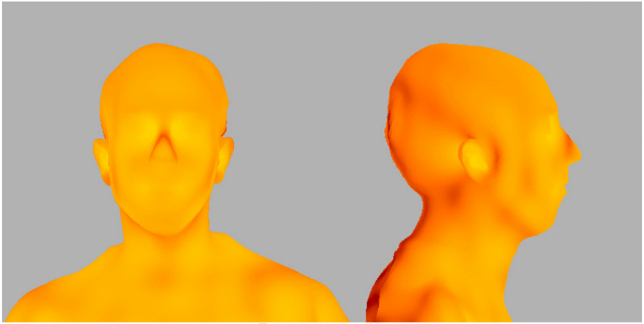

Frequenz: 4000Hz

Acoustic pressure distribution for different frequencies. The source is positioned 1.2m in front of the person.

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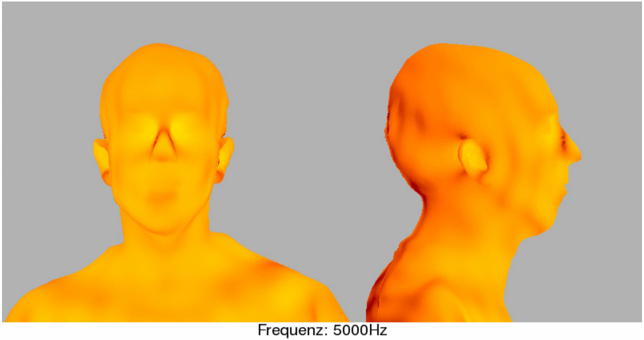

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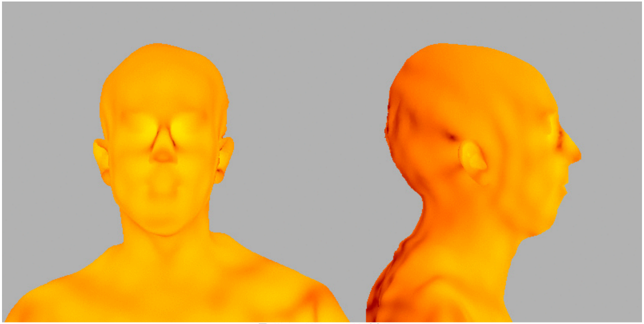
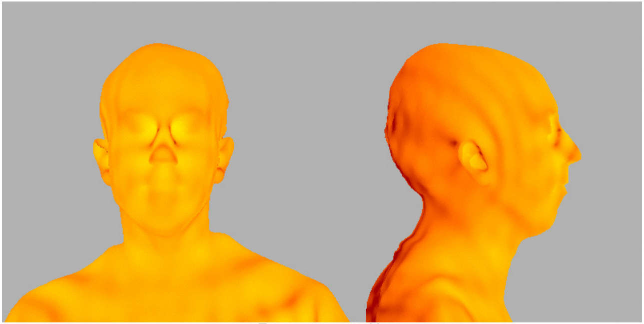


Frequenz: 6000Hz

Acoustic pressure distribution for different frequencies. The source is positioned 1.2m in front of the person.

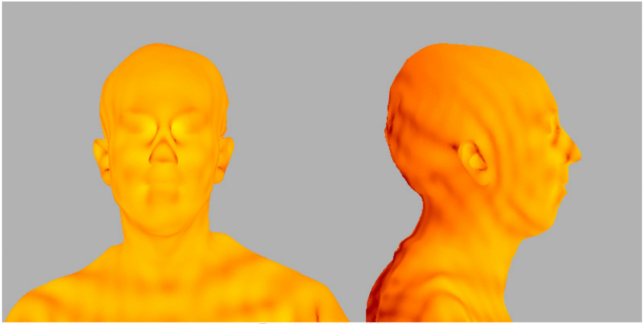
Different frequencies



Frequenz: 7000Hz

Acoustic pressure distribution for different frequencies. The source is positioned 1.2m in front of the person.

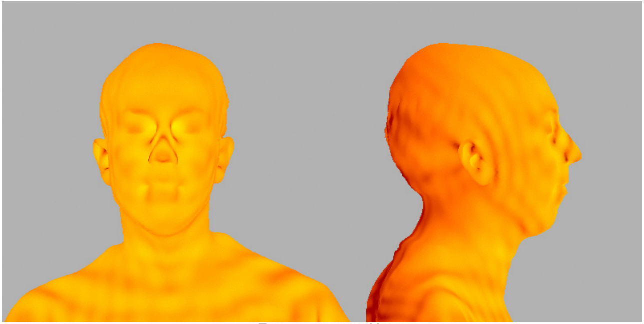
Different frequencies



Frequenz: 8000Hz

Acoustic pressure distribution for different frequencies. The source is positioned 1.2m in front of the person.

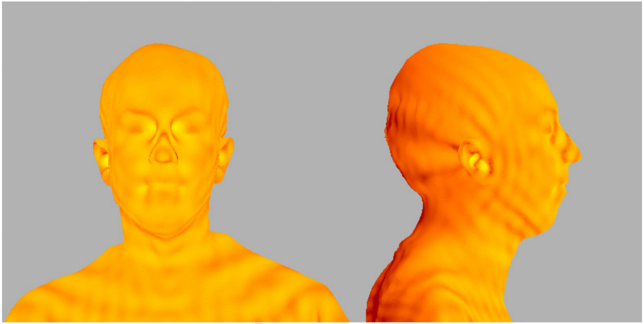
Different frequencies



Frequenz: 9000Hz

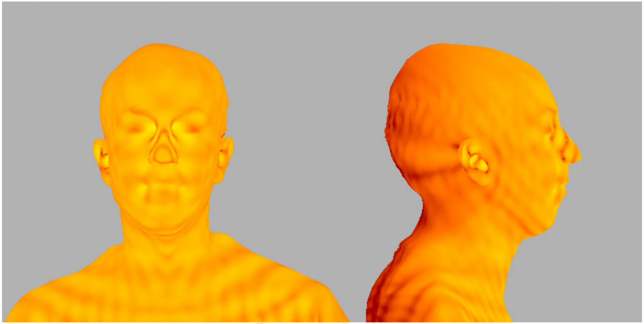
Acoustic pressure distribution for different frequencies. The source is positioned 1.2m in front of the person.

Different frequencies



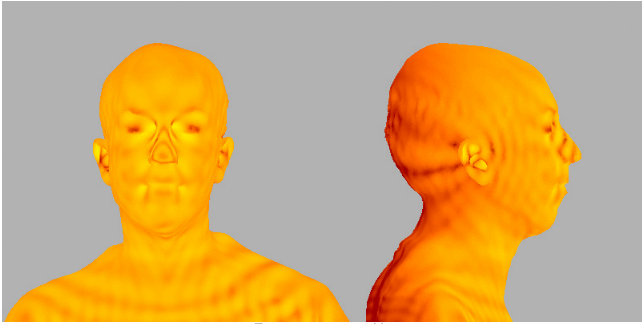
Acoustic pressure distribution for different frequencies.
The source is positioned 1.2m in front of the person.

Different frequencies



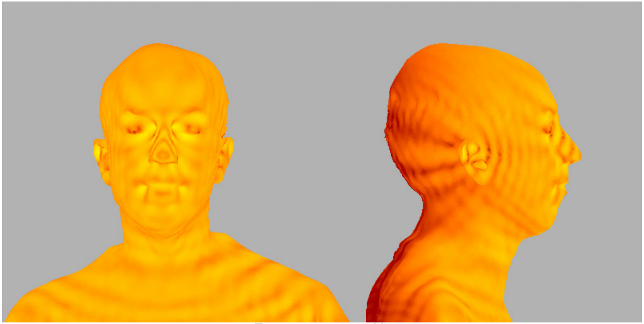
Acoustic pressure distribution for different frequencies.
The source is positioned 1.2m in front of the person.

Different frequencies



Acoustic pressure distribution for different frequencies.
The source is positioned 1.2m in front of the person.

Different frequencies


Frequenz: 13000Hz

Acoustic pressure distribution for different frequencies. The source is positioned 1.2m in front of the person.

Future and Current Projects

Galerkin, again

To solve operator equation

$$Bu = f$$

it is projected on finite-dimensional subspace:

$$\boldsymbol{B}\boldsymbol{u} = \boldsymbol{f} \text{ with } \boldsymbol{B}_{ij} = (B\phi_i, \phi_j)$$

Standard choices: (ϕ_i) Orthonormal basis [Sauter and Schwab, 2004] or Riesz basis [Dahlke et al., 2005].

There are other options: Frames!
Matrix representation of operators can also be done with frames [Balazs, 2008b].

Galerkin, again

To solve operator equation

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Adaptive Wavelet and Frame Techniques for Acoustic BEM

In a joint project with S. Dahlke (Univ. Marburg) and H. Harbrecht (Univ. Basel) we will:

Efficient wavelet solver: Implementation for Helmholtz problem.

Fully discrete adaptive wavelet method: Implement adaptive methods [Dahmen et al., 2007]. Use local error adaption.

Besov regularity theory. Investigate the regularity properties of boundary integral equations.

General frames for acoustics. Use adaptive frame methods [Dahlke et al., 2005]: Apply Wavelet and α-modulation frames for HRTFs.

All developments will be validated by calculating HRTFs.

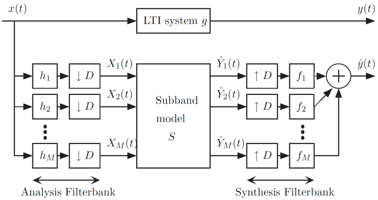
Time-Frequency Domain Implementation

Time-Frequency Domain Implementation of Head-Related Transfer Functions for Real-Time Virtual Acoustic Applications: allows the implementation of HRTFs, which offers flexibility in the trade-off between *error, delay and efficiency*. (D. Marelli will join ARI.)

This is linked to best approximation by Gabor [Feichtinger et al., 2004, Dörfler and Torrésani, 2010] and frame multipliers [Balazs, 2008a] but also allows optimization of analysis and synthesis.

Time-Frequency Domain Implementation

Subband Method:



Allows

- modeling for discrete set of spatial position
- continuous approach for real-time interpolation

HRTFs for Psychoacoustics

Projects of Psychoacousticans at ARI:

- Best practice for localization experiments with Virtual Acoustics.

- What are the perceptional relevant features of HRTFs?
- How can localization of sound be improved for Cochlea Implantees.
- ...

Conclusions

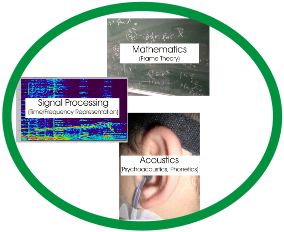
Conclusions

Measuring, modeling and applying HRTFs is a inter-disciplinary research topic linking mathematics, signal processing, numerical acoustics, acoustical measurment and psychaocustics.

Linking Theory to Applications!

Thank you for your attention!

Questions? Comments?



Thanks to P. Majdak and W. Kreuzer for help with this presentation!

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