DYNAMIC ACOUSTIC SIMULATION FOR HEARING AID DEVELOPMENT AND FITTING

PACS: 43.55.Ka, 43.66.Ts

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ABSTRACT

An astonishingly high performance in acoustically challenging environments is a fascinating feature of normal hearing. Hearing aid wearers have large problems in such situations. In laboratory situations in hearing aid development usually static situations are tested with just a few sources of speech and noise. The influence of dynamic aspects in such a scene has an importance on the auditory perception. These aspects are highlighted and it is explained how listening experiments can be designed for hearing aid applications. Pros and cons of reproduction methods and binaural aspects of hearing aids as well as the ambient simulation are discussed.

RESÚMEN

La audición de un oyente medio en un ambiente acústicamente hostil resulta ser asombrosamente buena. En cambio, las personas que usan audífonos pueden tener grandes dificultades en condiciones similares. Cuando los audífonos son evaluados en laboratorio suelen someterse a pruebas en las que las fuentes utilizadas, de voz o de ruido, son pocas y estáticas. Sin embargo, los aspectos dinámicos de las situaciones reales son de mucha importancia en la percepción auditiva. En esta comunicación se ponen de relieve esos aspectos y se propone una nueva metodología de diseño de experimentos audiométricos para audífonos y aplicaciones de ayuda a la audición. Además, en la comunicación se discuten asuntos muy relacionados, como son: ventajas e inconvenientes de los métodos de reproducción sonora de los audífonos, sus aspectos binaurales, y la simulación de las condiciones ambientales.

1. INTRODUCTION

Hearing, recognizing, and understanding in acoustically challenging environments causes a person with normal hearing abilities little problems. A person who suffers from hearing loss, however, encounters difficulties under such circumstances. Source separation and speech comprehension in noise are significantly reduced. In laboratory situations, tests are nowadays often only processed in static situations with few sources. Yet the influence of a person's own movement within a scene is of great importance for acoustic perception. Another criterion is the acoustical environment, hence indoor and outdoor space and its specific effects on source localization, attention, and speech comprehension.

Throughout this article, procedures will be presented that also include these important aspects of hearing in diagnosis and in therapy. Advantages and disadvantages of the different identification methods of the hearing aids' binaural aspects as well as of the simulation of environment or room and of the reproduction technique will be highlighted.

2. FUNDAMENTALS – STATE OF THE ART

The ability to process dynamic acoustic situations is an essential component for communication and orientation in everyday life. Due to binaural hearing, humans are able to separate one sound source from many others and to identify useful sound, background noise, and reverberation. Aurally handicapped persons suffer from a lack or a limitation of this ability and they have therefore disadvantages in communication, orientation, and security. Hearing aids help to increase the acoustic signal, but the quality of a realistic binaural starting position for further analysis and processing within the hearing system is still limited and unsatisfying in comparison to persons with normal hearing abilities.

Real sound field situations are complex and cannot be described as perfect free field or diffuse field. The propagation path from sound source to listener within a complex sound field is represented by an impulse response or a transfer function. Binaural hearing is incorporated through an impulse response on two channels, because the communication path is described from the sound source to both ears as recipients (for overview see Fels 2013).

Sound fields can be differentiated between outdoor and indoor scenes. With the aid of the binaural signals, sound fields can be tested in closed rooms with diverse characteristics or in dynamic situations such as transport (cars, trains, etc.), and also the proper motion of the listener can be investigated. Validated simulation methods make it possible to create binaural room impulse responses of a virtual scene, until now, however, primarily for persons with normal hearing ability.

3. BINAURAL HEARING AID TECHNOLOGY

Thanks to the binaural approach, it is also possible to test dynamic acoustic scenes with hearing aids. Figure 1 shows the concept of such an approach, which is admittedly based on standard methods and therefore has to be adapted and extended for the special conditions of hearing aids or cochlea implants (CI). On the upper part, the production of multichannel microphone signals appropriate to a dynamic virtual scene is described. The signals, which are simulated for the position of the hearing aid's microphone and which count as its input, are processed within a Master-Hearing-Aid, which simulates the processing of the hearing aid's signal and the test person's hearing loss (see lower part of the figure). To incorporate dynamic scenes as well as the test person's proper motion, the test person's head position has to be tracked. Merely a silent booth is needed for the reproduction of the produced signals.

If open otoplastics are used, the portion the hearing aid does not record must additionally be reproduced through loudspeakers. Such an approach provides many diverse application possibilities and experiments, e.g. for alertness. The technical effort is very low compared to sound field methods with loud speaker arrays (e.g. wave field synthesis, ambisonics).

4. ADVANTAGES AND DISADVANTAGES OF SPATIAL REPRODUCTION METHODS

In principle, spatial sound fields can be created in two different manners. The first approach has already been described in the above section "Binaural Approach". In this approach, the sound field is created and reproduced with the aid of signals relating to the head, which has the advantage that the hearing event only depends on the two input signals at the eardrum.

The second possibility is the production of the sound field as complete wave field within a more or less spatially limited acoustic range ("sweet spot"). The main difference is that more than one person can hear in such an environment. In this environment it is advantageous that the influence of the individual head and torso geometry as well as of the hearing aid itself can be respected with all signal processing strategies (such as beamforming, etc.).

The upper frequency limitation, however, is disadvantageous, because here the wave field can no longer be produced correctly. Thereby, the procedures Wave Field Synthesis (WFS), Higher-or Ambisonics (HOA), and Panning Methods (VBAP) are comparable and they equally offer a correct wave field within a limit underneath a few kHz only, depending on the spatial resolution of the loudspeaker arrays.

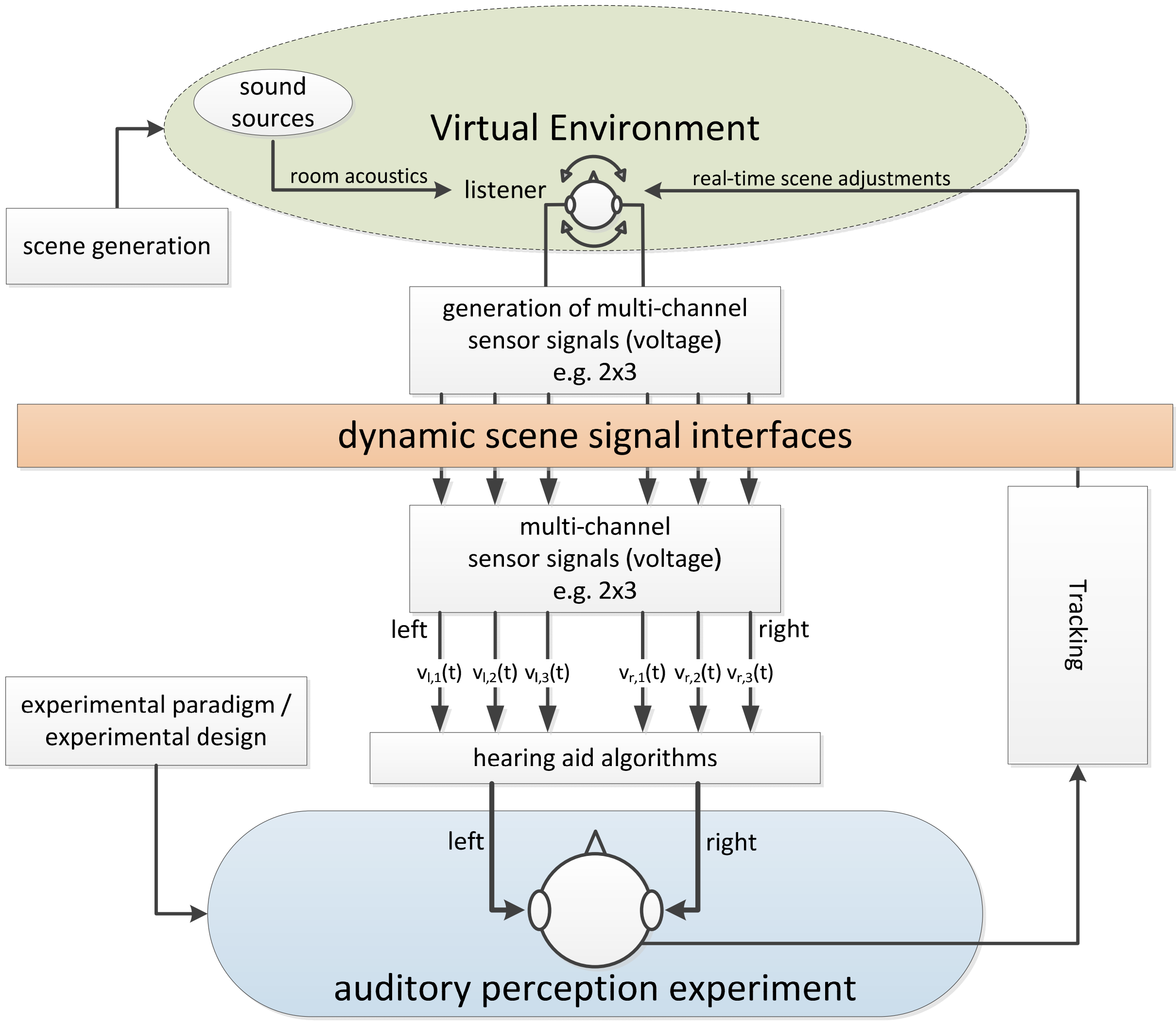

Figure 1: Concept of a dynamic acoustic room simulation for hearing aids with binaural technology

During loudspeaker synthesis procedures, the human hearing system creates some kind of natural hearing impression for higher frequencies through masking and summing localization (phantom sound sources); it is entirely unclear though, how technical systems (hearing aids with microphones) function in such a sound field when they are not fed with correct sound pressure signals. Imagine how a signal which is enforced with aliasing artifacts affects the hearing aid's beamformer. Relative to the physical representation of the sound field, significant uncertainties concerning minor head movements unfold, because the hearing aid's microphones fall into a more or less chaotic sound field through spatial aliasing effects. A further disadvantage of loudspeaker procedures is the fact that sound fields close to the ear cannot be well created. For the binaural approach, accuracy depends mainly on the accuracy of the HRTF. More details on wave-based procedures and their limits can be found in Spors (2014).

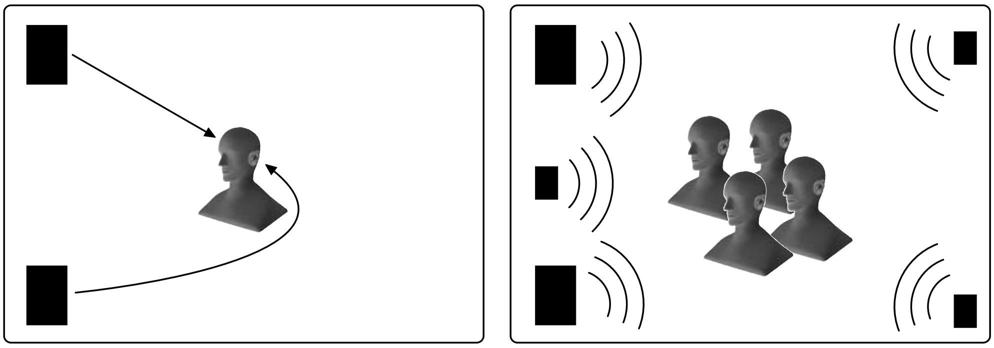

Figure 2: Binaural technology (left) and sound field technology (right) (Vorländer 2008)

	Ambisonics	Wave Field Synthesis	Binaural Synthesis
Pros	• Simple • Clear reference to spherical harmonics • Medium hardware requirement • Large sweet spot • Loudspeaker interface	• More or less exact wave field reproduction • Clear reference to array wave decomposition • More than one listener • Larger sweet spot • No tracking	• Exact reproduction at listener's ear entrance point or microphone positions of the hearing aids • Low hardware requirements
Cons	• No close to head sources possible • No good distance perception • Sweet spot frequency-dependent, upper limit	• High hardware requirements • High processing power • No universal loudspeaker interface • Spatial aliasing, upper frequency limit	• Tracking • Only one listener • Individual equalization • Special adaptation necessary for hearing aids

Table 1: Advantages and Disadvantages of Spatial Reproduction Methods

5. BINAURAL TECHNOLOGY AND BINAURAL SYNTHESIS FOR HEARING

Uncertainties within the binaural approach due to HRTFs and head-tracking are rather insignificant compared to mistakes in wave-based procedures that can disadvantageously occur due to spatial aliasing, phantom source effects, and spatial masking effects.

The implementation of binaural technology for dynamic scenes, however, is not in the least trivial. The acoustic scene is simulated through the production of binaural impulse responses, which are convolved with a "dry" source signal. For persons with normal hearing ability, these signals would be reproduced with the aid of headphones (preferably open). This leads to a perfect source distinction. In the case of a hearing aid, the signals have to be simulated precisely for the microphone's position at the hearing aid. The signal processing on the side of the hearing aid is carried out by means of a master hearing aid.

With the simulation of sound pressure at the microphones' positions, the sound wave can be accurately modulated (cf. Figure 3) if the dependence on direction of head and ears (HRTF) is taken into consideration. Accuracy, in this case, depends on the precision of the HRTF. The relative differences within the complex transfer functions at the microphones' positions must be correctly recreated to provide the appropriate input signals for beamforming algorithms, for instance.

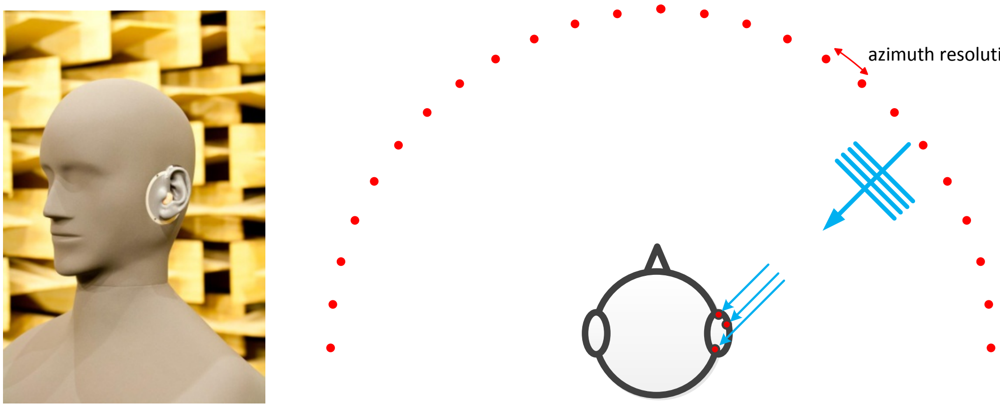

Figure 3: Definition and measurement of the multichannel-HRTF at the positions of the hearing aid's microphone

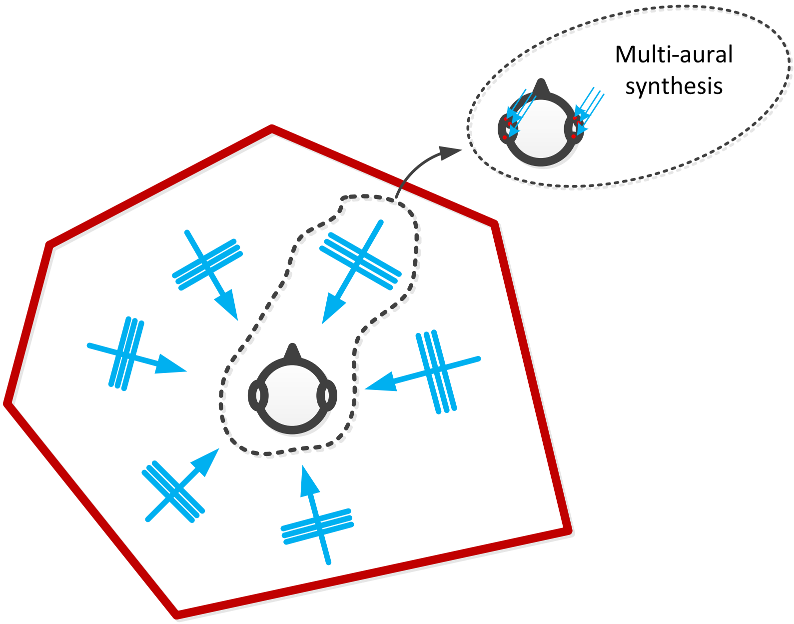

Figure 4: Virtual environment of a complex acoustic situation (red). Multichannel synthesis by means of plane wave fields and convolution of the respective simulated paths with direction depending multichannel HRTF (cf. Figure 3)

6. EXPANSION OF THE BINAURAL SYNTHESIS FOR DYNAMIC COMPLEX ACOUSTIC SCENES

The approach of the binaural synthesis for the direct sound and of the early reflections is very plausible. Through individual reflections and with high precision in the multichannel HRTF data, all parts of the impulse response are well pictured. For indoor and outdoor scenes with a reverberant sound component, however, the exact illustration of sound pressure, pressure differences, and coherence between the microphones by means of those algorithms that simulate the reverberant sound has to be assured. Any stochastic, artificial, or recorded reverberant sound fails in this interrelationship. Instead the reverberant sound field has to arrive as a sum of plane waves with a specific spatial distribution, which can then be processed with a coherent binaural synthesis.

In binaural technology, static and dynamic acoustic scenes have to be examined separately. In dynamic scenes, the user benefits from head movements. To obtain ideal results in static scenes, the individual characteristics of the user should be reproduced as exactly as possible. Therefore, individual or at least individualized HRTFs as well as individual rectification techniques should be used.

For users of hearing aids, existing approaches can be utilized, because the only difference lies in the position of the input signal. The measurement of individual HRTFs is currently object of research of several groups (cf. e.g. Majdak 2007; Enzner 2011; Masiero et al. 2012). At the Institute of Technical Acoustics, a system is presently developed with which the individual HRTFs of a person can be measured in less than 6 minutes (Pollow 2012; Fels 2013). Another approach is the individualization of HRTFs based on a standard dummy head HRTF (Bomhardt & Fels 2014). This procedure could be realized more easily, because an anechoic room, which is necessary for the HRTF measurement, is not always available. The individualization can be realized through scaling or indirect individualization based on anthropometric data or by means of subjective adjustment (for overview see Xu 2007). For binaural hearing, though, an essential improvement of localization and source distinction originates in the tracking of head movements. This can be implemented with fast head tracking systems.

7. CONCLUSION AND OUTLOOK

This article gives an overview on procedures for the production of dynamic virtual sound field scenes, which can be used in hearing aid technology. Advantages and disadvantages of binaural procedures and wave based procedures as well as the limits of the different procedures are presented.

Up to today, it is not yet possible to identify the ideal procedure for clinical application. Extensive research is still missing both for persons with normal hearing ability and with hearing loss, especially in the field of wave-based procedures. For now, it is entirely unclear how uncertainties and artifacts such as spatial aliasing affect technical equipment with beamformers (hearing aids).

Nevertheless, promising approaches exist which, in the near future, will allow examining users of hearing aids in virtual "realistic" scenes with regard to diverse perception capacities such as localization, source distinction, and attentiveness.

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