System for Excitation of selectable hearing locations

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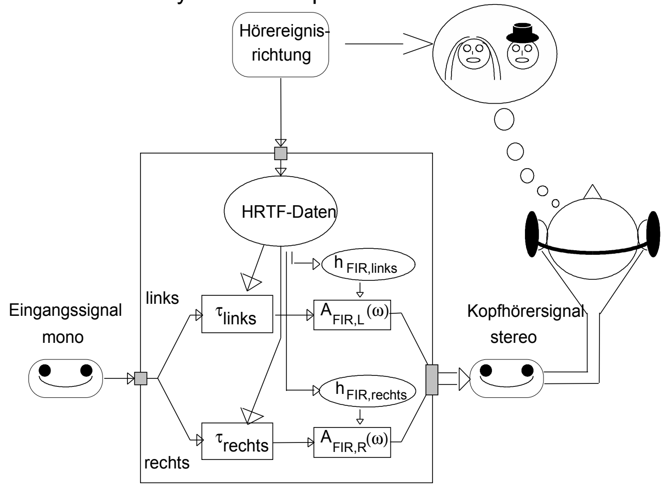
Introduction

The ability of the auditory system to localise several sound sources is well known since a long time. The auditory system is able to give a sound source a hearing location, when the heard event is heard live. This happens also during the playback of so called artificial-head recordings when listened with binaural headphones. In the following I am going to describe a system, which allows the post-preparation of a single, earlier recorded channel with the goal to produce a 3D hearing impression with a selectable hearing localisation.

System Concept

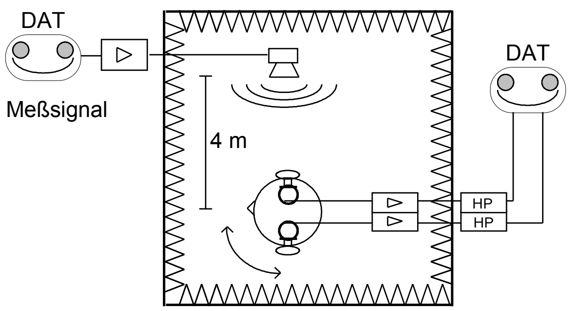
As drawn in picture 1 the incoming input signal is convoluted with the impulse answer of the head related transfer function (HRTF). The convolution is reduced for both left and right channel to a group-delay element and a digital FIR filter in order to shape the phase and the absolute value of the HRTF separated. In order to calculate for the left earphone, the HRTF-data of the left ear were used. the HRTF of right is archived similar.

Picture 1: system concept



After the Input signal is running through a delay element, the transfer function is shaped by FIR filters. h_{FIR} is the corresponding convolution function.

Picture. 2:
experimental setup in a reflection less environment.



Measuring of the head related transfer function

Using an artificial head recording system (Neumann KU80) a representative head related transfer function was measured. In order to do this for all horizontal directions, the KU80 was held pivoted. The HRTF was measured using quasistatic measuring signals of varying frequency. These quasistatic signals were sinus waves of the interesting carrier frequency f with a gaussian envelope. The carrier was varied from 200Hz to 16kHz

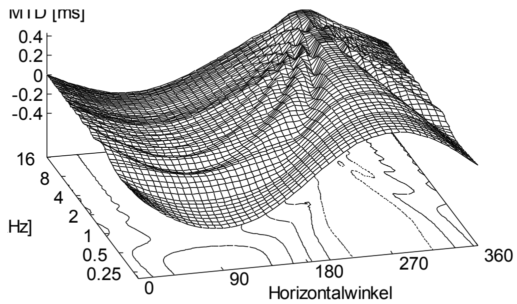
Calculation of the phase information.

Related to KUHN 1977 the pressure transfer function of a acoustical hard spherical is calculated. Together with the formula for the group delay time

$$\tau_{gr,calc} = \frac{d}{d\omega} \arg\left(\underline{A}_{calc}\right)$$

one can derive the dependency of the monaural time difference (MTD) of the incoming direction and the frequency f.

Picture 3: monaural time delay MTD



Calculated monoaural time delay of a „left“ ear (with Azimuth_{ear}= 90° and Elevation_{ear}= 0°) of a acoustically hard spherical with a radius of 8,75 cm.

The phase Information (Picture 3) and the values of the measured frequency response of the head related transfer function make it possible to shape the complete head related transfer function of a representative artificial head .

Hearing Experiments

In order to Verify the system, several hearing experiments were solved. For this purpose FIR Filter of 16 Taps were used. At this resolution the average variance between measured and synthetic head related transfer function decreases to about 1.2 dB.

The trial participants were presented a stimuli and were told to draw the heard direction and distance on a diagram. Furthermore the participants were asked for the certainty of their estimation.

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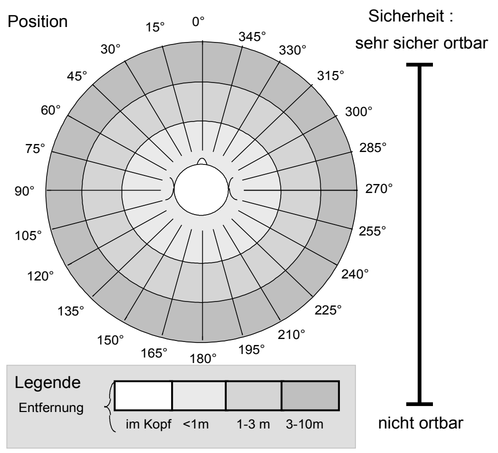
Results

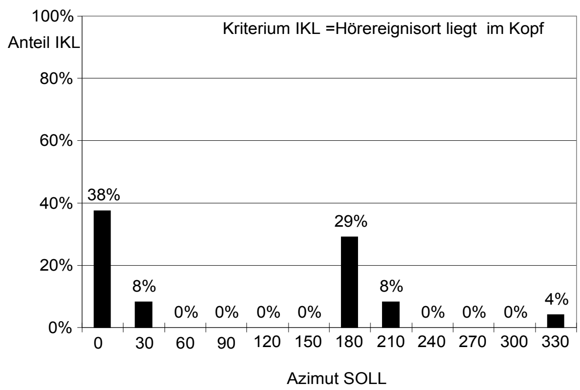
The mapping of the given hearing locations compared with to the subjective listening impression of the participants fits very good for locations outside the median plane

This is shown by the certainty of the estimation. These were for directions outside the azimuthal plane always in the upper part of the line length in the neighborhood of "very certain located". For directions inside the median plane, in the case that no time delay differences occur, there exists a little bigger part of Inside-Head-Localisation and the certainty of the estimation decreases.

Picture 4 estimation diagram



Picture 5 part of inside-head-localisation [%]

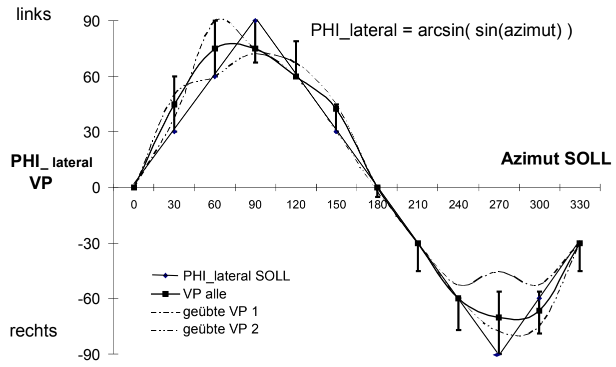


part of the estimations that give the impression of inside-head-localisation deviated from the given position. Only for directions inside or nearby the median plane there occurred a fraction of inside-head-localisation For these direction the signal doesn't contain any or few interaural time differences.

The degree of lateralisation measured by the heard horizontal angel is calculated as an horizontal angel mirrored to the frontal half-plane by using the formula arcsin(sin(heard azimuth). In Picture 6 the triangular wave shows the theoretical optimal fit. The heard results of sound processed by the described system fits very good with respect to the property of lateralisation.

The heard and the shall be positions deviate only by a kind of directional compression near the outer right and left direction.

Picture 6 : degree of Lateralisation

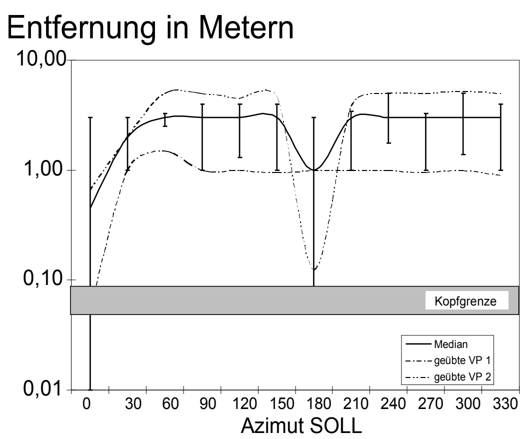


Lateral position of all given (shall be) directions computed by mirroring the backside half-space to the frontal half-space by the formula arcsin(sin(horizontal-angel))

The triangular line gives the ideal best case.

The estimation of the heard distance shows, that the participants located the sound wide outside the head. The sound was located for directions outside the median plane about 3 Meter away. Inside the median plane there occurred up to 38 percent of inside-head-location. This can be seen by the lower interquartile laying nearby the head radius. The (average) median value lies far outside the head.

Picture 7 : heard distance in meter



Real Time Performance

On a Pentium II with 350 MHz it is possible to calculate more than 4 sources of input of CD-Quality in realtime when using fixed source positions.

When considerating realtime head motion in the horizontal plane, which was not discussed in this document, a single channel still can be calculated in CD-quality on the described system

Literature

Kuhn 1977 , Kuhn George F. ; „Model of the interaural time differences in the azimuthal plane" ; J.A.S.A Vol 62 (Juli 1977) pp 157-167

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