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Detection of Reflections in Free-Field Directional Hearing by Waveform Analysis of Accurate Dummy-Head HRTFs

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Abstract ***– The human spatial hearing and localisation investigations often need non-reverberant environment. In these so called "free-field" situations we try to avoid reflections, e.g. by making the recordings in the anechoic room. An analysis in the time-domain based on the impulse response has only low SNR, but measurements of transfer functions using a noise excitation have increased accuracy and SNR. This paper shows a simple method using waveform analysis in the frequency domain to find the location and effects of reflecting surfaces, and an example of using the difference of Head-Related Transfer Functions in spatial hearing applications.***

Keywords ***– HRTF, waveform analysis, reflections, directional hearing, anechoic room, HRTF differences, concert hall.***

I. INTRODUCTION

On the field of spatial hearing research one of the most important tasks is to record the transfer functions of the ears. The Head-Related Transfer Functions (HRTFs) describe the transmission from a point in the "free-field" to the eardrum and they work as linear, directional dependent complex filters [1]. This directional filtering helps us to localise the sources and, thus, reflections and reverberations are considered as undesired and disturbing effects [2]. Although, they are present in everyday-life and contribute to perception, at least as far as waves coming from the ground are concerned. These secondary soundpathes influence the HRTFs and their measurement situations. The measurements can be made on real human subjects or by using artificial head and torso simulators (dummy-heads). Both methods have their advantages and are widely used (see Fig.1) [3], [4].

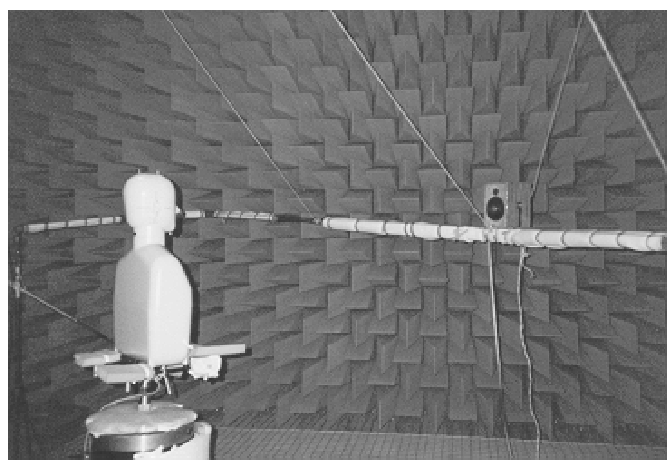


Fig.1. Recording of dummy-head HRTFs in the anechoic room.

The existence and location of reflecting sources in the 3D space can be detected in the time-domain by analysing the (room)impulse response. This method is simple and fast but has only a reduced signal-to-noise ratio and an impulse signal input. HRTF measurements can be also made using white noise excitation with increased accuracy and SNR but it needs more time and a spectral waveform analysis in the frequency domain.

II. SPECTRAL WAVEFORM ANALYSIS

We make *our* investigation in order to create and extend hearing models. Human localisation performance can be explained in free-field situation and partly in reverberant rooms as well. Because of the modelling, investigations were made with sinusoid and low-frequency signals so far [5]-[7]. While measuring, we can also look for spectral "properties" in the measured HRTFs indicating environmental reflections.

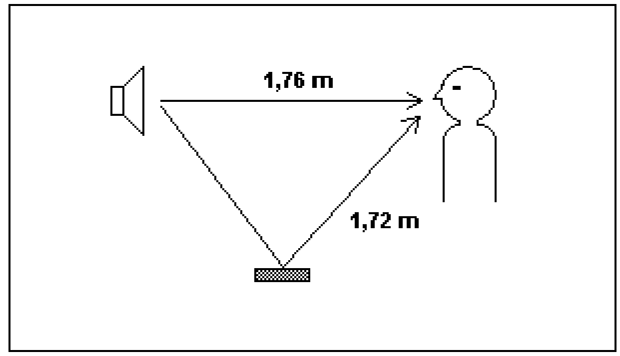
A full automatic, computer controlled, DSP card based accurate transfer function measurement system was installed in the anechoic room, first of all to measure the HRTFs of a dummy-head with high SNR and large spatial resolution using noise-like stimuli [8]. The HRTF database recorded with this system is evaluated in the frequency domain. We can detect reflections by a simple waveform-analysis without any additional measurement.

Let us define HRTFD as the "difference" of two HRTFs measured in the same direction but under modified situation (1). The result will show the effect of the modification only:

$$HRTFD = 20\log\left|\frac{HRTF_{original}(j\omega)}{HRTF_{\text{mod}ified}(j\omega)}\right|. \quad (1)$$

In order to find the effects of reflections in the HRTFDs we created artificial reflecting sources. Fig.2. shows how a wooden plate influences the HRTFD simulating reflections from the ground. The distance of the reflecting source can be calculated using the "waveness" of the HRTFD. This waveness has a periodicity of 1/200 (5 waves in 1 kHz bandwidth). Using (2) we can calculate the distance of the surface and furthermore, we can see which frequency regions will be affected. The size of this surface influences the HRTFD.

$$dist = \frac{v_{sound}}{T} = 344\frac{m}{s} * \frac{1}{200s} = 1{,}72m. \quad (2)$$



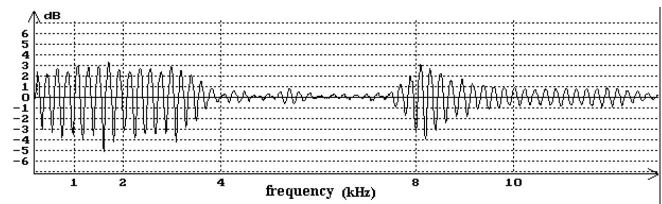


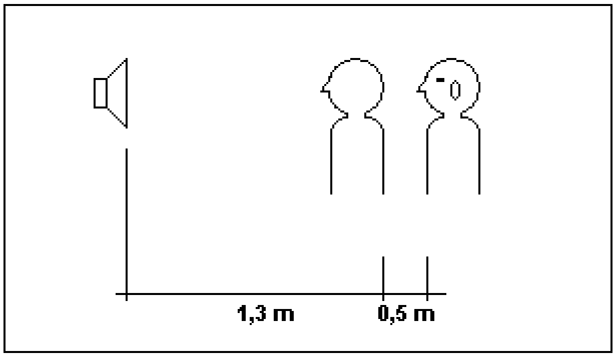
Fig.2. Significant "waveness" of a HRTFD representing the existence of a reflecting surface in a distance of 1,72 m. The secondary soundpath in this case affect only the region below 4 kHz and above 8 kHz. Note the linear x-axis.

III. APPLICATION OF HRTFD: THE CONCERT HALL

This section shows preliminary results and figures about the effect of the phenomena "other people near to the listener".

The HRTFD is a useful tool for analysing the parameters of the hearing quality. An interesting scope could be e.g. in a concert hall, where the listeners have different HRTFs depending on whether other people are sitting near to them. Another torso was placed with different tallness and distance *before*, *next to* and *behind* the torso being measured. The sound source is always in the front of the listener, so the object placed near to the listener produces shadowing, sound absorbing or even reflecting effects [9].

We found that a man sitting *in the front of* affect the HRTFs up to 20 dB in the entire frequency range, mostly above 4 kHz. The taller the man is, the bigger the differences are. The distance of the second torso influences the results above 500 Hz. Fig.3. shows the setup and an example HRTFD.



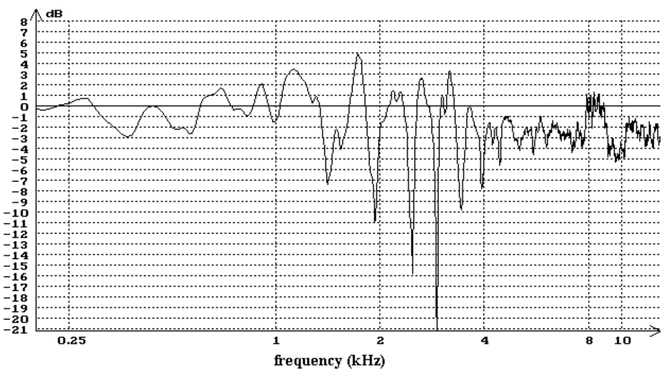
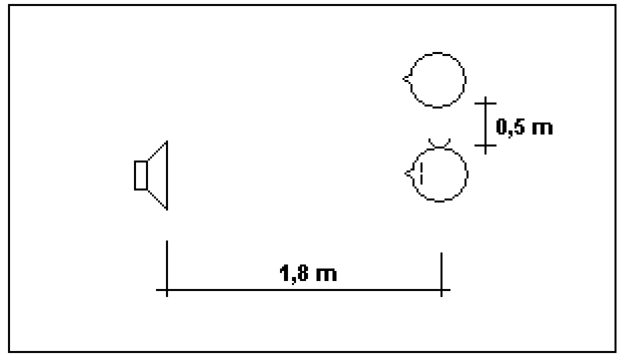


Fig.3. Increased changes in a dummy-head HRTFD from frontal incidence. The second torso is in the front of the listener at equal height in 0,5 m distance (one ear). Note the logarithmic x-scale.



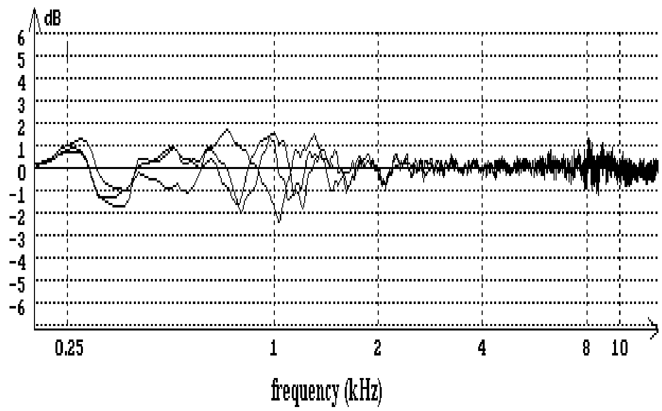


Fig.4. Reduced changes in HRTFDs. Three figures show the effect of a man sitting next to listener in 0,5 m distance (closer ear) with different height (lower, equal height, taller). No significant influence appears above 1500 Hz regardless of the distance.

People sitting *next to* the listener do not have significant influence regardless of their distance and height. The changes in the HRTFD are ±2 dB up to 1500 Hz and less than 1 dB above (Fig.4.). This result is interesting because the monaural sensitivity is very good from this direction. Similar effect can be observed by a person sitting *behind* the listener, but his height does influence the result more, up to 3 dB.

Studies of distance and azimuth perception have been made in concert halls by using reflected sound as a variable parameter. These studies have been applied to the perceptual effects of reverberation, early reflections from the ground and walls under the condition where the distance from the source to the listener is rather long. They evaluate only a few sitting positions called "the best seat in the house" and seek to establish methods for how to build or modify a new hall. The temporal and spatial aspects of early reflections have been found to be significant in forming preference criteria: lateral reflections (from the sides) should dominate over reflections from the front or rear [10]. None of the studies implement the effects of HRTFDs, or other listeners or reflections coming from the environment near to the head. Our findings clearly show that nearby reflecting sources influence the HRTFs from the front rather than from the left and right sides corresponding to the subjective preference criteria.

IV. CONCLUSION

With accurate measured transfer functions (in this special case: HRTFs) we are able to detect the existence, the effect and maybe the location of reflecting sources in free-field measurements. The analysis consists of a simple quotient of two amplitude characteristics of transfer functions. The results show a significant "waveness" in the frequency depending on the distance and size of the reflecting source. The HRTFDs show the affected frequency regions as well.

The stimuli for this evaluation can be the *same* as used for the measurement itself. We do not need any time-domain impulse excitation with low SNR or low-frequency narrow-band signals but we can use white-noise or any other noise-like excitation with the same increased SNR accuracy and resolution as the measurement. This simple method does not need the phase information at all.

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