A Study of the Perceptual Changes Caused by Sound-Source Occlusion

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Introduction

For realistic sound-rendering in complex auditory virtual environments to be achieved, sound-source occlusion should be accounted for. Yet, the accurate analytic modelling of occluders is computationally expensive and hence, in order to achieve a simplified model, the changes in psychoacoustical parameters accompanying the perception of sound-source occlusion have to be identified and understood. The tone coloration caused by the occlusion and the effect of the sound-source occlusion on the position of the auditory events of the listeners are two important parameters that have to be studied. Impulse response measurements, recorded under anechoic conditions, are used, in which rectangular wood plates of different dimensions are used to represent the occluders. It was shown in [1] that the location of the auditory events of the listeners differs from the physical location of the sound source when the source is occluded. The auditory event is perceived at the location of the edge whose signal is perceived first by the listener (precedence effect). In this paper the signals recorded by the dummy head are analysed with the help of the Lindemann binaural model, which uses contralateral inhibition added to the model of binaural cross correlation [2,3] and the results are discussed.

1. Measurement Procedure

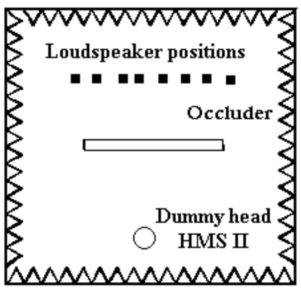

Figure 1: Setup in the anechoic chamber.

The measurements were carried out in an anechoic chamber of dimensions: 5.13×4.98×4.76 m^3 with a lower cutoff frequency of 110 Hz. The measurement setup is shown in Figure 1. The loudspeaker was placed at azimuth angles of –35, -25, -15, -5, 0, 10, 20 and 30 degrees (the negative values indicate that the source is to the left of the dummy head) at the same height as the ears of the dummy head.

The measurements were carried out in the absence of the occluders and repeated in the presence of one of two wood plates used as occluders of dimensions: 1.33×2.5× 0.015 m^3 (width × height × thickness) and 2×2.5× 0.015 m^3 respectively. For the impulse response measurement, white noise sequences were used.

2. Model of Binaural Hearing

2.1 Introduction

Models of binaural hearing aim to reproduce the signal processing of the sound signal from the moment it enters the outer ear till it is categorized as an auditory event. There have been several approaches for such models, but to discuss these is beyond the scope of this paper. For a detailed review on the different models of binaural hearing the reader is referred to [4].

The interaural cross-correlation function has been used as the basis of computational laterlization models [5]. In these models, the cross-correlation peak is an indicator of the position of the auditory event of the listener. In the binaural model introduced by Lindemann [2,3], it is assumed that a primary cross-correlation peak, which corresponds to the direct sound, initiates an inhibition mechanism, which causes the suppression of secondary peaks within a definite time interval. In the case of sound source occlusion, there is no direct sound, but we have different delayed signals coming from the occluder's edges, which may be replaced by secondary line sources [6]. Using the same concept, introduced by the Lindemann model, the primary cross-correlation peak would in the case of sound-source occlusion correspond to the line source representing the edge, whose signal arrives first at the listener's ears. The secondary peaks emanating from the other edges will be suppressed, depending on the value of the time delay between them and the signal radiated from the edge whose signal is perceived first. If the time delay is less than 1 ms, we observe "summing localization" and the auditory event is perceived somewhere between both vertical edges. If the delay is larger than 1 ms and smaller than the echo threshold, the auditory event is at the position of the edge whose signal is perceived first by the listener. For details on the precedence effect the reader is referred to [4]. It is hence interesting to find out whether the Lindemann model, which is able to simulate simple scenarios introduced by the precedence effect, can be used as well in the case of sound-source occlusion to simulate the perceived change.

A schematic diagram of the implementation of the Lindemann model is shown in Figure 2.

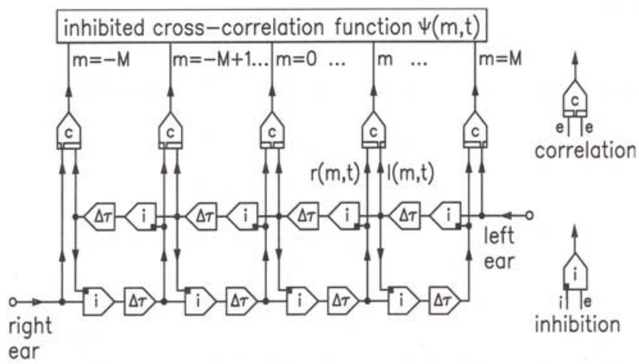

Figure 2: Schematic diagram of the implementation of the Lindemann model (copied from [4]), where: l(m,t) and r(m,t) is the signal on the delay line originating at the left and right ear respectively at tap m and time t.

The inhibition mechanism can be described by the following equations:

$$r(m+1,t) = r(m,t)[1 - i_r(m,t)] \quad (1)$$
$$l(m-1,t) = l(m,t)[1 - i_l(m,t)] \quad (2)$$
$$i_r(m,t) = i_{s,r}(m,t) + i_{d,r}(m,t) - i_{s,r}(m,t) i_{d,r}(m,t) \quad (3)$$

where:

$i_r(m,t)$: inhibition coefficient attenuating the signal r(m,t)

$i_{s,r}(m,t)$:stationary inhibition component of $i_r(m,t)$

$i_{d,r}(m,t)$:dynamic inhibition component of $i_r(m,t)$

For the complete set of the equations the reader is referred to [2].

2.2 Analysis of the Recorded Signals

The recorded impulse responses were analyzed using a simple cross-correlation algorithm and then using the Lindemann model. The Lindemann model gave results similar to the psychoacoustical data described in [1], whereas the simple cross correlation gave less satisfying results. The better results can be explained by the fact that the Lindemann model suppresses secondary peaks which otherwise would rise owing to the periodic nature of the cross-correlation function. The results obtained using the Lindemann model are shown in Figure 3a and 3b. The negative cross-correlation time corresponds to auditory events to the left of the listener. When the simple cross-correlation was used, the peaks obtained were broader. This is due to the absence of inhibition and hence the delayed signals are taken into account

2.3 Results and Discussion

From Figure 3a and 3b it can be seen that in the case of sound-source occlusion the cross-correlation peaks, and thus the position of the perceived auditory event coincide with the position of the vertical edge, whose signal arrives first at the listener's position (the vertical edge to which the sound source is physically closer). This agrees with the results found in [1]. In the case when the presented angle is 0° the peak is observed at cross-correlation time zero. This is due to the fact that the dummy head was placed at the center between the two vertical edges and hence both edge signals arrive at the same time and, accordingly, the position of the auditory event is perceived exactly in the middle between both edges (summing localization).

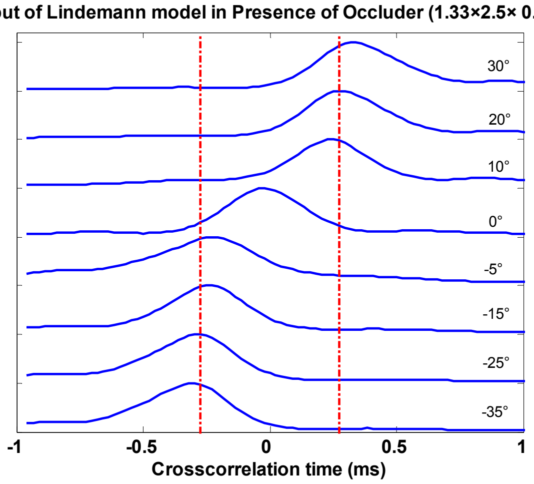

Figure 3a

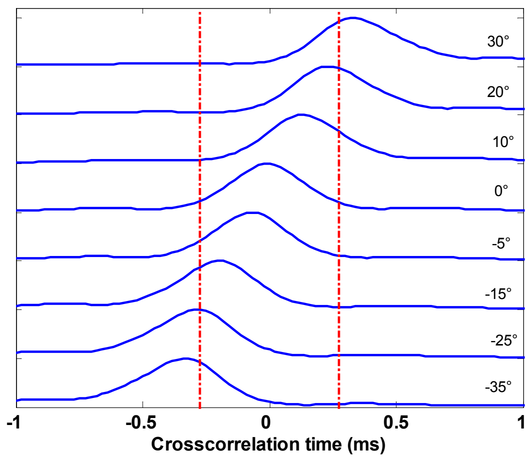

Figure 3b

Figure 3: The output of Lindemann model is shown for the different presented angles in the case of occluder of dimensions : 1.33×2.5× 0.015 in Figure 3a and no occluder in Figure 3b. The dash-dotted line represents the cross-correlation time obtained if the source was placed at the position of the vertical edges of the occluder.

As can be seen in Figure 3, an inhibition mechanism is definitely needed to explain what happens to the position of the auditory event in case of sound-source occlusion

Conclusion

The agreement between the analysis of the recorded signals and the listening tests performed in [1], suggests that a simplification of the occluder model with the aid of the precedence effect in case of determination of the position of the auditory event in the horizontal plane is justified. The simplification is based on the results of the psychoacoustical tests, which point out that the position of the auditory event is perceived at the position of the edge, whose signal arrives first at the listener's position, and hence only this edge needs to be modelled. This can lead to reduction of computational effort needed to render sound in auditory virtual environments in the presence of occluders.

Acknowledgement

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