Elevation of Horizontal Phantom Sources

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Introduction

A horizontally arranged pair of loudspeakers can evoke the perception of an auditory event between the loudspeakers, a so-called phantom source [1]. The horizontal position of the phantom source is typically controlled by level differences (ICLDs) between the loudspeakers [2]. For low frequencies, these differences cause binaural phase differences between the listener's ears that again lead to a stable localization [3]. However, binaural differences only allow for horizontal localization, as the perception of elevation is based on spectral cues [4].
Although horizontal loudspeaker pairs are intended to create phantom sources in the same horizontal plane, audio engineers often report the effect of elevated phantom sources. This contribution investigates the elevation of phantom sources for horizontal loudspeaker pairs symmetrically arranged to the median plane. The investigation comprises the effect of ICLD and the aperture angle of the loudspeaker pair. It employs results of a listening experiment, theoretical considerations of the directional bands [5], as well as a vertical localization model [4].

Listening Experiment

This contribution presents excerpts of a larger listening experiment that evaluated the localization of phantom sources created by horizontal, vertical and diagonal arrangements of two loudspeakers, loudspeaker triplets and quadruples, as well as single loudspeakers [6, 7, 8].
The Genelec 8020A loudspeakers were placed at a distance of 2.5 m from the subject's head in the IEM CUBE and covered by an acoustically transparent screen. The assessment of the perceived direction utilized a pointing method with a toy-gun [9]. The subjects were requested to face the 0° direction and to keep their heads immobile during stimulus playback. The stimuli were pink noise bursts (3×300 ms) at a level of 65 dB(A). On a loudspeaker pair at ±20° azimuth in the horizontal plane, 4 ICLDs were tested. A single loudspeaker at 0° azimuth and elevation was included as a reference. Each of the 5 conditions was evaluated twice. The listening experiment was carried out with 15 normal hearing subjects.

Figure 1 shows that the reference loudspeaker is well localized and yields a larger variation in the vertical direction.

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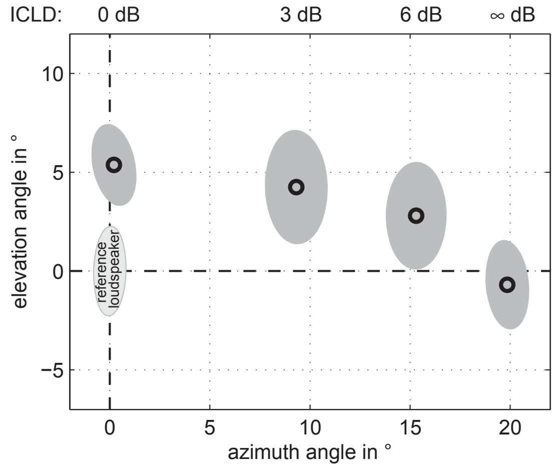

Figure 1: Experimental localization results (mean and 95% confidence area) for phantom sources created by a horizontal loudspeaker pair at ±20° in dependence of ICLD and a single reference loudspeaker at 0°.

The latter holds true for all other conditions. Beside the expected control of the azimuth angle, phantom source elevation is clearly recognizable and decreases towards large ICLDs. It is thus not surprising that an analysis of variance (ANOVA) reveals the ICLD to be a significant factor for both the azimuth ($p \ll 0.001$) and the elevation angle ($p = 0.007$) of the phantom source. All neighboring ICLD conditions yield significantly different azimuth angles ($p \ll 0.001$). However, this does not hold true for the elevation angles ($p \geq 0.48$), except for 6dB and ∞dB ($p = 0.059$). Nevertheless, the elevation angles for ICLDs of 0dB and 3dB are significantly different from the angle for ∞dB ($p \leq 0.01$). The elevation angle of the phantom source with an ICLD of 0dB is significantly different from the angle of the single reference loudspeaker ($p = 0.004$), whereas the azimuth angles are not different ($p = 0.77$).

Directional Bands

In the sixties, Blauert found out that for identical ear signals, the center frequency of third-octave band noise pulses determines the perceived elevation angle of the auditory event [5]. These directional bands correspond to characteristic peaks in the magnitude spectra in head-related transfer functions (HRTFs) for similar angles. As the spectra are depending on the geometry of the pinna, the actual bands are individually different. Nevertheless, the directional band for the perception of height was found to be around 8 kHz for most listeners.
Figure 2 exemplarily shows the characteristic peak for the perception of height in the HRTF for a sound source at

an elevation angle of 15°. The HRTF was selected from a database of 66 subjects[1]. Interestingly, the superposition of 2 HRTFs for the simulation of a phantom source results in a spectrum that exhibits a similar peak. This peak is due to a comb filter that is caused by the ITDs of the loudspeaker pair and its exact position depends on the aperture angle of the loudspeaker pair and the head diameter.

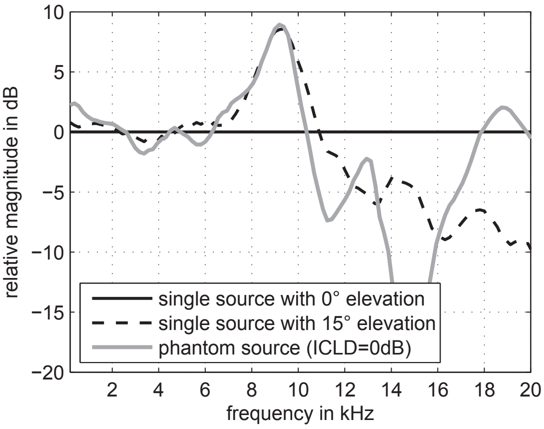

Figure 2: Exemplary magnitude spectra of single sources on the median plane with 0°/15° elevation and of a phantom source created by a frontal loudspeaker pair at ±30° in the horizontal plane with ICLD = 0dB. Left and right ear signals are superimposed energetically and the spectra are normalized to the spectrum of the single source with 0° elevation.

Vertical Localization Model

This contribution uses the model proposed by Langendijk and Bronkhorst [4] which is part of the Auditory Modeling Toolbox[2]. The model performs a template-based similarity comparison and has been verified by listening tests [10]. Similarly to horizontal localization models [11], the centroid of the probability density function is employed here to achieve a single elevation estimate.

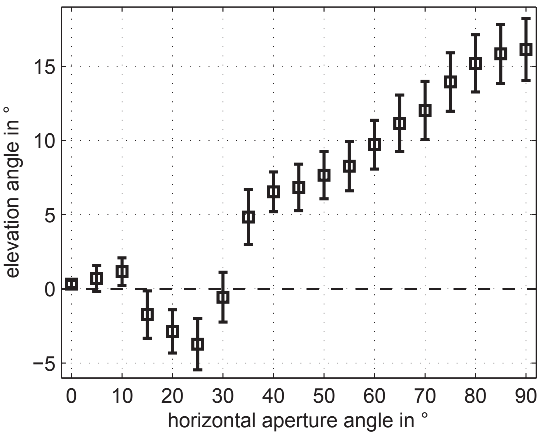

Figure 3: Predicted elevation (mean and 95% confidence interval calculated from HRTFs of 66 subjects[1]) of phantom sources with ICLD = 0dB in dependence of the aperture angle of a horizontal loudspeaker pair.

[1]available at `www.kfs.oeaw.ac.at/index.php?lang=en`
[2]available at `www.amtoolbox.sourceforge.net`

The estimated elevation angle of a phantom source increases for larger aperture angles of the loudspeaker pair, cf. Figure 3. Furthermore, the experimental results (40° aperture angle) are similar to the model estimates.

Conclusion

Elevation of horizontal phantom sources depends on the ICLD: Phantom sources are least elevated for ∞ dB, i.e. when only a single loudspeaker is active, and most elevated for 0 dB. In the latter case, elevation increases for larger aperture angles of the loudspeaker pair.
However, this elevation effect can only be perceived if:

1. the stimulus is broadband enough,
2. the spectrum of the stimulus is known,
3. comb filter of the phantom source due to head diameter and loudspeaker pair matches the pinna elevation cue.

Nevertheless, if the first two requirements are met, the experimental results and the localization model confirm that the last requirement can be assumed for most listeners.

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