Phantom Materialization for Headphone Reproduction

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Abstract

Loudspeaker reproduction systems are subject to a compromise between spatial realism and cost. By simulating loudspeaker reproduction on headphones, the resulting spatial realism is limited accordingly, despite the virtually unlimited spatial imaging capabilities of binaural audio rendering technology. More particularly, phantom imaging as often used for stereo audio material intended for loudspeaker reproduction is subject to various restrictions in terms of loudspeaker positioning in simulated space.
As a consequence, phantom imaging should preferably be avoided when simulating virtual loudspeakers over headphones, especially if head tracking is incorporated or if a wide sound stage is desired. A novel method is described to extract phantom sound sources from stereo audio content and convert these to sound sources in a virtual listening environment.

The stereophonic compromise

Stereophonic audio relies on amplitude panning to position *phantom sources*.
This process is subject to several limitations:

- Sound source positions are limited to an arc between the loudspeakers
- The aperture of the speakers is limited to approximately 60 degrees
- The listener should be placed in the sweet spot
- The listener should be facing towards the center of the loudspeaker base
- Undesirable comb-filter effects arise from the superposition of loudspeaker signals

Virtual challenges

- Without additional processing, stereo audio is perceived 'inside' the head
- Head-Related Transfer Functions (HRTFs) can help to position a sound source *virtually everywhere*, but:
- Personal HRTFs are required for accurate localization
- Head-tracking is required to resolve front-back confusions
- Early reflections are required for an 'out-of-head' percept

Virtual stereo loudspeaker setups

- Many existing solutions for enhanced headphone rendering simulate a virtual loudspeaker setup (virtual stereophony)
- In this case, the resulting *virtual phantom sources* are subject to the same position limitations as exist for loudspeakers, without exploiting the unlimited positioning capabilities on headphones
- The perceived position of phantom sources is not robust against head rotations; hence head tracking will not be as effective as it would be without phantom sources
- The perceived quality of phantom sources is suboptimal due to comb-filter effects which can in principle be circumvented using headphone rendering

⇨ ***Phantom sources should be avoided when rendering audio for headphones***

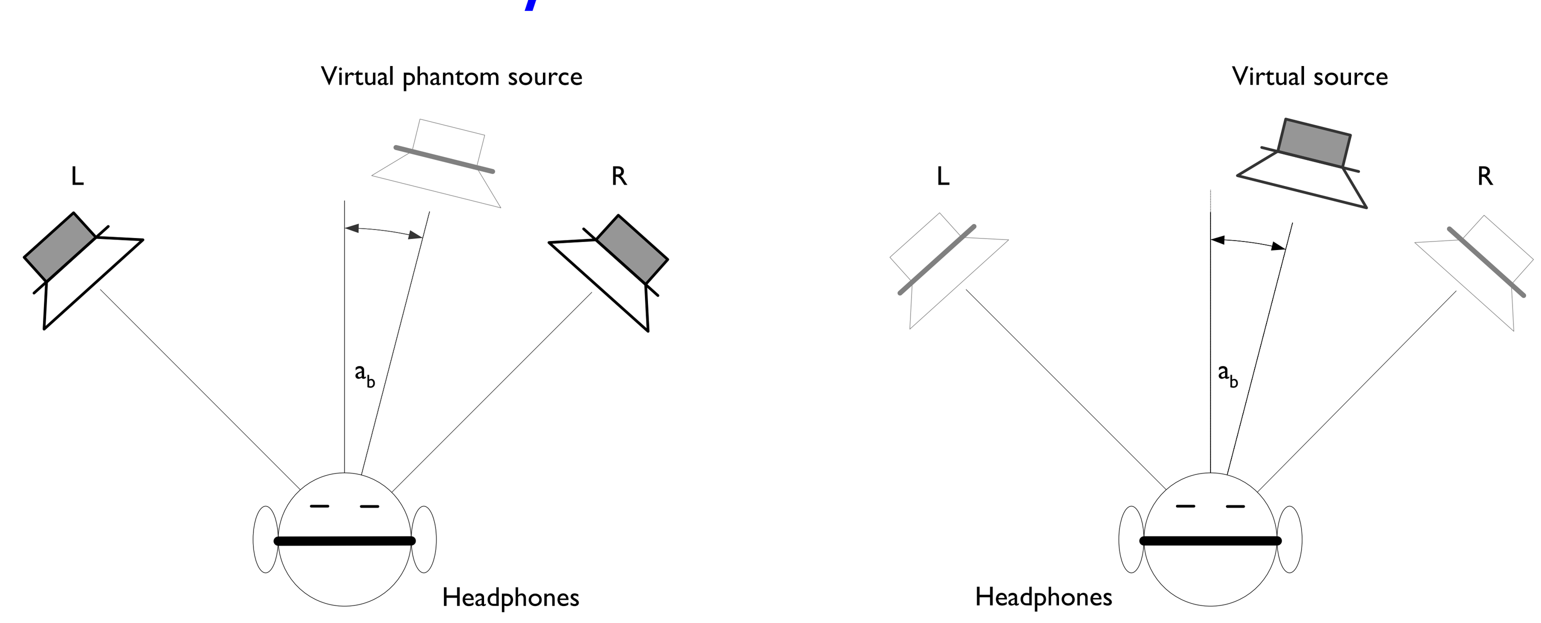

Figure 1 - Virtual phantom sources created by two virtual loudspeakers (left) should be converted to virtual sources (right)

Method

- Convert input signals to individual time/frequency tiles
- Treat each T/F tile as pseudo auditory object with a certain sound source position
- Spatial analysis: Decompose T/F tile into phantom sound source with a certain position, and two residual signals that do not fit into the employed model
- Spatial synthesis: generate 3 virtual sources (one phantom source and two residuals) at the intended sound source positions using HRTFs

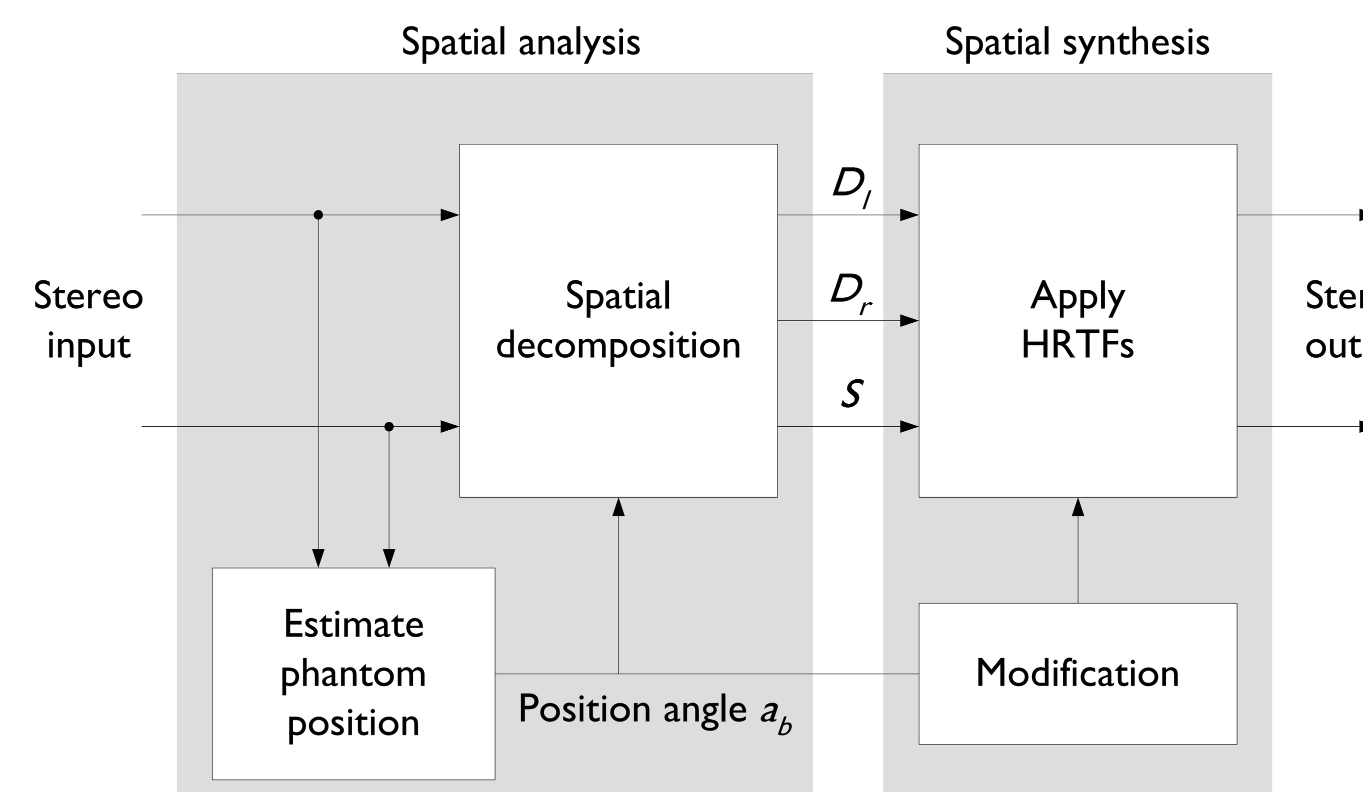

Figure 2 - Employed method to convert phantom sources to virtual sources. This process is performed independently on individual time/frequency tiles (not shown).

Experiment

- Double-blind listening test with 9 subjects and 8 excerpts
- Comparison of three conditions by means of user preference scores
- No incorporation of head tracking
- Anechoic dummy-head HRTFs + parametric early reflections module

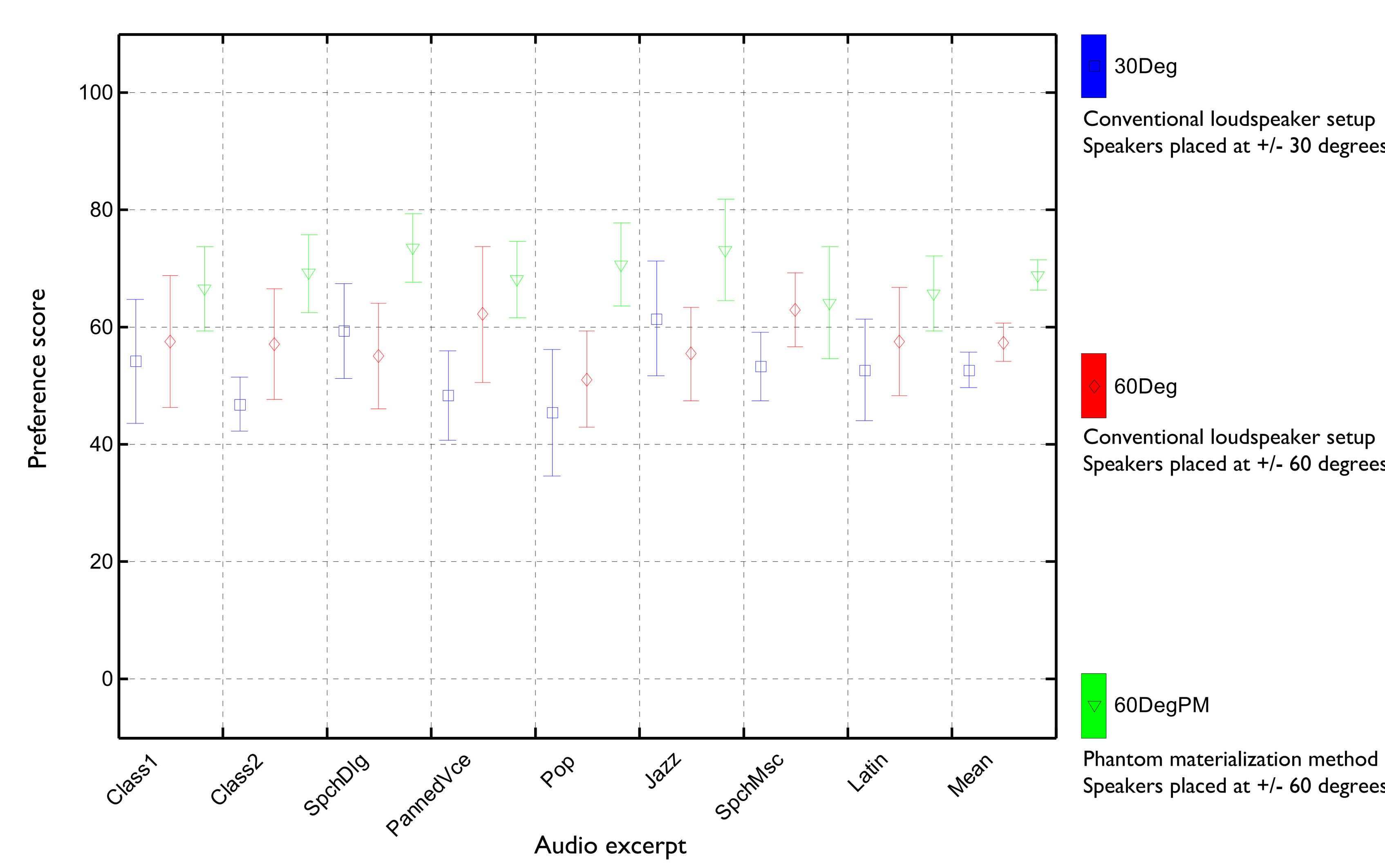

Figure 3 - Listening test results for 8 excerpts and the mean across subjects and excerpts. Error bars denote the 95% confidence intervals of the means.

Conclusions

- Subjects seem to prefer a wider aperture angle of 120 degrees instead of the standard 60 degrees
- Phantom materialization significantly improves the spatial image quality (even without head tracking)

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