

Adaptive Adjustment of the "Sweet Spot" for Head Rotation

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ABSTRACT

Spatial reproduction in a conventional stereophonic audio system (e.g., stereo or 5.1 surround) works in a small area known as the "sweet spot". If the listener changes his position, the phantom source moves in the same direction and finally collapses into the nearer loudspeaker. A play-back system that adjusts the loudspeaker signals depending only on the listener's position in real-time was evaluated in a previous study. Additionally, the orientation of the head in relation to the loudspeaker setup has an influence on phantom source localization. Localization errors that occur when the head is turned are discussed in this article. For this purpose a binaural localization model is used. It shows that the auditory event moves towards the median plane of the listener. This effect becomes stronger as the original phantom source position deviates further from the median plane. A compensation function is proposed and evaluated. Stable phantom source localization can be achieved using adaptive signal adjustment depending on the listener position and orientation.

ADAPTIVE "SWEET SPOT" ADJUSTMENT

Different *static* methods exist to broaden the area of stereophonic perception. A discussion of the advantages and disadvantages can be found in [1]. This paper focuses on a *dynamic* system. This system adaptively adjusts the loudspeaker signals in real-time depending on the listener's position. The "sweet spot" is updated as soon as the listener moves. The localization in such a system was evaluated in [2] using a binaural localization model described by [3]. However, head rotations were not discussed.

The same model was used in the following study to analyze the stereophonic localization for head rotation. Band limited white noise (300 Hz to 1300 Hz) was used as a test stimulus. The point of origin ($x = 0$ cm, $y = 0$ cm) was in the left loudspeaker.

LOCALIZATION WITH HEAD ROTATION

Figure 1 shows the localization angle φ of a center phantom source that depends on the viewing direction of the listener. It can be seen that the phantom source moves if the head is turned. This movement is in the same direction as the turning and depends on the amount of head rotation. The modeled results here are in agreement with experimental results by Pullki [5] who proposed a compensation function for VBAP.

Figure 2 a) shows the localization of a center phantom source if the listener moves sideways (in the x -direction). The loudspeaker signals are adaptively adjusted for all listening positions in reference to the center of the listener's head. Time and amplitude are adapted as if the listener were in the conventional "sweet spot". The head orientation is always straight ahead ($\kappa = 0^\circ$). Due to signal adjustment, this corresponds to head rotation in the conventional "sweet spot". However, the stereo base angle changes depending on position (e.g., 50° for $x = 0$ m and $y = 1.73$ m). It can be seen that the phantom source displacement is stronger than that for head rotation in the center listening position (see Fig. 1), which is also true if

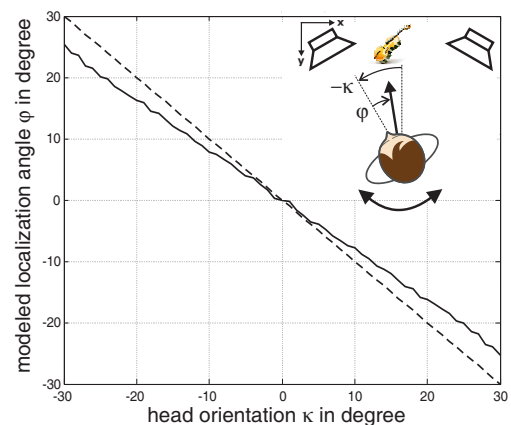


Figure 1: Localization of a centered phantom source as a function of the head rotation of the listener ($x = 1$ m, $y = 1.73$ m, loudspeaker distance = 2 m). The plot shows the localization angle φ (solid) and the target angle to center φ_{middle} (dashed). The localization angle is modeled using interaural time differences.

the phantom source is deflected to the left, as shown in Figure 2 b). The farther the line of sight deviates from the target phantom source position, the stronger the effect that the perceived phantom source position is displaced.

COMPENSATION FUNCTION

An absolute compensation of the perceived phantom source displacement due to head rotation can only be achieved if the target position of the phantom source is known, which is not the case for standard stereophonic recordings. Thus, a compensation in reference to the middle between the loudspeakers is proposed. The displacement that has to be compensated

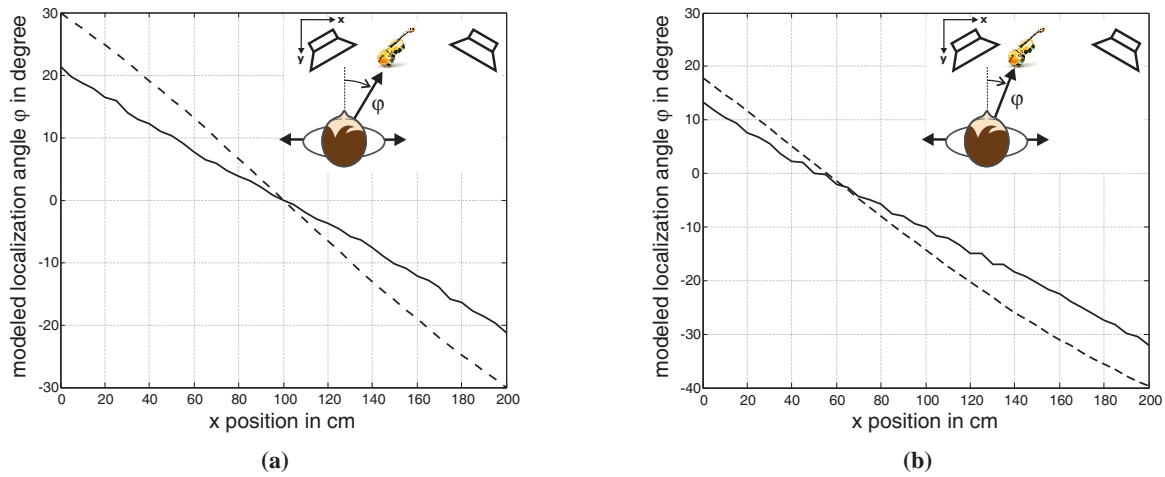


Figure 2: Localization of a phantom source versus the x-position of the listener ($y = 1.73 \text{ m}$, $\kappa = 0^\circ$, loudspeaker distance = 2 m). The plot shows the localization angle φ (solid) and the target angle to the phantom source (dashed). The localization angle is modeled using interaural time differences. The loudspeaker signals are always adjusted to the center of the listeners head. Figure (a) shows the simulation for a centered phantom source and (b) for a shifted phantom source to the left using a 6-dB level difference (target angle after [4]).

$\varphi_{\text{compensation}}$ is therefore dependent on the head related angle to the middle between the loudspeakers φ_{middle} (see Fig. 3). This angle depends on the position of the listener (x, y) relative to the loudspeakers and the angle of the head rotation κ :

$$\varphi_{\text{middle}} = \tan^{-1} \left(\frac{0.5 \cdot \text{loudspeaker distance} - x}{y} \right) - \kappa.$$

The compensation angle can be deduced from Figure 1 using a linear regression:

$$\varphi_{\text{compensation}} = \frac{5^\circ}{30^\circ} \cdot \varphi_{\text{middle}}.$$

The phantom sources can now be shifted by the compensation angle using intensity stereophony (e.g., the tan-law). The proposed compensation function underestimates the phantom source displacement for asymmetrical listening positions (see Fig. 2). In addition, excentric phantom source positions are over and accordingly under compensated, which results in a narrower stereo stage.

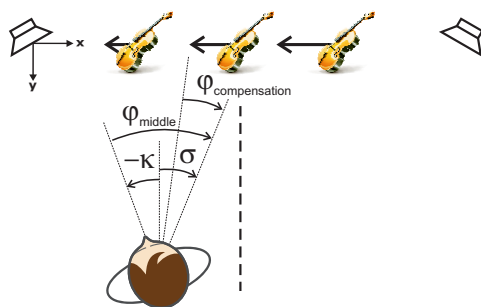


Figure 3: Phantom source shift with signal adjustment for different phantom source positions. The residual error increases the further the phantom source position deviates from the median plane of the listener.

IMPLEMENTATION

A real-time test program for adaptive "sweet spot" adjustment was implemented on Windows (see Fig. 4). The listener was tracked using a camera and a face recognition algorithm. The delay and level were adjusted accordingly. A demo version can be downloaded at www.sweetspotter.de.

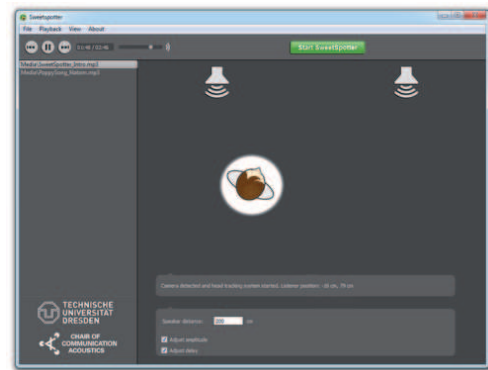


Figure 4: Guided user interface for SweetSpotter.

SUMMARY

The displacement of phantom source positions due to head rotations was investigated. As a result, a compensation function for stereophonic signals was proposed.

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