

Adaptive Adjustment of the “Sweet Spot” to the Listener’s Position in a Stereophonic Play Back System - Part 1

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Introduction

The spatial reproduction of sound in a conventional stereo system works in a small area which is located on the symmetry axis between the loudspeakers - the so called “sweet spot”. Beyond this area, the spatial perception collapses and the stereo image moves to the nearer loudspeaker since the signal arrives both louder and sooner. Finally, the stereo image is completely located in the nearer loudspeaker due to the precedence effect as can be seen in Figure 1. However, in desktop applications or virtual environments, image and sound have to correlate even though the listener is out of the “sweet spot”. Although, stereophony has a long history, the listener has not yet been released from its static hearing position [1, 2].

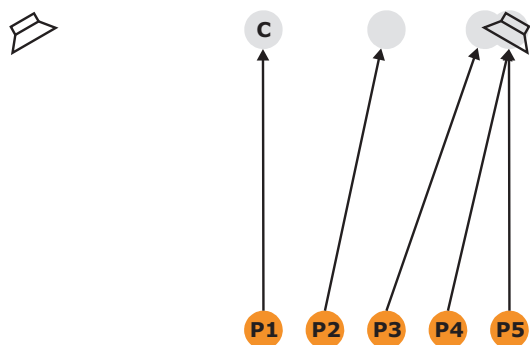


Figure 1: Localization shift of a center phantom source C in a conventional stereophonic reproduction system depending on listener position P after Bauer [3].

Literature Survey

Most methods try to broaden the area of stereophonic perception by the adjustment of loudspeaker characteristics. One of the early studies was published by Bauer [3]. He proposes a system, where the angle between the loudspeaker axes is approximately 120° to 130° . Frequencies above 250 Hz should be radiated using dipoles. In such a system, the level difference between the loudspeaker signals remains almost constant over a wide area as can be seen in Figure 2. If the listener is moving away from the symmetry axis, the signal from the nearer loudspeaker will arrive earlier but the signal from the further loudspeaker will become louder. This leads to contradicting localization cues, resulting in localization blur for off center listening positions [3]. An example of determining the optimal loudspeaker directivity by using listening tests is Aarts [4]. Further publications dealing with loudspeaker directivity are [5, 6, 7]. Problematic

is the frequency dependent radiation pattern of real loudspeakers, thus only a small improvement can be achieved.

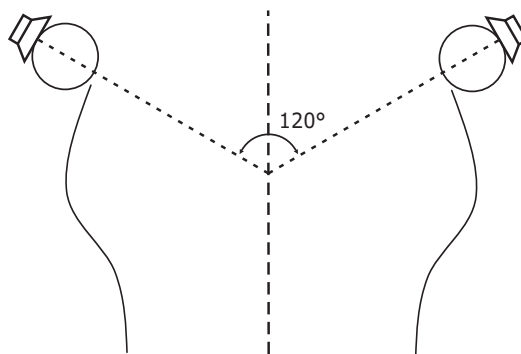


Figure 2: Area in which the level difference between the loudspeaker signals is smaller than 3 dB using loudspeakers with dipole characteristic after Bauer [3].

Another method is the adjustment of the delay between the loudspeaker signals to compensate for different distances to the listener’s position. This adjustment can be done manually or by using a measuring microphone. Aoki [8] describes an interesting system which uses groups of delayed directional loudspeakers. In all cases, the systems are designed for static positions and do not respond to movement of the listener.

For the first time Kyriakakis [9] described a system which uses head tracking and time delay between the loudspeaker signals to move the “sweet spot” automatically. Unfortunately, there are no publications about the usefulness of time delay and amplitude adjustment in off-center listening and emerging artifacts.

Adaptive Signal Adjustment

This paper presents a system which adjusts the “sweet spot” in real-time to a listener’s position. An approach to estimate the location of the listener by tracking the remote control of a TV set is stated in Kim et al. [10]. Because the precision of the tracking data is not required to be very high, a markerless, camera based method (stereo or monocular camera using a face tracking algorithm) is implemented in this study. If more than one person enters the listening area, the signal adjustment can automatically stop. Our current system runs in real time on a single laptop using the integrated camera. Figure 3 shows the interface of the C++ program “Sweetspotter” which adjusts the loudspeaker signals depending on the listener’s position.

The practicability of the system was confirmed through informal listening tests.

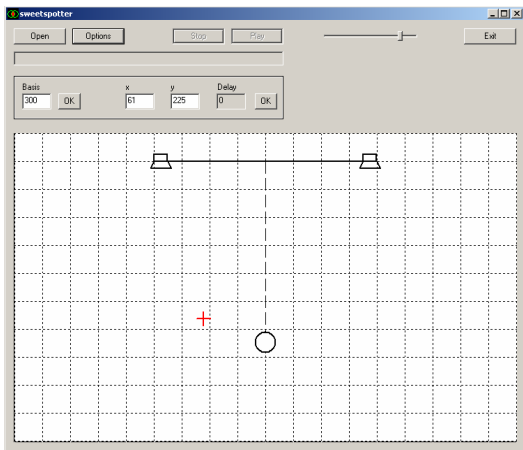


Figure 3: “Sweetspotter” is a real time C++ implementation running on Windows. The listener position is tracked using a camera and a face recognition algorithm. Delay and level are adjusted accordingly.

To study the utility of the system in detail, different binaural models are implemented. As a first approximation, an analytic approach by Lipshitz [11] is used. This approach analyzes the superimposed signals at the listener’s ears, if several sources emit low-frequency sine waves. The emerged phase or level difference is converted into an Interaural Time Difference (ITD) or Interaural Level Difference (ILD) and finally in a corresponding azimuth angle.

Figure 4 shows the setup for an off-center listening position. The signals are adjusted, so that identical loudspeaker signals would reach the center of the head at the same time and with the same amplitude. It can be seen that the signal paths between loudspeakers and ears become asymmetric regarding head shadowing and travel distances.

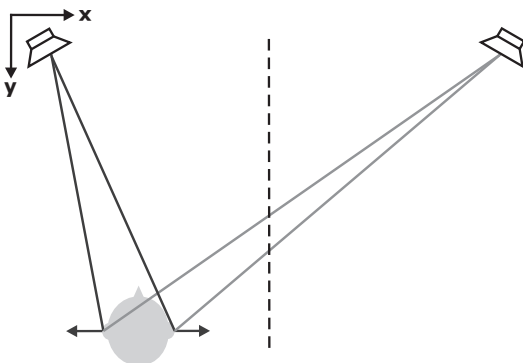


Figure 4: Asymmetric signal paths between loudspeakers and ears for an excentric listening position.

The effect of adaptive signal adjustment will be discussed using a center phantom source. If signals are adjusted in reference to the center of the listener’s head, it can be assumed that the position of the phantom source will remain constant in front of the listener ($\Phi = 0^\circ$ referring to viewing direction) if the listener is moving from left to right. This is not the case, because of the asymmetric

signal paths. In Figure 5 the modeled localization angle Φ is compared with the actual target angle to center. A standard stereo setup with a loudspeaker distance of 2 m is used. The listening position is moved in x direction with constant $y = 1.73$ m. The orientation of the listener is straight ahead, as shown in Figure 4. It can be seen, that the localization angles match with a maximum deviation of 8° in the extreme positions in front of the left ($x = 0$ cm) and right ($x = 200$ cm) loudspeaker. This means that the perceived position of the center phantom source remains almost constant in the middle between both loudspeakers, with a slight shift in the direction of listener movement. This remaining error can be estimated and compensated for by using the binaural model. Thereby, a correct localization over the whole off-center listening area is achieved.

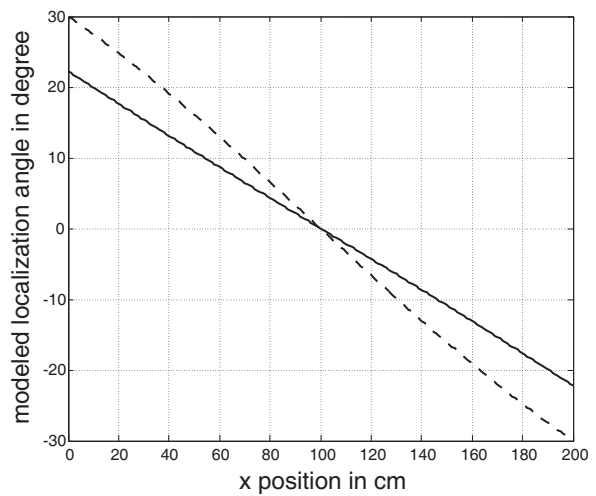


Figure 5: Localization of a center phantom source against the x position of the listener ($y = 1.73$ m, loudspeaker distance = 2 m). The plot shows the perceived angle to phantom source (solid), which should be at center, and actual angle to center (dashed). Delay and level differences due to different distances between loudspeakers and listener position are compensated for using the described method of adaptive signal adjustment.

To study transient or broadband signals an advanced approach, a binaural model after Braasch [12], is used. The model simulates outer ear, inner ear and the central nervous system. The results confirm and extend the findings from the analytic model. A detailed description of both approaches can be found in [13, 14, 15]. In addition, the models are used to discuss the influence of different stereophonic recording techniques, head orientation and tracking accuracy on the utility of the method.

Conclusion

The stable localization of phantom sources in a stereophonic reproduction setup can be significantly improved by using the described method. Adaptive signal adjustment in reference to the center of the listener’s head still results in a small localization error, which can be estimated and compensated for using a binaural model.

Figure 6 shows the localization of a center phantom source in a stereophonic reproduction system with ideal adaptive signal adjustment.

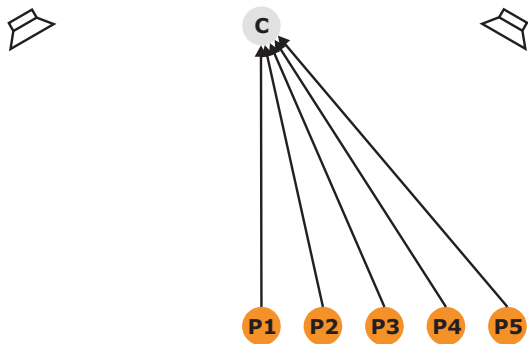


Figure 6: Localization of a center phantom source C in a stereophonic reproduction system with adaptive signal adjustment depending on listener position P.

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