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Factors for awareness and consideration when composing for or performing with multi-channel sound projection systems

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Preliminary information

Awareness and consideration of several major points is required for simulating stationary and moving sound sources within a multi-channel audio playback system. These points include: ear physiology, sound source characteristics, host space characteristics, lateral localization cues, distance cues and positional shift cues.

Ear physiology

Of the many factors contributing to localization, the pinnae (the outer projection of cartilage of the ears, called the auricles or pinnae) are the most significant. Their filtering action is most pronounced above 4000 Hertz. To increase the fidelity of localization, researchers Shaw and Vaillancourt (1985) have measured *head-related transfer functions* (HRTFs) over a wide range of incidence angles. These functions express the frequency response imparted to the sound by the pinnae for a particular angle. HRFTs also depend on the distance between the source and the listener. Because reduced variation is observed for source locations more than 2 meters away, HRTF measurements are most often made at more than 2 meters away from the sound source.

Sound source characteristics

The sensation of loudness is primarily determined by the amount of acoustical energy received by the ear. The loudness of a sound is a measure of the subjective response to its amplitude. Loudness is strongly influenced by the frequency and spectral composition of the sound. According to the research done by Fletcher and Munson (as early as 1938) regarding equal loudness of sine tones of different frequencies, the ear is most sensitive to sound in the range from 250 to 6000 Hertz (2000 Hz to 4000 Hz is the prime focal point), and that below 60 Hertz and above 10,000 Hertz the loss of sensitivity is considerable.

For the purposes of this research, as well as ease of simulation, point sources (those emanating from small points rather than from larger surfaces) are recommended and assumed.

Host space characteristics

The volume and dimensions of the host space, the number of surfaces and the sound reflective (and/or absorptivity) qualities of all surfaces help to determine the amount of reverberation or reflections of sounds off of surfaces within the host space. Large quantities of reflected sound from numerous surfaces within a host space create confusion for an observer when the observer is trying to determine a sound source location. For the purposes of this research, a less reflective and more absorptive host space is desirable.

Factors for determining the lateral localization of a sound source

According to the research done by Gary Kendall of Northwestern University, for sounds whose frequencies are approximately 270 to 1400 Hertz, a listener's ability to identify a sound's location (left, center or right) is determined by *interaural time difference (ITD)* - time delay information indicating the amount of time it takes the sound to travel the additional distance around the head to reach the other ear. This timing difference of the initial transient as perceived by the brain allows us to determine whether the sound we are hearing is coming from the left, center or right. Interaural time difference is effective in determining sound location with frequencies whose wavelengths are larger than the size of the listener's head, thus the reason for indicating the above frequency range stipulation.

For sounds whose frequencies between 1400 to 8000 Hz, the wavelengths are smaller with significantly shorter time delay in moving around the listener's head to be received by the other ear thus making the timing difference of the initial transient difficult for the brain to distinguish. For such frequencies, *interaural intensity difference (IID)* (comparison of levels of perceived loudness between the left and right ears) is used to determine lateral location of the sound source.

Since most sounds are made up of composite frequencies, the brain often uses both techniques to determine the lateral location of a sound source.

Factors for determining a sound's distance from the observer

The most decisive cue used for determining distance is perceived loudness; as amplitude reduces with increased distance. Secondly, low amplitude, high frequency and low frequency partial content of a sound's composite timbre diminishes with increasing distance from the listener. Finally, a change in the ratio of the amplitude of the direct sound to the amplitude of the indirect or reflected sound (sound reflected off of objects, walls, floor and ceiling: the host space) assists in determining distance proximity.

Factors contributing to positional shift cues

When a sound location is moved during the sound's duration, the acoustical phenomenon known as the Doppler effect plays a significant role. The Doppler effect is a change in perceived pitch that results when the sound source and the observer are moving closer together causing the perceived pitch to be raised from its fixed value, or when the sound source and the observer are moving further away from each other causing the perceived pitch to appear lower. The Doppler shift may be represented as:

$f^d = f\ {}^{c}/c\text{-}v$ where f is the fixed frequency, f^d is the perceived frequency, c is the speed of sound (approximately 345 meters per second) and v is the speed of the source relative to the observer.