Echoes from New Orleans

Making Spatial Music Accessible: Investigating elementary spatial movements

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Significant research has been performed for the creation of auditory virtual environments where the goal is to reproduce spatial qualities of sound, such as direction, distance and properties of the space, such as reverberation time and listener envelopment. Such systems are used much in the entertainment industry, but also in music. For their successful deployment it is important to ascertain concise perception of spatial manipulations for listeners in large spaces such as concert halls. This can be a difficult task since most techniques for simulating space in audition are optimized for listeners in the center of circular or spherical loudspeaker arrays (i.e., the sweet spot) with reference to a dry, reflection-free environment. In practice however, there is substantial variation in concert hall acoustics, the spatial distribution of the audience, and practical limitations in loudspeaker placement.

Spatial events cannot be perceived consistently in an absolute manner due to the differences in the location of the listeners in the space. Even with a perfect spatial audio system, an event appearing in front for a listener seated in the middle of the hall, will be perceived as originating from the front right direction for a listener at the left end of the hall. What could be perceived consistently, however, are discrete or continuous changes in location of sounds and the spatial interrelations among the elements of the spatial scene. From a psychoacoustics point of view, this idea is related to the minimum audible angle (MAA), i.e., the angular displacement of a sound that is perceivable with a probability of 75%. It depends on the sound used (in particular the spectral content of the sound), the direction from which the sound is emitted, the plane in which the movement is taking place (i.e., horizontal, vertical or diagonal) and to a smaller extent on the duration of the sound. Typical values for MAAs are about 1 degree for a sound directly in front of a person, 1.5 degrees for a sound at 60 degrees and 5 degrees for a sound at the side of the listener, (estimations done with broadband noise stimulus and real sounds, after Saberi *et al.,* 1991 and Chandler & Graham, 1991).

Perception of sound displacement for virtual systems in reverberant spaces has been little studied. Studies focus mostly in absolute localization judgments, the majority being in anechoic conditions. In addition, they are mostly concerned with listeners in the center of the loudspeaker deployment. The effect of the room is important in sound localization, especially when sounds with regular temporal variation are considered, sounds that often occur in music. Reflections, especially side ones, are known to affect localization. Furthermore, the location of a listener relative to the loudspeaker array distorts the localization image. This is because the time of arrival and levels of the signals emitted by the loudspeakers vary as a function of the location of a listener in the concert hall. For virtual audio systems designed with the sweet spot in mind, listeners at different locations experience a mixture of lead and lag signals and levels. The result of this phenomenon is hard to predict in an analytical way. Depending on time and level differences of the lead and lag signals, a variation of phenomena such as summing localization, the precedence effect or in the extreme case,

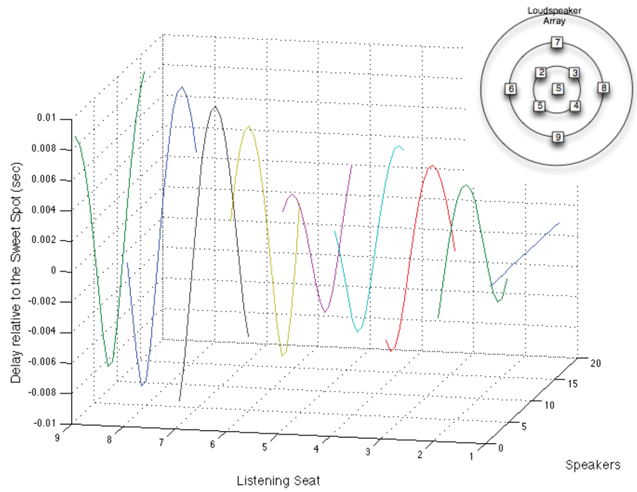

Figure 1. Variation in the time of arrival of the sound of each speaker to each of the listening seats in the test relative to the sweet spot. Level differences are aligned with the time differences therefore furthermore blurring the localization process. Estimation is for 16 speakers equally spaced on the array with an offset of 11.25 degrees.

echoes, will essentially reduce the spatial resolution delivered to the audience as a whole. It is important therefore to establish empirical laws with respect to loudspeaker placement that take into account the psychoacoustics of auditory space perception.

The aforementioned problems can be approached by way of evaluation experiments. As a departure point, we focused on the perception of sound displacement and movement and examined how this varies for measurements in a studio set-up and in a large area similar to that of a concert hall for the case of amplitude panning.

Identification performance was estimated for four angular displacements and three nominal directions of incidence in nine seats in the concert hall for amplitude panning with 8 and 16 speakers. The same experiment was performed in the studio for a person in the sweet spot with an 8- and 4-speaker system. Identification rates were then used to estimate MAAs. The results show that increasing the number of speakers improved localization performance for VBAP. For four speakers results were disappointing even for a studio setup. With eight speakers, MAAs were comparable for frontal incidence but deteriorated more than expected for sounds emitting from the sides of listeners. In addition, we found that these values deteriorate significantly for sounds originating from locations on or close to a loudspeaker. In the concert hall, for frontal incidence, the best performance was found for listeners aligned with the source. Performance deteriorated as the angle between the seat of the listeners and the sound increased, as would be expected. Localization using the 8-speaker system was in general less accurate than in the studio, implying that the room had a significant effect. Overall it improved when 16 speakers were used and became comparable to the studio for frontal incidence. Performance for sounds at oblique incidence was however sig-

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Figure 2. Measurement process in a big space

nificantly degraded and the effect of the room became more pronounced. For listeners away from the centre of the array, identification performance was confounded with the difference between the nominal and the apparent angle of incidence and angular separation and the distortion to the localization image due to violation of the symmetry with respect to the time of arrival of the speakers. In addition, considerable variation is observed in the measurements for sounds on the sides of the listeners, which can either be attributed to unfamiliarity with spatial sound experiences, but also to individual differences.

It appears therefore feasible to create a uniform experience of sound displacement both in the studio and in the concert hall; however in the latter case a specialized measurement procedure is necessary to compensate for the effect of the room and the variability in listener positioning. Composers, performers and practitioners should be particularly careful for sounds at the sides of listeners where the expectations of algorithm designers are not met especially in room conditions. We are currently extending our research to accommodate sound movement and a variety of spatialization algorithms.

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Best student paper/young presenter awards (New Orleans)

Architectural Acoustics
First: Samantha B. Rawlings and Joshua A. Magee (University of Hartford)
Second: Gordon Rubin (Rensselaer Polytechnic Institute)

Animal Bioacoustics
Joy Smith (Coastal Carolina University)

Acoustical Oceanography
First: David R. Barclay (University of California, San Diego)
Second: Megan S. Ballard (Penn State University)

Engineering Acoustics
Tim Marston (Penn State University)

Musical Acoustics
First: Rohan Krishnamurthy (Kalamazoo College)
Second: Edward L. Toussaint (Lawrence University)

Rohan Krishnamurthy (Musical Acoustics) presented a mini-concert on the mridangam.

Noise (young presenters)
Yun Jin (Rensselaer Polytechnic Institute)
Cole V. Duke (Brigham Young University)

Signal Processing in Acoustics (young presenter)
Joris Vanherzeele (Vrije Universiteit Brussel)

Speech Communication
First: Youngsok Jung (Harvard-MIT Div. of Health Science and Technology)
Second: Melissa Baese (Northwestern University)

Structural Acoustics and Vibration
First: Kyungmin Baik (Washington State University)
Second: R. Benjamin Davis (Duke University)

Underwater Acoustics
First: Yaniv Brick (Tel Aviv University)
Second: Shawn F. Johnson (Penn State University)