Volumetric Modeling of Acoustic Fields in CNMAT's Sound Spatialization Theatre

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Abstract

A new tool for real-time visualization of acoustic sound fields has been developed for CNMAT's sound spatialization theatre. Unique features of the theatre and the acoustic and volumetric modeling software are described.

1 Sound Spatialization Theatre

We have built a sound spatialization theatre into the main performance and lecture space at the Center for New Music and Audio Technologies. The theatre features a flexible suspension system built primarily for loudspeakers.

Each speaker hangs from a rotating beam. The pivot point for each speaker runs in a track that slides along rails bolted to the ceiling. With height adjustment of each suspension cable, this system safely allows speakers to be moved anywhere in the room and oriented along two of the three possible axes. Rotational symmetry of the concentric drivers in Meyer HM-1 speakers obviates the need for adjustments around the third or "roll" axis.

Rather than use subwoofers that are fewer in number and spatially separated from the medium to high frequency speakers, we chose to place a subwoofer at each of the 8 channel locations. Admittedly this is not common practice, but when confronted with the question of how to manage the delivery of low frequencies from several primary speakers to a few spatially disassociated subwoofers it became clear that our research interests would be better served by having full range performance at each speaker location.

Real-time, low-latency audio signal processing for the speaker array is performed using a multiprocessor Silicon Graphics Octane workstation or a Macintosh PowerPC system each of which is equipped with 8 discrete channels of digital-to-audio conversion.

2 The Problem

Optimizing the speaker array positioning and sound processing for each performance in the theatre is challenging. The traditional empirical approach is far too time-consuming to support situations in which there are weekly (and sometimes daily) performances with varied configurations. It takes too long to evaluate the effects of new speaker positions and software parameter changes for all listening positions. It is easy to optimize the listening experience for the lucky person in the "sweet spot" at the expense of the rest of the audience. The challenge is to find a compromise where as many listeners as possible experience the intent of the sound designer and as few listeners as possible endure disastrous seats.

3 A Solution

To aid sound designers and composers in achieving a good compromise for the diverse applications of the theatre, we have developed software for visualizing speaker signals, a model of the acoustic sound field in the room, and interpretations of the field according to perceptual models. Important examples of prior work in this area include visualization of acoustic simulation (Stettner and Greenberg, 1989) and visualization of beam tracing (Monks, et al., 1996). Unique features of the work described here include the emphasis on interactive, real-time visualization, the use of a highly configurable performance space, and the focus on adapting the processing and space to achieve diverse artistic goals.

The visualization software is part of a complete system managing audio, gestural flow and visual display. The heart of the system is a database describing the room. It contains information on geometric features such as the shape of the room, positioning and orientation of the speakers, microphones and audience seating, live performer locations and their musical instruments' locations.

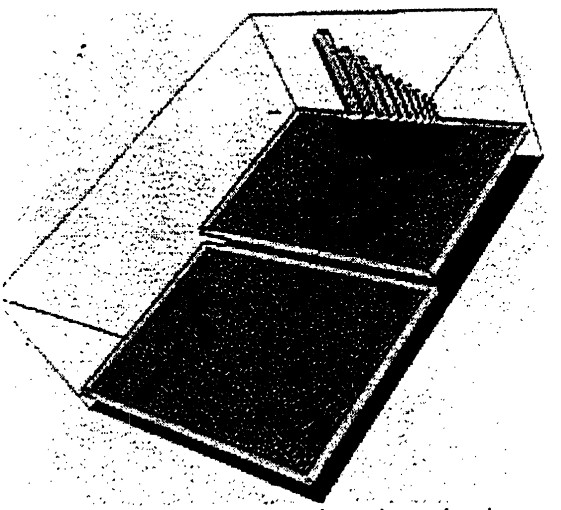
Acoustic properties of each object in the room include frequency dependent radiation patterns and the location of their acoustic "centers."

This database is used by the spatial sound processing software to process source signals to create an audience percept of virtual sources from arbitrary regions in space. The desired percept may also involve creating the illusion that listeners are in a room of a different size than the actual theatre (Lehnert and Blauert, 1991). The location of these sources is controlled in real-time through gestures (Hand, 1997) or arbitrary control messages arriving from the network (Wright and Freed, 1997).

The visualization software has access to the room database and real-time parameter estimates from the spatialization software. Since it has no access to the real sound pressure levels in the room it must estimate these based on an acoustic model of the room. The image source method was used (Heewon and Byung-Ho, 1988) because of its amenability to real-time computation.

4 Application Examples

4.1 Pressure Levels



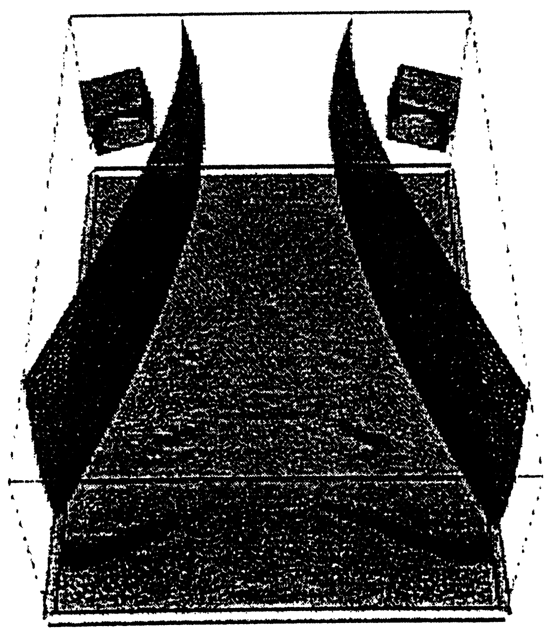
The reader is advised to explore the color images and animations available on CNMAT's web site [www.cnmat.berkeley.edu/AcousticVisualization] for a clearer indication of the system's potential. Sound pressure levels are shown using a color map on a horizontal cut plane through the space. This movable plane is typically set to the average positions of audience5s ears in the room. This surface may be moved to show, for example, effects of tiered seating or to evaluate the experience of a performer who may be standing on a raised stage. Several simultaneous cut surfaces may be necessary, for example, for balcony seating in large theatres.

It is interesting to contrast this volumetric visualization with traditional audio metering where scalar signal levels are displayed for various nodes in the signal processing chain. Such metering is useful for managing signal levels in the electrical elements of the audio system to avoid distortion and speaker overload. However it is hard even for experienced sound engineers to use scalar metering to predict actual sound pressure levels in many locations in a venue.

4.2 Summing Localization

A commonly adopted strategy for sound localization with speaker arrays is the summing localization model (Blauert, 1997), known in its general form as vector panning (Jot, 1999, Pulkki, 1997). Virtual sources are placed between pairs of speakers by dosing the signal level of the source appropriately for each speaker (Chowning, 1970).

In CNMAT's venue, vector panning failed to provide good virtual source imaging for most of the audience. This may be explained by the precedence effect, also known as the "law of the first wavefront" (Blauert, 1997), which may work against summation localization. As the difference in the time of arrival of wavefronts from the two speakers increases towards one millisecond, the source of the earliest wavefront is perceived as the actual source, regardless of the amplitude dosing performed by vector-panning. Visualization of an isosurface along which wavefront time difference is a constant illustrates the geometric implications of this perceptual phenomenon. In the figure below the listening locations between the two surfaces have wavefront-arrival-time differences less than the value determining the isosurfaces.



This representation is also effective with other important time delay effects in spatial hearing such as the varied values of the echo threshold, backward masking, and multiple event thresholds (Blauert, 1997).

We have generalized this isosurface representation to multiple speaker arrays by allowing the user to select appropriate subsets of two speakers and simultaneously display the multiple surfaces.

One of the discouraging observations about these surfaces is that optimal, i.e., precedence-effect-free, listening regions can be quite small. Indeed, only a privileged few in an audience find themselves in or near the "sweet spot." With the goal of providing a spatial enveloping auditory experience to a larger segment of the audience we have explored techniques to limit the influence of the precedence effect.

Inspired by the "Clifton effect" (Clifton, 1987, Clifton and Freyman, 1996) we have explored the use of roving time-delays on the direct signals form each speaker to breakdown precedence. Clifton and her associates have demonstrated that precedence breaks down for a while when the delay structure is altered to favor another speaker as the leading signal source. Precedence is then reestablished with further stimulation from the new temporal configuration. The idea behind the continual roving of speaker time-delays is to continually inhibit the establishment of precedence. Initial results of this technique appear promising.

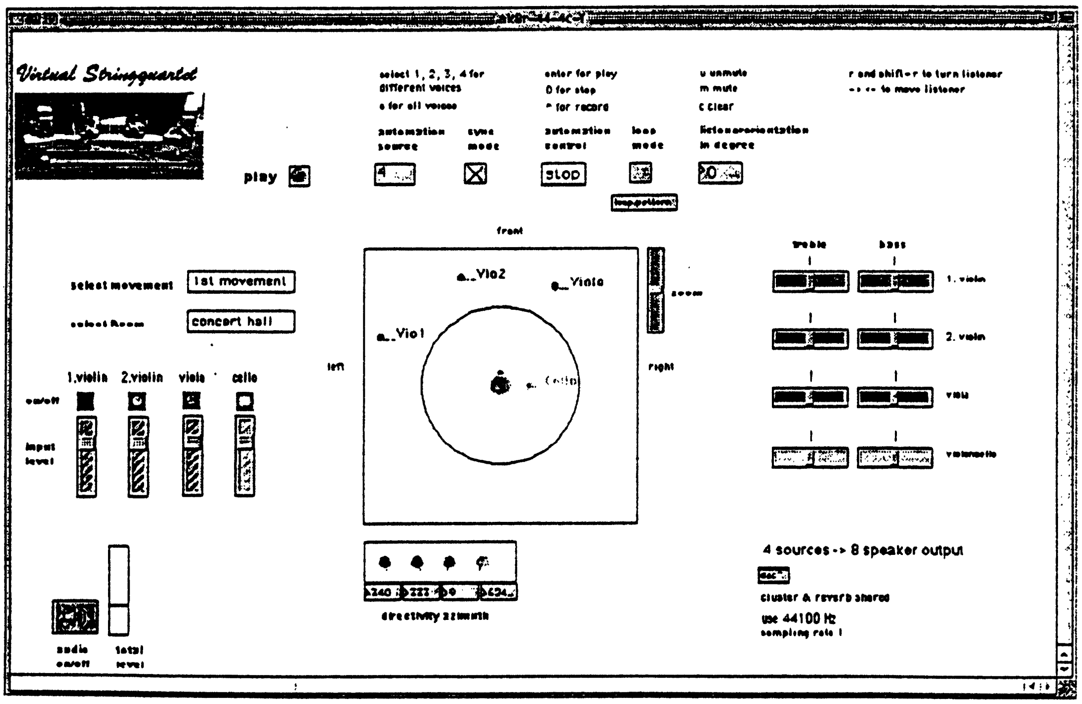
We have also successfully applied the decorrelation techniques developed by Gary Kendall and his associates (Kendall, 1995). Here features of both the magnitude and phase spectra are made to differ in the speakers where the vector panning is operative.

These efforts to reduce the effects of precedence so that a larger number of people in the audience can have a compelling spatial experience may have additional perceptual consequences. In particular, the decorrelation techniques give rise to considerable ambiguity as to the location of the source. Here there appears to be a real trade-off between the enveloping nature of the spatial audio experience and the precision of localization.

5 Multiple Source Spatialization

One recent application of the theatre is the "virtual string quartet." We are able to spatialize four independent sound sources in real time on a Macintosh G3. In the example illustrated below the four sources are stored sounds of instrumentalists recorded under anechoic conditions. We have extended this spatialization technique to allow for the movement of the listener as well as the sources. We have also experimented with the use of filters to simulate the directivity of the instruments.

Instead of the mixing console we have begun to use the desktop computer with multi-channel I/O in the diffusion of prerecorded electro-acoustic music and in concerts with live performance. With the current SGI and Macintosh G3 technologies we have achieved sound I/O latencies solidly under 7 milliseconds, an acceptable delay for many situations.



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