AuSIM3D Vectsonic™ Loudspeaker Display

Overview

What

AuSIM's AuSIM3D audio simulation engine exclusively supported headphone (binaural) displays until the 2007 introduction of the AuSIM3D Vectsonic™ loudspeaker system. Two primary reasons drove this exclusivity: 1) technology – AuSIM3D computed the final sound signals as they should be in the listener's ear canals; it is easiest to simply present them directly there, and 2) market – AuSIM3D was developed for mission-critical applications, which for the most part excluded external sound through the use of headphones. AuSIM3D Vectsonic™ was born from both market (mission-critical customer demand) and technology (algorithms, computing power, and multi-channel interfaces) influences.

The Challenge and Opportunities

Presenting virtual aural environments over loudspeakers is difficult, primarily because the physical environment, in all of its complexity, will always be part of the perception. Physical environments are also very dynamic. It is theoretically possible to account for all of the physical environment's properties in the simulation. But the properties of physical environments tend to change without notice. The advantage of the physical sound of loudspeakers is that the entire body feels it and listeners like physical sound. Listeners are much more forgiving of physical sound. Computed binaural signals must be perfect to convince the listener, because their bodies feel nothing.

The Requirements vs. Options

To support AuSIM3D, a loudspeaker display system must be capable of presenting the perception of a sound source from any direction, and further support one or more listeners in any attitude. Stereo and surround present terrific images, but are limited to sounds on the horizontal plane and constrain the listener to be front-facing. Quadraphonic and Ambisonics can be very good, but also limited. The transaural display delivers convincing aural images from all directions, but the listener is tightly constrained. Tracked-transaural displays frees the listener quite a bit, but the listener's nose must still be pointing between the loudspeakers. Cooper-Bauck's theory suggests transaural supports multiple listeners so long as there is at least one transducer per ear. AuSIM3D supports transaural loudspeaker displays as an output model plug-in.

The ultimate loudspeaker display may be wavefront synthesis. While wavefront synthesis has been under development for many years, it requires hundreds of transducers and thus may be cost-prohibitive for many more years. Wavefront synthesis is a very different process than AuSIM3D.

Vector-Based Amplitude Panning

VBAP is a public-domain technique, originally developed and extensively evaluated by Dr. Ville Pulke at Helsinki University of Technology (http://www.acoustics.hut.fi/research/cat/vbap/), for displaying a virtual aural environment to a group of people with a loudspeaker array. VBAP does not use phase and coloration as a perceptual tool and thus gains a larger sweetspot than competitive techniques. VBAP images suffer from the lack of phase and color control when compared to stereo or almost any of the presentation methods above. However, the listener is very forgiving with enveloping physical sound. VBAP supports any arbitrary dynamic sound trajectory as well as discrete reflections, both of which are readily produced by the AuSIM3D engine. VBAP places very little constraint on the listener. In summary VBAP satisfies most of the AuSIM3D requirements for loudspeaker display with a small tradeoff in image quality.

The power of VBAP is that it produces physical wavefronts with appropriate directional characteristics, whereas competitive surround techniques rely on the phase-coherent combination of waves (interference pattern) to produce an illusion (at a specific place) of particular wavefronts.

VBAP requires a two-dimensional loudspeaker array "surface", which can be triangulated with a mesh. The surface can optimally be shaped in a sphere to envelope the listening space.

Vectsonic Technology

AuSIM3D Vectsonic™ loudspeaker rendering technology is a derivative of the unique AuSIM3D rendering engine, inspired by Dr. Pulke's VBAP ideas, but not constrained to VBAP. Vectsonic makes several significant improvements over comparative loudspeaker displays, such as support for run-time parameterization, single-source sound pressure levels (SPL) louder than a single loudspeaker, a mix of different loudspeaker types, optional direction-dependent spectral compensation, optional direction-dependent phase compensation, dynamic cross-over, and following a tracked listener with a focused sweetspot. Further Vectsonic includes all of the advanced features of AuSIM3D's simulation engine and model plug-in architecture.

Further differentiating, it may be incorrect to associate this AuSIM3D Vectsonic™ loudspeaker rendering with "VBAP". First, while vector-based amplitude panning is the first Vectsonic implementation for mapping a sound source vector to loudspeaker nodes, many alternative and hybrid methods may be implemented in the future. Secondly, unlike Pulke's VBAP, AuSIM3D does not vectorize to the loudspeaker nodes at run-time. For marketing, a VBAP association may be confusing. AuSIM3D Vectsonic™ parallels the binaural AuSIM3D in that it simulates audio propagation to a defined number of sinks with positions in an environment. From that point of view, removing the phase component is effectively vector panning.

A critical advantage to AuSIM's Vectsonic™ is that it runs coincidently with AuSIM's binaural AuSIM3D in a mixed listener environment, which would be a preferred operation method for most CAVE's with a tracked prime operator[1].

How

While VBAP still works very effectively in quad and surround setups for live/dynamic mixing, VBAP is most effective when implemented with 20 or more loudspeakers. Without the advantage of phase coherence, the maximum angle between loudspeakers such that a panned image does not collapse to discrete loudspeakers is approximately 60 degrees. The image generally improves proportionately with the number of loudspeaker nodes, with the exception of the negative effect of the transducer's reflecting surface on the environment. Two hundred 6" cones focused towards the center of a space is a very difficult acoustic space to work with.

Because of 1) the potentially large number of loudspeakers and 2) the desire to have point-source, uniform radiation patterns, preferred designs employ small, single-driver full-range loudspeakers with minimal coupling surfaces. AuSIM3D Vectsonic™ supports a mixed environment of loudspeakers, for example, four subwoofers (20-100 Hz) and eight bass loudspeakers (50-400 Hz) complimenting dozens of satellite loudspeakers (200-20K Hz).

A Vectsonic auditorium at NASA Langley, as depicted in the drawings below, employs 28 satellites and 4 subwoofers.

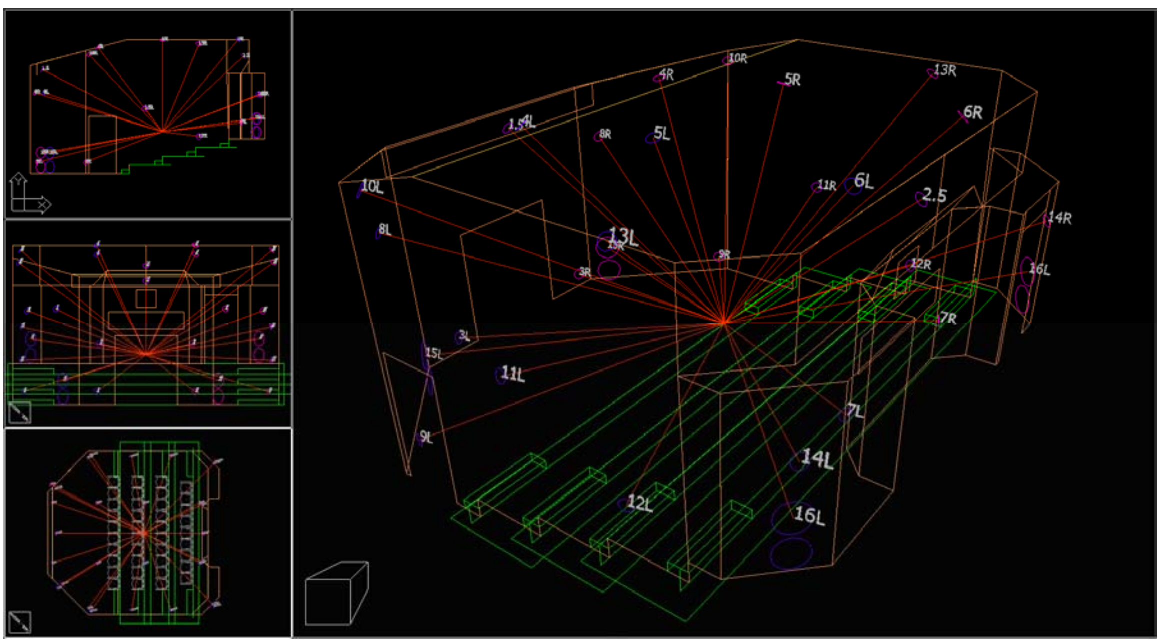

Figure 1 – VBAP 32-loudspeaker arrangement for an auditorium.

[1] A CAVE is a perfect visual parallel for VBAP. (CAVE stands for "CAVE Automatic Virtual Environment".) CAVE's consist of multiple projection planes of virtual images that surround a viewer. CAVE's typically employ rear-projectors, requiring a big, expensive space. CAVE images are computed for a particular viewpoint, yet multiple viewers are forgiving of the distortion from their perspective due to the envelopment.

CAVE Loudspeaker Arrays

While CAVE's represent interesting problems for loudspeaker placement because of their visual projection requirements, there are many solutions with different loudspeaker densities.

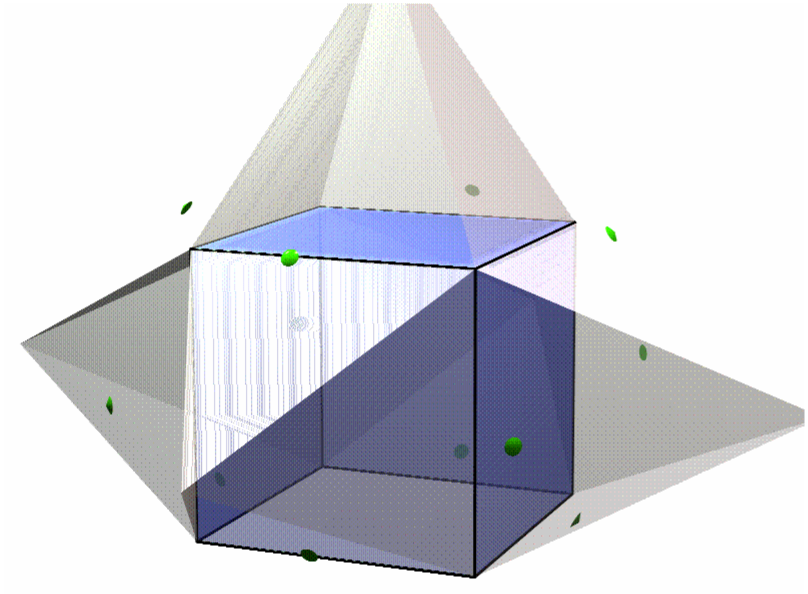

Figure 2 – VBAP 16-loudspeaker arrangement for a six-sided CAVE.

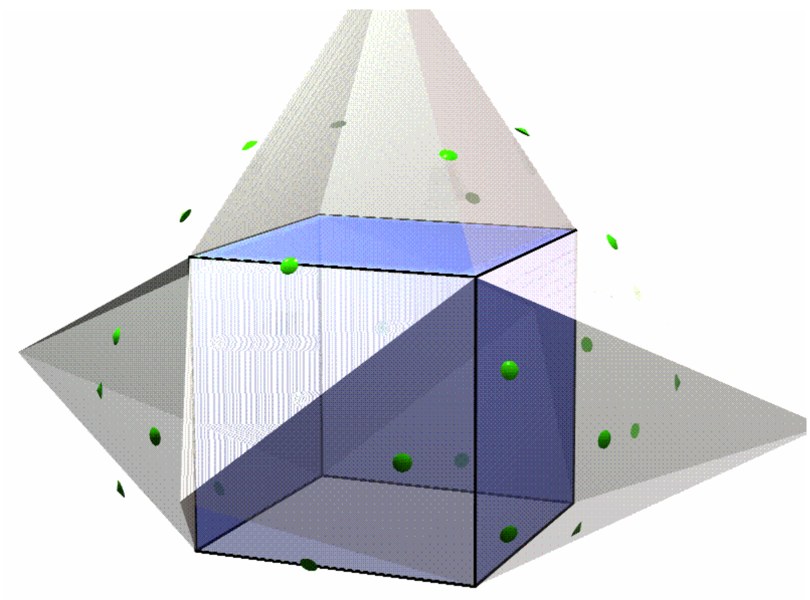

Figure 3 – VBAP 32-loudspeaker arrangement for a six-sided CAVE.

Optimal Configurations

The VBAP sweetspot falls off very gradually. In general, the prime listening area is the middle third of the space defined by the loudspeaker array. Thus if the listening area is to be a 10' diameter, then the loudspeaker array sphere should be 30' diameter. An optimal room would be double this size, and have acoustically treated walls.

There are many physical limitations for loudspeaker placement in real spaces. These are simple compromises in the precision and accuracy of the possible aural imaging. Nevertheless, AuSIM3D Vectsonic™ methods compensate for a lot of issues. After the loudspeakers are hung, impulse responses at a dummy head at a sampling of the desired listening positions are recorded to create compensating digital filters. A pair of permanently-installed microphones records the compensated output for recalibration and validation over time. When driving a mixed-array of loudspeakers, the system acts as a digital crossover, distributing the appropriate spectral energies.

Competitors

Meyer Sound LCS Matrix3

Meyer Sound (Berkeley, CA) acquired Level Control Systems (LCS), which develops large facility loudspeaker controls.
http://www.meyersound.com/products/lcs_series/matrix3/

Iosono

Iosono is a spin-off of Fraunhofer IIS in Erlangen, Germany, specializing in wave-field synthesis. Wave-field synthesis requires 100's of loudspeakers.
http://www.iosono.com

Lake DSP (Dolby)

Lake DSP, a division of Dolby, designed and furnished the complex sound control for the 2004 Olympic Games in Athens.
http://www.lake.com