Spatial Sound Effects in a Software Effects Processor

Gary S. Kendall
Mathew D. Moller
Center for Music Technology
Northwestern University
Evaston, IL 60208
g-kendall@nwu.edu, mmae@nwu.edu

keywords: 3-D sound, image distance, diffuse sound fields

ABSTRACT: NuEffects is a software-based effects processor written with NoXTape that specializes in three categories of spatial sound effects: dynamic decorrelation, simulated head-related transfer functions (HRTFs), and distance cues between the listener and the plane of the loudspeakers. These spatial effects can be executed in real-time or be applied to soundfiles.

Introduction. NuEffects is a software-based effects processor that specializes in spatial sound effects. While NuEffects incorporates a variety of standard filters and delay-line effects found on commercial effects processors, its most unique module focuses on spatial sound imagery. There are three major categories of spatial effects in the current implementation: dynamic decorrelation, simulated head-related transfer functions (HRTFs), and distance cues between the listener and the plane of the loudspeakers.

Implementation. NuEffects provides the user with a general purpose input/output panel, an effects selector panel, and an individual control panel for each effect. The input/output panel (Figure 1) is divided into three sections labeled “Input”, “DSP”, and “Output”. The input section enables the user to select the input soundfile and switch the input between soundfiles and the Arixl digital microphone. The output section provides playback control for the output soundfile and enables the user to switch the output between soundfiles and the D/A converters. The DSP “Start” button cues up the input/output sections and starts the effects processing. On the NoXT workstation, all signal processing is performed by the onboard 56000 DSP. NuEffects supports real-time processing as long as the DSP is capable of keeping up, but otherwise drops out of real-time so that the user can record a soundfile.

Spatial Effects. The input signal for each spatial effect is a monophonic source or a stereophonic source that is mixed to mono. The output signal is always stereo.

1. Dynamic Decorrelation. Decorrelation creates a diffuse sound field that is spatially akin to the late reverberant field of a concert hall, but without the reverberation. There are many unique perceptual features associated with decorrelation described by Kendall (1994: 1995). One of perceptual features is that sound fields are not affected by “image shift”, and, therefore, unlike many other spatial sound effects, the diffuse sound field does not collapse when the listener is not directly between the stereo loudspeakers.

Dynamic decorrelation is achieved with a pair of high-order IIR filters, one for each output channel. These filters maintain an all-pass amplitude response by using the conventional complementary pairing of pole and zero locations in the z-plane. More importantly, they create random phase pattern for each output channel by using a random number sequence to set the distance of pole and zero pairs from the unit circle.

The stereo output signals have identical amplitude response characteristics and very complex inter-channel phase differences. The filter becomes dynamic when the random number sequence controlling the pole/zero locations is permitted to vary through time. The listener experiences a spatial effect akin to the sound of an environment with moving reflecting surfaces or moving sound sources, such as the movement of leaves and branches in a forest or the movement of a crowd within an auditorium.

The control panel for the dynamic decorrelation effects enable the user to specify the number of 2nd order all-pass sections making up the filters and the update rate for the dynamic variation (Figure 2).
2. **Simulated Head-Related Transfer Functions (HRTFs).** 3-D spatial cues are typically implemented by using the impulse responses of measured HRTFs as the coefficients for FIR filters. An alternative approach is to model HRTFs with simple pole/zero techniques that provide approximations to measured HRTFs as shown in Figure 3 (Kendall and Rodgers 1982). NoEffects provides a real-time control panel that is divided into sections for the left and right output channels (Figure 4). For each output channel, the user can manipulate sliders that set the gain, the delay, and the pole/zero positions of the HRTF simulation. With a little background in the acoustics of HRTFs, the user can design custom HRTFs by ear. This customization is particularly useful when considering non-standard reproduction settings. Once, the sliders for a particular 3-D cue are set, the user can store the slider positions in a library of such customized directional cues. A full complement of directional cues can be treated, stored in the library, and retrieved when needed.

![Figure 3. Pole-zero approximation to head-related transfer functions: (a) pole/zero positions in the s-plane. (b) amplitude response.](image)

![Figure 4. Control panel for simulating head-related transfer functions (HRTFs).](image)
3. Distance cues between the listener and the plane of the loudspeakers. Kendall (1995) discusses how the perception of distance beyond the plane of the loudspeakers relies on the simulation of indirect sound, while perception of distance between the loudspeakers and the listener is dependent on interaural cues alone. NuEffects simulates these cues by use of "constant-phase offset" FIR filters (Kendall 1994). These filters maintain a constant magnitude response and a constant phase value (Figure 5). As the phase offset, \( \Delta \phi \), changes from 0 to \( \pi \), the image moves from the loudspeakers and toward the listener. The change in phase offset is accomplished by selecting a set of FIR filter coefficients. The distance control panel (Figure 6) provides a slider that selects one of 30 sets of filter coefficients (and a gain slider that enables the user to rebalance the left and right channels in case the image is not centered).

**Figure 5.** Constant phase-offset filter with a magnitude response of 1.0 and a phase response of \( \Delta \phi \).

**Figure 6.** Control panel for controlling distance between the loudspeakers and the listener.

Conclusion. NuEffects is proving to be a powerful program because it provides a collection of spatial effect tools. The variety of effects achieved with NuEffects provides the user with a spatial effect palette. We expect the palette of spatial effects to grow as new ideas emerge.

References

