An Interactive Real-Time System for the Control of Sound Localization

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Abstract: The goal of this work was the implementation of a tool which allows the composer to project musical sound into an illusory acoustical space using a variable number of speakers. Although readily extensible to three dimensions, we limit ourselves for the moment to a two dimensional model. The implementation of the model for a single source and four channels transducers using a Macintosh II, two Yamaha DMP-7 digital mixers, a synthesizer (Yamaha DX7 at the present) is presented. The user interface of the interactive software package, written in the C language, allows one to draw a sound path on the screen (which corresponds to the illusory space) and hear the displacement of the sound (complete with Doppler shift) in real time. Results and future work are discussed.

Introduction

In order for localization to occur, the listener needs to define the angular location of the sound source as well as the distance of the source relative to the listener. With regard to the distance cue, we know that the amplitude of the variation of the sound pressure is inversely proportional to the distance, r , between the source and the listener; there is also an exponential decay in the amplitude introduced by the attenuation of the signal in the air which is function of the distance r . In enclosed environments intensity differences alone are only a relative cue to distance perception and it is the contribution of the reverberant energy that determines our ability to make distance discriminations (Sheeline 1982). Experiments have shown how the angular perception of sound images is affected when the sound energy is distributed between speaker pairs (Gardner 1973). If two loudspeakers with same acoustic outputs are placed at equal but opposite angles from the listener on either side of the median plane, the listener perceives an apparent single image located in the midway position between the speakers. If the intensity applied to the loudspeaker pair is not the same for each speaker, this can cause the illusion of an angular displacement in the sound image. This allows one to simulate the angular location by distributing the source intensity between the speaker pair. The intensity coming from each speaker direction is determined by the ratio of the angular position of the source relative to the speakers, and the angular separation of the two speakers (Chowning 1971).

Overview of the Model

Our goal is to attain control over the spatial characteristics of musical sound through a system which allows real-time interaction and which would be portable and flexible enough to be used in many different situations. We would like to be able to draw a sound trajectory and hear in real-time the displacement of the sound source. The model described here is based on the following elements:

- The position of the sound source within the illusory space relative to the listener.
- The number of loudspeakers and their locations as well as the characteristics of the listening space such as shape, size, absorption, etc.

The configuration of the variable number of loudspeakers can be arbitrarily chosen in order to reproduce any possible "real" configuration (for example an open air concert situation where the loudspeakers are placed in semicircle in front of the public, or the classical quad configuration, or any other precise location one needs). Given the position of the speakers, (R_i, Θ_i) , and, at each

instant, the position of the source, (r, ϑ) , we can determine at each instant the relative intensity values delivered by the active channels i and $i+1$:

FIG. 1. Loudspeakers configuration

$$I_i = I C_i p_i = \frac{I_0}{r^2} e^{-kr} \left(\frac{R_i}{r}\right)^2 \frac{\Theta_{i+1} - \vartheta}{\Theta_{i+1} - \Theta_i}$$

$$I_{i+1} = I C_{i+1} p_{i+1} = \frac{I_0}{r^2} e^{-kr} \left(\frac{R_{i+1}}{r}\right)^2 \frac{\vartheta - \Theta_i}{\Theta_{i+1} - \Theta_i}$$

A variation of the source position in the radial direction will affect its frequency through the Doppler effect. We can determine at each instant the corrected frequency, f' , known its velocity.

The reverberation plays an essential role in the perception of distance. In our model we consider the reverberant energy to be spatially uniform, therefore the ratio of reverberant to direct sound energy reaching the listener will increase as the distance r between the sound source and the listener increases.

Implementation

In figure 2 is shown the system implementation for a single source ($j = 1$) and four channels transducers ($i = 1, 2, \dots, 4$). A Macintosh II sends MIDI control signals to a Yamaha DMP-7 digital mixer which provides modules for the spatial processing algorithm. MIDI control signals are sent as well to a synthesizer source (Yamaha DX7 at the present). Once the position of the speakers is selected, as the user draws a sound trajectory on the

FIG. 2. System schematic

screen with the mouse, the information about the position (r, ϑ) of the sound source with respect to the listener and the velocity are detected. The intensity of the source, $I(r)$, is computed and the

active channel pair is determined based on the angular location of the source. The value I for each speaker is then mapped to a midi number in the range 0-127 according to the DMP7 fader control function. The velocity of the sound source determines the Doppler correction factor to the value of its frequency. This is mapped to a midi number affecting the pitch bend function of the synthesizer (Loy 1985). The reverb module used (the DMP-7 rev room effect at the present) allows one to modify the reverberation time and to set an initial delay which depends both on the source position and the listening space. The user interface is shown in

FIG. 5. User interface.

figure 5. As one draws a sound path on the screen (which corresponds to the illusory space) one can hear the displacement of the sound in the acoustical environment specified by the user. The control panel allows the user to select the amount of reverberation, the room size, as well as the display scale. The source position (x and y coordinates in meters) within the illusory space is indicated at each instant at the bottom of the control panel. It is possible to record sound trajectories and to create and edit files of recorded trajectories. The loudspeaker configuration within the space can be varied by pressing the option key while dragging the loudspeakers (indicated by black squares on the screen) with the mouse.

The goal of this work is to provide the composer with a tool to project the musical sound into an illusory acoustical space using a variable number of speakers. The model implementation, realized in a real-time implementation for the Macintosh II and midi devices, allows one, through an interactive software package written in the C language, to draw a sound trajectory on the screen and hear the movement of the sound (complete with Doppler shift) in real time. This system was tested in different acoustical spaces using a quadraphonic reproduction system and listeners found that it produces convincingly localized sound images. Although the initial implementation allows for simple room geometries, one of our goals for future work is to take more accurate account of the features of the acoustical space. We also would like to replace the use of the digital mixer with a spatial processing software. The model presented could readily be extended to three dimension.

References

- Chowning, J.M. 1971. "The Simulation of Moving Sound Sources." *Journal of the Audio Engineering Society* 19:2-6.
- Gardner, M.B. 1973. "Some Single- and Multiple-Source Localization Effects." *Journal of the Audio Engineering Society* 21: 430-437.
- Kuttruff, H. 1973. "Room Acoustics." New York: Wiley.
- Loy, G. 1985. "Musician Make a Standard: The MIDI Phenomenon." *Computer Music Journal* 9(4): 8-25.
- Sheeline, C.W. 1982. "An Investigation of the Effects of Direct and Reverberant Signal Interactions on Auditory Distance Perception." Stanford Department of Music Report STAN-M-13.