Teaching Orientation and Mobility Skills to Blind Children Using Computer Generated 3-D Sound Environments

Dean P. Inman, Ken Loge, Aaron Cram
Oregon Research Institute
Applied Computer Simulation Labs
1715 Franklin Blvd.
Eugene, OR 97403, USA
+1 541 484 2123
deani@ori.org, kenl@ori.org, aaronc@ori.org

ABSTRACT
This paper describes a computer program designed to teach orientation and mobility skills to visually impaired persons. The system utilizes off-the-shelf computer hardware and a proprietary virtual reality authoring library to create 3-D spatial audio environments. Simulation environments currently being developed emphasize sound identification, localization, and tracking skills which are requisite to effective orientation and mobility in real world settings. Data describing how well a blind individual is able to identify, localize, and track various sound sources within each virtual training environment will eventually be collected and correlated with actual orientation and mobility performance data.

Keywords
3D Sound, Blind Access, Education.

INTRODUCTION

Individuals who are congenitally blind, or who are blinded as a function of injury or disease, learn to rely on audition to compensate for their lack of vision. Effective listening skills appropriate for spatial navigation require considerable time and effort for both the orientation and mobility trainer and the student. Orientation and Mobility training can also expose individuals to significant risks and hazards due to the multitude of physical variables present in real-world navigation activities, such as crossing a street (Chew, 1984). Through training, audition can provide a highly sensitive warning, alerting, and scanning system with which to maintain a constant awareness of physical activity in three-dimensional space (Wenzel & Fisher, 1990). Audition is also significant in the development of a sense of spatial orientation and distance, as well as obstacle detection and avoidance by the blind (Barsch, 1968; Berner & Lindh, 1980; Cratty, 1971).

Orientation and mobility skills in blind children are slow to develop and require extensive training. Before blind individuals can be independently mobile they must first know how to identify their position in space, and establish their relationship to other significant objects around them. The formal acquisition of these skills are referred to as orientation and mobility (OM), which is defined as "the process of instructing individuals who are visually impaired to maximize the use of their remaining senses to move about safely within their environment" (Berner & Lindh, 1980). Computer generated three-dimensional acoustic simulations are an emerging technology that may be used to teach blind children to function in actual acoustic space (Cooper, Pearson & Petrie, 1999). The Oregon Research Institute Applied Computer Simulation Labs is developing a series of auditory spatial training environments to facilitate traditional orientation and mobility training.

In many training facilities, OM instruction begins with the utilization of sighted guides, who assist the blind individual with spatial identification techniques that include sensory environment training (Halpern-Gold, 1988). The Texas School for the Blind and Visually Impaired has produced a widely adopted OM curriculum called TAPS, which focuses on orientation and mobility activities students need "to move safely and efficiently in home, school, work, and/or community settings as independently as possible" (Pogrund, 1995). The TAPS curriculum includes numerous evaluation and assessment methods for functional mobility tasks, auditory discrimination abilities, sound localization and tracking, and directional and positional conceptualization within various environments. The TAPS curriculum model is the basis for much of the orientation and mobility education currently used by OM trainers in the United States, and is therefore the model for the virtual training environments being developed by the Oregon Research Institute Applied Computer Simulation Labs.

SIMULATION TECHNOLOGY FOR THE BLIND

The value of simulation has long been recognized in education and training. It is well known that training complex sensory-motor skills can be done effectively and safely in computer simulation environments (Inman, Loge, & Leavens, 1997). Immersive sound simulation environments make it easy to provide learners with repeated guided and unguided practice, and allow dynamic accentuation of specific auditory stimulus while selectively diminishing background noise, until the learner knows what to "listen for." The computer can then slowly change the signal-to-noise ratio until the simulated situation matches the real world situation after which it is modeled. Other audio parameters can also be adjusted to suit the specific needs of an individual's auditory acuity and OM related abilities. The efficacy of a computer simulation to improve human performance is unparalleled in any other currently existing technology.

With the advent of 3-D audio processing hardware such as the Convolvotron, developed in the late 1980s by NASA and Crystal River Engineering, and the more affordable sound cards developed since, 3-D sound applications can finally be developed using personal computers (Wenzel & Fisher, 1990). Since the mid 1990s the computer gaming industry has begun to embrace the virtues of computer generated 3-D sound, a trend that has helped the price of 3-D capable sound cards drop below $30. After investigating the price and performance capabilities of various 3-D sound cards and their respective hardware drivers, we decided to focus initially on the Creative Labs SoundBlaster Live 3-D sound card, which is widely used, well supported, and affordable for public schools. By fine-tuning some of the 3-D audio API parameters we have found the SoundBlaster Live hardware to provide very good spatial accuracy and performance for our initial OM training purposes, and we expect the fidelity to improve as the technology continues to mature.

Immersive computer simulation technology is more affordable than it has ever been, and the costs of the computer hardware needed to model a three-dimensional sound environment after a relevant real-world situation have dropped dramatically. For $20-$200 dollars, depending on performance and fidelity requirements, a sound card capable of creating highly realistic three-dimensional auditory environments can be installed in most standard personal computers. Such cards allow multiple sound source generators, such as automobiles, to move independently of one another relative to a perceived spherical auditory radius from the listener's head. The recent surge of availability and the drop in price of three-dimensional sound hardware is largely due to the success of the computer gaming industry, which is continuing to exploit immersive sound for game and entertainment titles.

GOAL

The primary goal of this research is to create a series of three-dimensional sound environments with special features built-in which are designed to teach orientation and mobility skills to children who are blind. Our initial efforts focus on the development of requisite learning skills pertaining to orientation and mobility, and include sound identification, localization, and tracking.

THE SIMULATION PERFORMANCE PLATFORM

In 1993, the Oregon Research Institute Applied Computer Simulation Labs was awarded a grant from the U.S. Department of Education to demonstrate the feasibility of applying virtual reality technology to the problem of mobility training in orthopedically impaired children. Children included in the study were between 3 and 15 years of age and have orthopedic impairments that require them to use motorized wheelchairs for mobility. Training was accomplished by having children experience a series of three virtual training scenarios with the use of a specially designed "roller platform" treadmill wired with sensors, so the computer could determine the driving performance of each student. These immersive "virtual worlds" were sequenced in terms of difficulty and complexity, and all training was conducted using actual motorized wheelchairs in order to facilitate generalization of skills learned in virtual reality to actual reality. (Inman, Loge, & Leavens, 1995).

In October of 1999 another grant from the U.S. Department of Education allowed us to begin developing a virtual reality OM training system for the blind. Based on our initial research results with training simulations for orthopedically impaired children, we enhanced the system to create the Simulation Performance Platform (SPP) to suit a variety of human performance purposes.

The SPP is a Pentium-based computer with off-the-shelf hardware and a virtual environment development engine created in-house. The SPP hardware consists of a fast Pentium-based computer equipped with a 3-D sound and 3-D graphics card, an external headphone distribution amplifier (to accommodate multiple headphones simultaneously), and a 3-degrees-of-fredom spatial tracking device affixed to a baseball cap so it can be worn on the head with headphones. The SPP software is a proprietary world-building system written in C++, and utilizes the Microsoft DirectX and OpenGL libraries. The system can currently render up to 32 simultaneous dynamic sound sources with high polygon count 3-D models at over 60 frames per second on a dedicated machine. The SPP supports Internet network access for multiple users with TCP/IP, but a full network implementation of synchronized spatial audio features is still under development. The fully implemented network spatial audio system will allow multiple participants to work together in the same virtual acoustic space. This will allow an OM training specialist and student, for example, to simultaneously hear the same dynamic acoustic spatial events, such as traffic flow at a virtual street intersection, even if they are geographically separated. The addition of network audio capability has the potential to be a valuable too for OM training specialists, many of whom spend much of their time commuting to rural areas to work with blind students in their respective states (Gense, 1997).

Students using the SPP wear a head tracker attached to a baseball cap, over which are placed a pair of flat-response headphones. As the student turns her or his head, the apparent location of sound sources within the auditory training environment changes accordingly. Navigation is accomplished with a standard PC analog joystick. Though students utilizing the SPP for this project are visually impaired, a graphic three-dimensional representation of the audio space is rendered on the computer's monitor to help OM Training Specialists identify the relative location of nearby objects and obstacles in context with the simulated acoustic space. Footsteps can be optionally heard to help the student determine how fast they're moving, and what surface materials they're walking on over various terrain.

The collection of student performance data is facilitated by the SPP software. The position and orientation of the student's head compared to the position of a sound source, for example, can be measured and recorded in real time. This may help to assess the student's ability to accurately localize static and dynamic sound sources, as well as the student's response latency to sound cues. With the tracking devices currently being used it is possible to accurately measure head movement in 3-D space to within hundredths of an inch. The interface for the SPP is being developed collaboratively with OM training specialists to ensure the software provides access to the most pertinent audio qualities of OM training activities.

The SPP software tools are still under development, but by September, 2000 we will begin collecting data at the Oregon School for the Blind to more fully assess the system's effectiveness for OM training with school aged blind children.

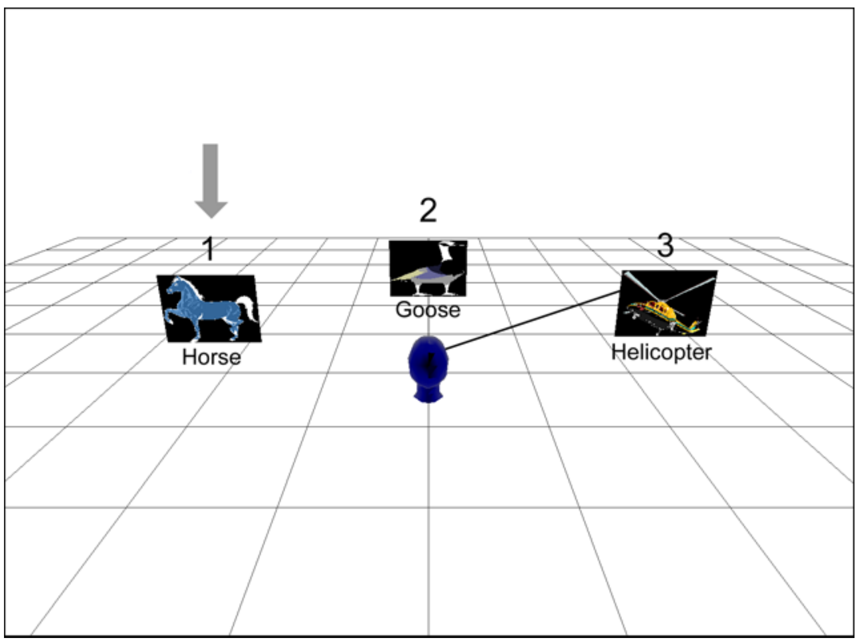

Figure 1

Figure 1: Shows a screen shot of a prototype orientation and mobility acoustic training environment. In this example, three sounds are available for playback. The arrow over the "Horse" icon indicates that the OM training specialist has selected this sound for activation. The icon in the center of the screen represents the orientation of the user's head, and the line extending from the head icon is the actual direction the head is pointing. Each of the sound sources can be activated or moved manually or automatically. Student performance data are automatically recorded so they can be plotted or correlated with the actual position and orientation of any sound generating source within the environment. Each square of the grid represents 2 meters to scale.

TYPES OF SIMULATION TRAINING ACTIVITIES FOR THE BLIND

The preliminary training environments we are currently developing are a starting point to help demonstrate some of the potential this technology has for OM training. Further training scenarios are planned, and will be determined by what is found to be most useful in the current SPP system. Other anticipated OM applications can be classified within four general categories, and are as yet to be fully investigated: a) Localization and proximity activities; b) Sound events modeled after real world environments; c) Augmented auditory events; and d) Guided orientation and mobility.

Localization and Proximity Activities

In localization and proximity training scenarios, single or multiple sound sources are positioned around the student and s/he is asked to identify, point toward, avoid, or locate sounds specified by the OM Training Specialist. The student begins in an environment containing only one sound source. Later, as skills improve, the student is given the opportunity to discriminate specific foreground and background sounds by timbre, amplitude, spatial location, or other pertinent acoustic properties.

Sound Events Modeled after Real World Environments

A sound environment modeled after a real space has many advantages for effectively teaching the blind OM skills, the least of which concerns safety. By creating a virtual street crossing scenario, for example, the OM student can safely learn how to locate a street crossing area by the sound of the traffic flow. Any physical acoustic property of the environment the student has trouble discriminating can also, theoretically, be simulated by the computer if enough processing power is available. Inclement weather conditions like rain or snow, or physical surface characteristics such as dry leaves, can be incorporated into the simulation as well to help the student navigate effectively in the real space after which the simulation is modeled.

Augmented Auditory Events

In this category of OM training the computer is programmed with a profile of the user's current skills and adjusts the environment accordingly, so some sounds that are difficult for the student to discriminate or identify, are exaggerated in loudness or pitch, or "turned down" so other sounds may be better heard. The speed at which a dynamic sound moves can be slowed down or accelerated, for example, to emphasize some desired salient quality. An augmented auditory event is one that is artificially adjusted to suit the skill level of the student. Auditory games like "sonic soccer" can be developed with an acoustic soccer ball of a size that is dependent on the student's skill level.

Guided Orientation and Mobility

Artificial Intelligence (AI) algorithms may be incorporated into the simulation environment so sounds can be programmed to respond dynamically to student interaction. An intelligent "sonic guide" can help a student follow a straight line along a sidewalk, or audio "crickets" can be placed around the student to outline in a marquee fashion the size or shape of a space or pathway. In this way three-dimensional sound can serve to guide an individual similarly to the way emergency lights in an aircraft guide sighted people. An intelligent sonic guide can accompany a student on a virtual walk to school, or to the grocery store, and help prevent the student from making a wrong turn. As the student becomes more familiar with the route, the guide will assist less and less, until such time that the student can find her or his own way on the real trek in which the simulation is based.

Simulated acoustic environments are a promising technology for teaching orientation and mobility skills to blind and vision impaired individuals. The low cost and availability of three-dimensional audio computer hardware and continued improvements in performance and fidelity offer unseen potential, and new tools for the assessment and improvement of spatial hearing, acuity, and human-computer interfaces.

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