SPATIAL SOUND DESIGN AND INTERACTION FOR VIRTUAL ENVIRONMENTS IN THE PROMOTION OF ARCHITECTURAL DESIGNS

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ABSTRACT

Virtual environment walk through applications are generally enhanced by a user's interactions within a simulated architectural space, but the enhancement that stems from changes in spatial sound that are coupled with a user's behavior are particularly important, especially within regard to creating a 'sense of place'. When accompanied by stereoscopic image synthesis, spatial sound can immerse the user in a high-realism virtual copy of the real world. An advanced virtual environment that allow users to change real-time rendering features with a few manipulations has been shown to enable switching between different versions of a modeled space while maintaining sensory immersion. This paper reports on an experimental project, in which an architectural model is being integrated into such an interactive virtual environment. The focus is on the spatial sound design for supporting interaction, including demonstrations of both the possibilities and limitations of such applications in presenting and promoting architectural designs, as well as in three-dimensional sketching.

1. INTRODUCTION

Virtual environments target all senses for high quality presentation, immersion and interaction, improving workflow and level of entertainment. Walk-through simulations, which combine high quality graphics with realistic spatial sound are an active area of research. Simulators for training (drivers cockpit, military simulations, architectural presentations, etc.) can benefit from realistic sounds, displayed with correct spatial placement [1]. A walk through high visual quality environment developed with Computer Aided Design, implemented spatial sound and the possibility for interaction mediates high immersion to the user. A low level of interaction like free navigation in the virtual environment does not allow acting with objects or other operators. In contrast, a high level of interaction can be achieved for example with three dimensional sketching or moving objects through space, allowing the user (e.g., an architect) to reposition objects (e.g., a pillar or a window), putting sound sources into the environment and respond to customers' requests during a design review session. 3D-Sketching improves the degree of interaction by making annotation or add objects to the scene, which can be positioned everywhere. Auditory displays with the ability to dynamically spatialize virtual sound sources under real-time conditions enable advanced navigation and orientation in virtual environments. The visual and audio senses of the user are more involved and deeply immersed while participating and interacting in the experience. This article reports about the second milestone of the ongoing project for the use of virtual environments in the promotion and evaluation of architectural designs [2]. For a comparability of reality and virtual environment, a copy of the interior entrance at the University of Applied Sciences Düsseldorf was set up and is based on stereo back-projection with IR shutter glasses and a hybrid tracking device for motion capture. The goal was to achieve high quality visualization in relation with spatial sound and high level of interaction in the virtual environment.

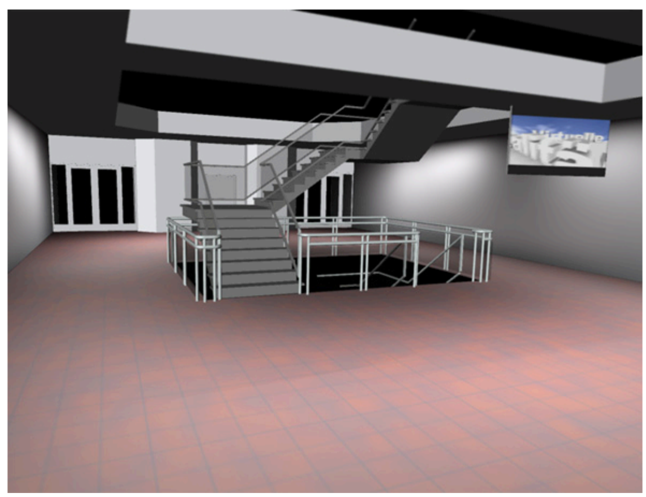

Figure 1: *Virtual environment of the entrance hall at the University of Applied Sciences Düsseldorf*

2. REQUIREMENTS

General requirements for virtual environments in the promotion and evaluation were already described in [2]. The superior aims were to immerse the customer into a architectural experience with a realistic impression of the entrance region of the building (Figure 1) . In the continuation of this project, the center of interest is the spatial sound design with several sound sources and interaction for audible feedback. Today's high quality visualization tools and sound systems allow to render photo-realistic textures and light effects as well as spatial sound with numbers of loudspeakers and subwoofers to create an aural experience. Although, many frontiers are still to overcome for a realistic virtual environment with the possibility of spatial orientation and navigation, as well as visual and aural interaction in space:

- A low interactivity level allows to changing the position of the camera or/and variations in pre-rendered materials.
- The impression of spatial sound or several sound sources can not be realized with only two speakers in a reverberation space. Spatial experience gets lost when not using surround sound based on speaker arrays [3] or head phones using HRTF's.

Virtual environments have the potential to approach solutions for these limitations:

- High accuracy input devices enable interactive manipulation of the 3D-model in space.
- Surround speaker systems in combination with spatial sound environments allow orientation and navigation in space.
- Audio displays can deeply immerse the user into an aural experience.

3. SPATIAL SOUND

Using spatial sound for orientation in a virtual environment is necessary to locate yourself and get feedback about space around you. Usually our eyes track an object while other senses are aware of the surrounding area. Especially the sense of hearing stays sensible for every change of sound in the environment while the center of interest is focused by the eyes. Depending on the sound the visual task need not to be influenced or even disturbed. As an example in a cinema situation, the eyes can follow the presentation while the location of talking spectators is given or the status like someone left or entered the movie theater is provided via spatial sound sources (e.g., opening and closing the door).

Predominantly, aural displays use binaural headphones and signal processing techniques, or stereo speakers using a cross-talk cancellation. The usage premise of these systems is a motionless head of the user or a head tracking device has to be implemented. Some virtual environment projects, such as The Cave, typically make use of at least four or eight loud speakers for a spatial audio impression in the usage [4].

Our attention strongly depends on the sense of hearing when the visual sense is confined, for example in low lightened environments or in front of a one direction visual display. Even when the visual difference is very slight, an acoustical event spatialized using a sound source can direct our attention very fast and gives the chance to react quickly. An example might be navigation in a low lightened building where only the aural feedback (e.g., sound of opening and closing doors or outdoor noise) can be used for orientation and navigation and the sense of hearing is the only sense he can depend on.

For today's architectural masterworks, it is important to please the eye, as well as the ear. For example, in a mall the positioned sound sources try to take the customer to a trip of aural experience and wellness. Waterfalls, sound of birds or even the sound of a forest can be found in different buildings to surmise harmony and peace. Asked customers in these locations felt more satisfied, which also influences consumer buying habit. In contrast to shopping centers, synthetic noise is added to bureaus in a office building for example to avert colleagues of eavesdrop others or to limit the hearing distance and setting confine the region of interest in the room they are working in.

name	description	function	spatialization
cafeteria	voices, cutlery and noise	navigation	fixed - space
door	door, outside, cars, birds	navigation	fixed - space
menu	voice commands	feedback function state report	relative close to viewpoint
walking	steps	feedback	relative close to viewpoint
laser pointer	laser sound	feedback and interaction	in front of the viewpoint
drawing	chalk	feedback and interaction	in front of the viewpoint

Table 1: *Sound source illustration*

The reverberation and position of sound sources is dependent on the purpose of the architectural environment and it's usage. In our virtual entrance you can notice several sound sources like the cafeteria with it's incisive cutlery and voice sound, as well as outdoor noise, traffic or birds behind the opening and closing door, which help to orientate in locate the user in space (Table 1). Another center of interest is the reverberation while moving through the scene and emulate the entry's room response function. The sound of a women's steps were recorded and adjusted with reverberation to a realistic walk through the university's entrance.

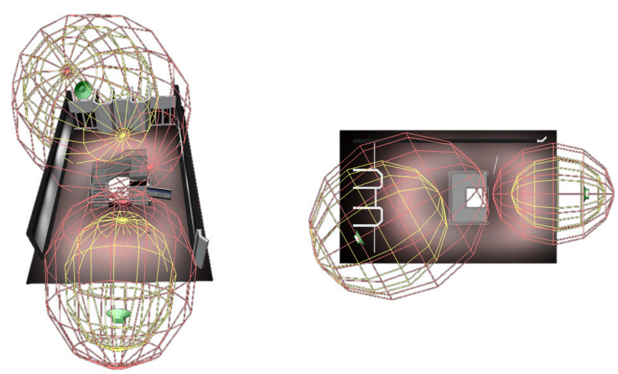

Figure 2: *Perspective and top view of the position of two sound sources*

The reverberation in a room can enhance spatial awareness and informs about the size and character of the room we are standing in. The spatial location and intensity of all sound sources gives information about our own location in space as well as the orientation or direction of a walk-through [5]. Compared to a visual display, which only gives information about the orientation in front of our eyes, an audio display is omnidirectional. The active sound sources are audible in the surrounding even when the source is not visible to our eyes. A better review of the history of reverberation in general is given by Bary Blesser [6].

For better visualization the spatial position of only two sound sources in the virtual environment is given in Figure 2. The original setup implements three sound sources with each audible range ellipsoid (specified by *maxFront* and *maxBack*) [7] overlaps the others and a linear increase up to the max level of the inner ellipsoid (specified by *minFront* and *minBack*).

4. INTERACTION IN SPACE

Navigation, the basic interaction task of a user in a virtual environment allows to review the complete architectural design. Constraining the freedom of movement helps the user to focus on his main task [8].

Navigation and possibility of changing interaction in our system is realized with a stylus for free movement in space and the support of a sound display. Optionally, a wand with several buttons and a joystick to interact with, can be supplemented to the system for a higher DOF (degree of freedom) and interaction possibilities. The orientation and position of the stylus is detected via ultrasound in collaboration with inertial sensors and changes the viewing direction as well as the velocity of movements. With two buttons, one for changing the interaction in the menu and the second to execute the interaction in the virtual environment, an increase of the DOF was realized. Using the 'changing button' allows the user to skip through the menu items like walk through the designed model, using a pointer in the environment, scroll through predefined camera positions or even positioning objects in space and 3D-sketching. By using the 'execution button' the point of origin is set in space from where on the user can navigate, point, change the view and sketch in the virtual environment. A threshold level of the response curve of the stylus (x_t = 10 cm) averts small unintentional movements to be detected by the system and stables the view. After reaching the threshold level the speed of interaction of the stylus (e.g., walking, drawing) increases quadratic with a scale factor of 0.5 as described in Figure 3. The user can stand in front of the screen and does not have to move while interacting freely in the scene.

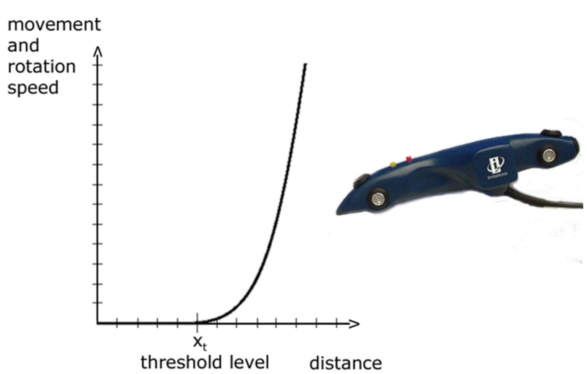

Figure 3: *The stylus and it's response curve for interaction*

The user can choose between several menu items, which are combined with audio feedback and a confirmation when entering a menu item. These modes are very useful for demonstrations where specific perspectives should be shown and customers have the possibility of pointing at areas, objects or even a visual display. In comparison to head mounted systems, the orientation of the user's head would be tracked and used for monitoring the moving direction [9]:

- Menu 1: Navigation
  Orientation and navigation in the virtual architectural environment with sound of steps as aural feedback near the user. Faster motion induces higher pitch level of the audio response with added reverberation simulating the hall.
- Menu 2: Pointing
  To point objects a laser is implemented in front of the viewpoint. Every pointing in space is coupled with a laser sound to complete the audio display.
- Menu 3: Positioning
  Positioning objects in space is realized in front of the user in a small distance for pleasant viewing by pushing the execution button once per object. With every object put in the scene a defined audio feedback is set (Figure 4).

Figure 4: *Pointer and positioning of objects*

- Menu 4: Drawing
  Continuous positioning of an object (advantageous a primitive) for easier drawings of pleased architectural objects during a discussion (e.g., rack, door or window). Every movement with a distance of more than 5 cm creates a new object (Figure 5).
- Menu 5: Sketching (chalk)
  The 3D-sketching menu item is realized with a chalk line, setting a thin cylinder every 5 cm with correct orientation the stylus is moved. For the aural feedback a special sound of drawing chalk on a black board is played while sketching (Figure 5).

5. IMPLEMENTATION AND SYSTEM DESIGN

The implemented virtual environment is part of a unique multipurpose space, using the InterSence IS-900 tracking system, which

Figure 5: *3D-sketching of architectural implements (e.g., door, window)*

can be used for camera tracking as part of virtual studio applications with a bluebox. The IS-900 is a hybrid tracking system, which uses inertial sensors for orientation and ultrasonic range measurements for position in space. The SDK of InterSense samples the data from the tracking system at a constant frame rate of 60 Hz for pleasant realtime working. The combination of two tracking systems, the hybrid approach allows high frame rate while keeping the absolute error small and the workspace relative large. 36 beacons (3*3*4), the ultrasonic transmitters, are placed on a defined grid in 3.0 m height, covering a space about 4.6 m x 5.3 m x 3 m for a sufficient large area to interact in. We use a BarcoReality 909 for a rear-projection featuring high resolution and fast phosphor dots for double refresh rates in active stereographic applications in combination with a high quality graphic card from ATI to make best use of the beamer's capacity. In combination with a special half-transparent screen with the measures of 2 m x 1.5 m, the immersion into the virtual environment is strengthened (Figure 6).

CrystalEyes shutter glasses synchronized via IR allow free movements in front of the stereoscopic projection. The runtime environment was developed in Microsoft Visual C++ and Open Inventor 4.0 (beta) from TGS. The sound system "Desktop Theater 5.1 DTT2500 Digital" form Cambridge Soundworks implements four surround speakers and one subwoofer. An implementation of every speaker is realized at a hight of 1.8 m for optimal orientation and navigation of the sound display and audio effects.

6. CONCLUSION AND FUTURE WORK

In this project a high quality architectural environment has been realized for a walk-through with the possibility of interaction and spatial sound design. The prototype for promotion and evaluation of architectural designs with audio support shows that immersion highly increases when every interaction gives feedback to the user. Instinctively, orientation and navigation are adopted and sensed convenient, when having to rely on the aural experience. Further on, more sound sources can be put into the scene for better feedback as well as more sensible sketching in the positioning in combination with head tracking and other interaction devices. More interaction modes shall be implemented for manipulating the environment.

Drawing in 3D-space without any constrains gave no satisfying sketches. Such kind of interaction shall be supported by mapping of drawings onto surfaces or planes as well as constraining the number of degrees while drawing in space. A snapping function and rules, like an object should stand upwards and being on the ground, would further enhance the interaction. Such support is well implemented in CAD applications.

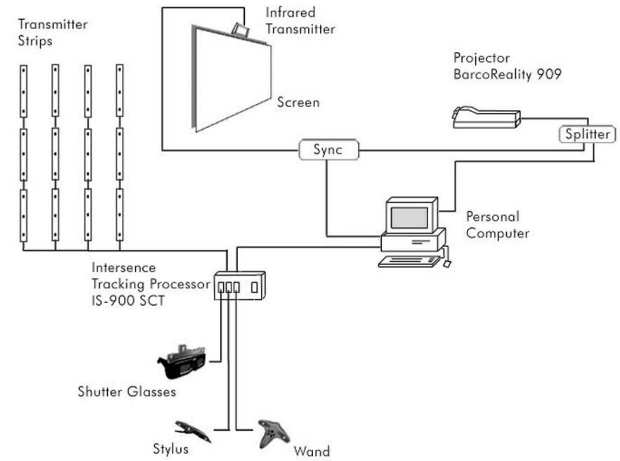

Figure 6: *System layout of the virtual environment*

7. ACKNOWLEDGEMENT

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