AUDIO-ENHANCED COLLABORATION AT AN INTERACTIVE ELECTRONIC WHITEBOARD

Christian Müller–Tomfelde and Sascha Steiner

GMD - German National Research Center for Information Technology
IPSI- Integrated Publication and Information Systems Institute
GMD-IPSI, Dolivostr. 15, D- 64293 Darmstadt, Germany
{mueller-tomfelde,steiner}@darmstadt.gmd.de

ABSTRACT

This paper describes an experimental setup to investigate new possibilities to support cooperative work of a team with audio feedback on a large interactive electronic whiteboard, called DynaWall®. To enrich the interaction and the feedback qualities within a team work situation the DynaWall is equipped with a set of loudspeakers which are invisibly integrated into the environment. Different forms of audio feedback are realized and discussed to meet the requirements for collaborative team work situations. An audio feedback for a gesture interface with sound cues is implemented to improve the use of gestures to execute commands. Furthermore a spatial sound property of moved and thrown information objects on the surface of the otherwise silent electronic whiteboard is introduced to add an imitated natural sound behavior. The focus of the setup is to experiment with sound feedback for a non-standard computer environment useful in a cooperative team work situation.

Keywords
Human-computer interaction, sonification, CSCW, spatial sound, auditory display, audio feedback, sound design, gesture interaction

1. INTRODUCTION

Audio feedback on a standard desktop computer environment is state of the art. In contrast team work situations in multiple computer environments raise new issues of human-computer interaction which need to be considered carefully. Solutions designed and realized for an individual work environment with individual audio feedback can not be simply transferred to a cooperative team work situation. This is due to the fact that individual feedback then becomes also audible to other team members. On one hand within a team work situation the audio feedback is more ambient, in contrast to a local visual feedback and can affect the human-human interaction, like face-to-face situations with speech communication. On the other hand, a spatial interface to information objects of a multiple computer environment demands to consider the spatial presentation of audio and to regard aspects of sonification, i.e., mapping data to sound for audio feedback.

In our approach, we use the computer hardware and software of an electronic meeting room and extend the environment with audio facilities. We adapt the existing cooperative software in order to pass the information of interaction to a dedicated audio system and to form different examples of audio feedback. The aim of this work is not to achieve a realistic and high-fidelity audio presentation and feedback, coming along with virtual reality environments [3]. In the context of group work the focus is more on usefulness in every day work situations and in combination with new forms of human-computer interaction [4]. The following describes aspects of the design of future workspaces and gives a more illustrating sample scenario for a team work situation at an electronic whiteboard using a cooperative software. Then, the concepts and realization for the enhanced audio feedback are presented, followed by a description and discussion of the audio architecture. This paper is accompanied by a demonstration video clip.

2. DESIGN OF FUTURE WORKSPACES

As described in [10],[11], future workspaces are based on an integrated design of virtual information spaces and real architectural spaces. The computer equipment will more and more integrated into the physical environment and therefore becomes 'invisible'. Future environments will move beyond desktops: The standard computer equipment of a workplace integrated into the environment will then 'disappear'. Consequently, the computer audio system should be also integrated into the environment seamlessly. On the one hand, the audio system with its loudspeakers etc. has to be adapted to new integrated environments and on the other hand, the functionality and quality of the audio feedback have also to be designed for these new integrated work environments.

The DynaWall, a large interactive electronic whiteboard is one realization of the proposed integrated design of future collaborative work. This is one component of the i-LAND environment (interactive landscape for creativity and innovation, http://www.darmstadt.gmd.de/ambiente) at GMD-IPSI. i-LAND serves as a testbed for the integrated design of real and virtual information spaces. At the DynaWall new forms of intuitive interaction with information objects are realized in order to cope with the challenges of the large display and interaction areas for cooperative work situations. We use the electronic whiteboard to experiment with new functionality and quality of audio feedback for the reason that different aspects like spatial sound, intuitive gesture interface and collaborative work are linked together.

2.1. Teamwork at an electronic Whiteboard

In a cooperative work situation supported with electronic media not only the human-computer interaction is an important aspect but also the human-human interaction. In a work situation both, the interaction with the computer and the face-to-face communication among the team members could happen in parallel and therefore the interface to the computer should be as simple as possible in order not to disturb or block the human-

human interaction with a large complexity of, e.g., commands menu items or hierarchies. The most intuitive way of interaction with information objects on a whiteboard is provided by the possibility of pointing and touching on the displayed information objects directly: the key affordance of the interface of such a device. Thus on an electronic whiteboard like the DynaWall the user should interact, as he is used to do: with a pen or finger. The work situation can be more informal as well as a planned meeting presentation or plenary discussion. The general goals for the work situation are to find solutions and to agree and to decide within the team. In an example scenario, two or more persons are using the DynaWall to work collaboratively (see figure 1). The team can display all relevant documents that are needed to discuss and to solve problems at the DynaWall. The resulting documents discussed and annotated by the team can be used by each team member for further elaboration at their individual workplace afterwards. Possible application could be also creativity support techniques (e.g. brainstorming, card-based techniques, ..).

2.2. The DynaWall

The objective of the DynaWall is to provide a computer-based device for teams. In team project rooms traditionally large areas of assembled sheets of paper covering the walls used to create and organize information. Therefore the DynaWall can be considered as an "interactive electronic wall" represented by a touch-sensitive information device. The current realization of the DynaWall at the GMD-IPSI institute at Darmstadt provides a total display size of 4.5 m width and 1.1 m height and covers one side of a room completely (Fig. 1). The DynaWall allows 3072x768 interactive pixel to be projected by computers.

Figure 1: *Cooperative work situation at the DynaWall*

A cooperative software enables teams to display and interact with large information structures on the DynaWall. Two or more persons are able to either work individually, in parallel or to share the whole display space. The size of the DynaWall provides new challenges for human-computer interaction. For example, it will be very cumbersome to drag an object holding down the finger or a pen over a distance of more than 4 m. Therefore, two mechanisms have been developed addressing these problems. The "take and put" feature [7] allows to take information objects at one position, walk over (without being in contact with the DynaWall) and put them somewhere else on the display. "Shuffle" allows to throw them from one side to the opposite side where they can be caught by another team member or stick on the boarder of the display area.

The DynaWall consists of three rear-projection units. Each segment has its own standard off-the-shelf multimedia computer, computer projector and touch-sensitive display device. The computers are networked with 100 Mbps to the local area network (LAN) infrastructure of the GMD-IPSI institute. The units were integrated as much as possible into the architecture to achieve a maximum of acceptance of the notion of "electronic wall" or "electronic whiteboard" for this setup. Therefore parts of the units were modified by the workshop of the Technical University of Darmstadt.

2.3. CSCW software

The software used at the DynaWall is called BEACH [13]. It provides a server-based software infrastructure for synchronous collaboration and cooperative sharing of information between computers in combination with the new forms of human-computer interaction. The cooperative software BEACH has a layered architecture. The lowest layer provides the functions necessary for distributing, replicating and synchronizing information objects among networked computers while higher levels provide cooperative tool and application modules. The major input is pen and/or touch, but also keyboard and mouse are available. The top level BEACH provides tools to support the different phases of creative team sessions. BEACH is developed in Smalltalk using Parc Place Systems' *Visual Works* environment.

3. AUDIO ENHANCED INTERACTION

To demonstrate and experiment with audio enhanced interaction for a team work situation in a multiple computer environment we identified different areas, while considering the overall design issue of future collaborative work environments:

- Non-standard computer environments: 'beyond desktops'
- Imitation of real behavior: 'natural and coherent interface'
- Interaction of multiple users with a multiple computer environment: 'mixed interaction'

At the large display of the DynaWall it becomes clear that not all orientation on the interactive display can be managed well by visual cues or feedback. Depending on the distance of the user to the DynaWall, his view can be restricted but the audio feedback can be used to go 'beyond' these limits [5]. The individual interaction with virtual objects can be augmented with an acoustical behavior similar to those of related counterparts in real environment. Additional, those interactions that are going beyond those on a standard whiteboard, i.e., gesture interaction to open or delete objects should be embedded in the overall sound schema and perceived in coherent way. The multimodal interaction extended by audio feedback should be also consistent with the visual one. To reach the goal of a natural and coherent interface with audio feedback we extract the characteristics of the real sound behavior of moved objects and imitate them in the artificial and virtual environment. The sound feedback should be perceived as natural as possible without spending to much effort on too realistic simulations (virtual acoustics) [2]. In contrast to a local visual feedback in a multiple computer environment sound allows to give not only individual feedback but also awareness of the activity to other team members. For example, at the DynaWall the individual interaction with the computer can happen in parallel to or mixed with the speech communication among the team members. The following three examples of audio-enhanced interaction at the DynaWall will demonstrate and illustrate these aspects in more details.

3.1. Gesture recognition feedback

At the DynaWall, information objects can be direct manipulated by finger or pen (e.g., opening work areas or deleting objects) with a set of gestures. This functionality is part of the BEACH software. Using the pen for interaction at the DynaWall leads to the classical dilemma of pen-based interfaces: ink versus control mode. Therefore BEACH provides an incremental recognition of gestures which checks continuously the character of input while the user scribbles at the DynaWall. Hence, different states of detection are identified.
To improve the individual use of these gestures each state of the recognition is passed as an event to the sound system, where the detection envelope, i.e., the tracked states over time can be mapped to feedback sound cues, e.g., to accompany a gesture and to confirm its successful recognition (see figure 2). This envelope stimulates a sequence of sounds like a rhythm pattern when a gesture is drawn on the electronic whiteboard. This gesture melody always begins in the same way but ends different depending on the detected gesture. This pattern could increase also the correct use of gestures. When no gesture is detected, i.e., the user is scribbling or annotating the gesture melody is not finished. We are working on an implementation which is adaptive to the habits of the users over time, e.g., the sound feedback fades out the more the user repeats the same interaction or gesture in a short period of time. This feature could help to avoid redundant information and to spare the resource of attention within a cooperative work situation. At the DynaWall each segment has its own individual audio feedback equipment so the team members are supported with peripheral awareness of the interaction of their colleagues.

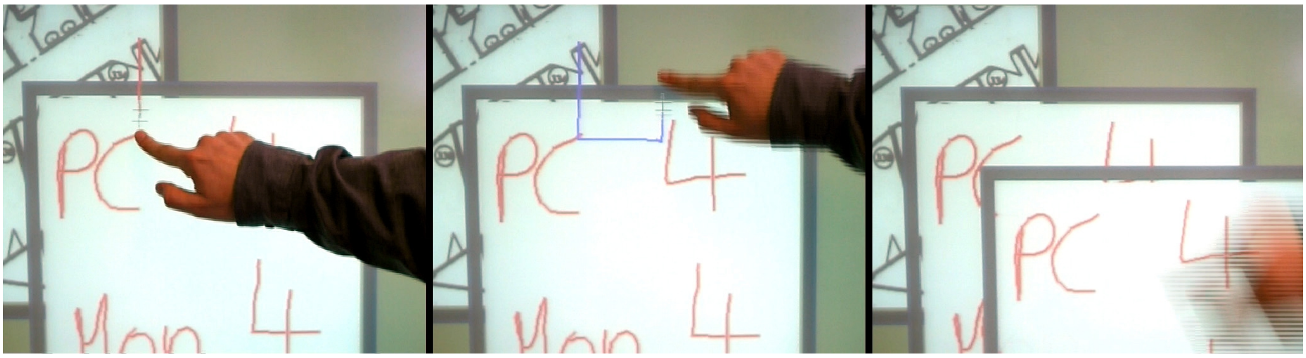

Figure 2: *Stills of a video of a gesture interaction to copy a workspace: start, end and execution of the gesture. The gesture is accompanied by a sequence sounds (gesture melody).*

3.2. Haptic subsonic feedback

In order to exploit new directions in audio feedback we propose also other sound effects. As in [3] subsonic sounds can be used to give haptic feedback to the user while interacting with information objects. The fact that the subsonic sound is hardly audible allows to use this kind of feedback also in a team communication situations in which more high frequency sounds could disturb. Of course, due to the low frequency characteristics of the sound it cannot be spatially focussed any more and hence becomes a more ambient, unobtrusive group feedback initiated by an individual.
In the current realization of the BEACH software (see section 2.3) a gesture called "abort gesture" overwrites all preceding gesture states and stops the recognition mechanism. This abort gesture can be activated when the user circles with a pen or finger several times around a point. Then the visual trace of the gesture changes its color and in parallel subsonic sine waves are emitted towards the front display. The surface of the display at the DynaWall is vibrating or resonating because of the energy of the sound waves. This feedback is on the one hand perceived by a soft tactile stimulus at the fingertip and on the other hand audible as a buzzing ambient sound. We tuned the frequency and the volume of a sine wave with some harmonics in order to control the trade-off between haptic threshold and a appropriate audible sound feedback level.

3.3. Interaction with information objects

One of the core features of the BEACH software running on the DynaWall is that it provides a homogenous area for interaction over all three DynaWall segments. The display of the three computers are "connected" simply by the Ethernet network connection so that an information object leaving one segment at the physical border becomes visible at the physical border of its neighborhood segment, without loosing its consistent visual representation. To manage the display space at the DynaWall in an appropriate way the BEACH software allows to move and throw information objects. Dragging the information objects all over the DynaWall is not very ergonomic because of the large width of the DynaWall. So a person A can throw his current selected information object on the electronic whiteboard to person B by simply accelerating the information object in the desired direction. After person A released his finger or pen the information object continues to move in the intended direction but then reduces its speed, just like a real object on a table-top. Moving and throwing information objects becomes important to structure and organize information objects and to clear up the current display area.
In our environment the moved and thrown information objects are enriched with sound cues that correspond to the speed and the position of the currently operated information object. Inspired by the sound of a wooden block when it is moved or shuffled over the surface of a table-top the sound feedback for information objects at the DynaWall consists of 'colored noise':

a seamless looped sound sample with a succeeding low-pass filter are controlled in real-time corresponding to the users interaction with the information object. This approach can be seen as a mixture of parameterized auditory icons as described in [6] and the dynamic data-to-sound mapping which is used in the context of sonification of huge amounts of data described e.g. in [1],[9]. Because the interface is enhanced with audio feedback of a sound reaction well known from the physical environment it is very easy for new users to understand, i.e., to decode the 'message' of the audio feedback ('natural interface'). The audio enhancement of interaction becomes important in a group work situation, in which the peripheral awareness of the partners' activities like annotating documents or shuffling information objects makes the mixed overall interaction more transparent, save and understandable.

Example 1: person A is aware that person B is writing some annotations on the electronic whiteboard. Hence A waits until B has finished his work before talking to him. Example 2: an information object thrown by person A is going to enter the working area of person B. This cue is relevant for the computer interaction of person B. The sound of the thrown object announces its arrival before person B is able to see it. The attention of person B is shifted from an audio to a visual and at the same time from a peripheral to a more central perception.

We are experimenting with different sound material to imitate qualities of surface and 'information object material' (chalk on slate, boardmarker on a flipchart, a book on a table etc.). In figure 3 and 4 the diagrams show the location of the loudspeakers in the DynaWall and positions of person A and B.

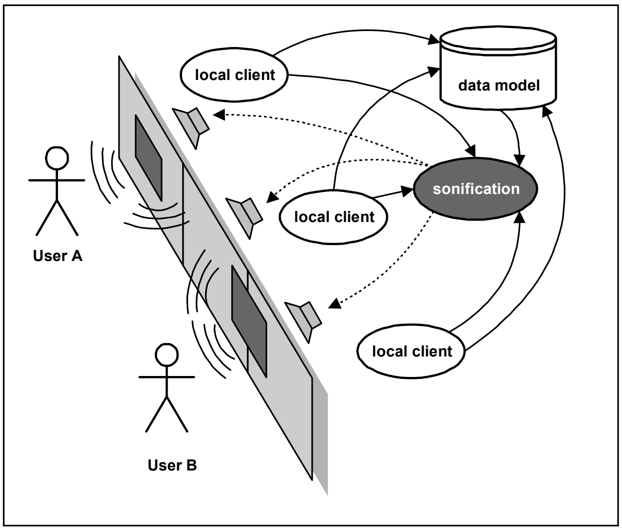

Figure 3: *Schema of the audio enhanced user interaction at the DynaWall*

4. AUDIO CONFIGURATION FOR THE DYNAWALL

As described in section 2.2 the DynaWall consists of three rear projection units (SMART Technologies, Canada). These units integrate the touch-sensitive display area and the computer projector and function also as a protection against light disturbing the projection on the front display. To follow the idea of an integrated design and to keep up the notion of an "electronic wall " or an "electronic whiteboard" we decided to put a loudspeaker inside each unit but, of course, outside the projection beam. This was our decision to solve the trade-off between integration of the equipment and sound quality for presentation. The coincidence of the location of interaction at the interactive display with the emanation of sound of a virtual information object guarantees a notion of a 'natural and coherent interface'. In contrast to a standard stereo-oriented desktop computer sound setup, in which the users' position is more or less fixed and defined. Finally, in our approach the audio equipment is completely 'disappearing' for the users as well as the computer.

All DynaWall computers in the units are connected with a dedicated computer (see the Audio PC in figure 4) running Windows 95. The Audio PC is additionally equipped with a multi-channel DA converter and PCI-soundcard with sample synthesizer facilities. All computers of the DynaWall are additionally star-like networked with Musical Instrument Digital Interface (MIDI) connections to the dedicated Audio PC to guarantee the continuous manipulation of sounds with low latency between the visual and the audible feedback independent from network traffic (see figure 4).

4.1. Loudspeaker integration

At the moment, three active loudspeakers are mounted inside each units at a height of approx. 1.8 m. The orientation of the loudspeaker is towards the center of the interaction surface of each DynaWall segment (elevation of -25 degree). The rear projection units are build from metal sheets and so the resonance of these units add a typical characteristic to the audio signals. Sounds played via these loudspeakers will be filtered or 'colored' in typical way. The sheets are damped with a special material stuck on them to absorb the energy of the vibrating planes to minimize the influences of these resonance effects.

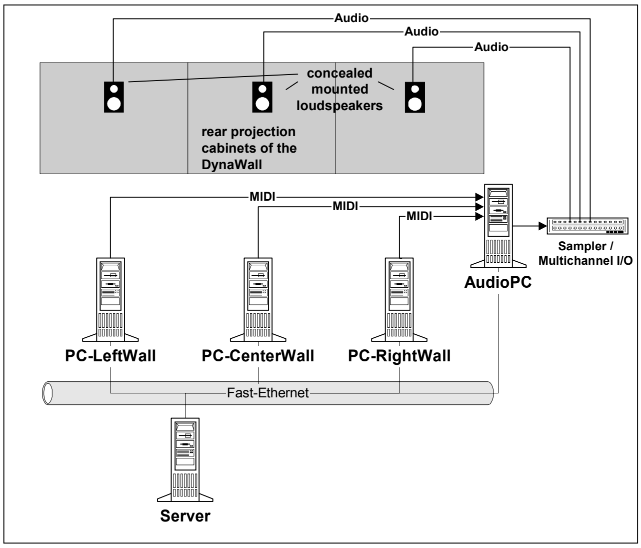

Figure 4: *Hardware setup of the DynaWall*

In the current installation the direct sound path which reaches the users ears first, becomes refracted and scattered by the rear-projection glass. This has consequences concerning the sound qualities and the pattern of sound emanation in front of the display. First, the overall damping of the glass surface makes it necessary to amplify the sound to an appropriate volume. Also the sound path through the gaps between the DynaWall segments becomes significant: the directivity of the loudspeaker is strongly modified. Second, the sound transmission through the rear-projection display damps high frequency parts within the sound and so display and touch surface is acting like a low-pass filter. Nevertheless, the ability to locate a spatial sound cue on the DynaWall is given, despite of these impairments of the sound presentation. At this point it becomes clear that it is not our intention to produce a high quality virtual sound simulation environment, like described in [3]. The focus of this work is more on the issues of 'natural and coherent interaction' and 'disappearing computer' in non-standard computer environments.

4.2. Audio information flow

When a user interaction happens on the DynaWall, the events to control the audio feedback are sent from each local client process of the cooperative software via a MIDI signal to Audio PC to achieve a minimum latency from the users' interaction to the audible sound feedback (see figure 4). As every client keeps the control over a visual information object that is shuffled from its segment until the object stops, it is possible to generate a continuous and dynamic sound cue of the object, consistent with its visual cue corresponding to the speed and position (figure 3 shows the underlying software structure, where the sonification process turns the interaction events into audio signals).

First, the audio server merges the incoming MIDI messages into a single MIDI stream, which then can be filtered or mapped to sound events in real-time. The MIDI data is sent to a sample unit of the soundcard where the playback of sounds is triggered, synthesized or running sound loops are modified in real-time while playing (for the MIDI and sampling technology we used, see [8]). In a second stage these sounds are mixed and distributed to the three loudspeakers. Since the MIDI-messages are sent on different MIDI-channels, independent panning and sound modification for each channel is possible. This allows simultaneous playback and separate spatial control for multiple information objects on the DynaWall ('polyphonic shuffling').

5. CONCLUSION AND FUTURE WORK

In a first step we enhanced the interaction at the DynaWall, an interactive electronic whiteboard with audio feedback to fulfil the notion of integrated design and 'natural and coherent interface' for team work situations in the workspaces of the future. Example realizations illustrate possible ways to enhance cooperative work with audio feedback for general and gestural interaction with objects. The next steps will be to extend this concepts also to other components of i-LAND project and to other forms of interactions within a collaborative work environments. An important part of our future work will be to experiment with different qualities and schemes of audio feedback and to evaluate the acceptance and use of the proposed enhancements.

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