SOUND EFFECTS FOR A SILENT COMPUTER SYSTEM

Christian Müller-Tomfelde

IPSI - Integrated Publication and Information Systems Institute
Fraunhofer IPSI, Dolivostr. 15, D-64293 Darmstadt, Germany
mueller-tomfelde@ipsi.fhg.de

ABSTRACT

This paper proposes the sonification of the activity of a computer system that allows the user to monitor the basic performance parameters of the system, like CPU load, read and write activity of the hard disk or network traffic. Although, current computer systems still produce acoustic background noise, future and emerging computer systems will be more and more optimized with respect to their noise emission. In contrast to most of the concepts of auditory feedback, which present a particular sound as a feedback to a user's command, the proposed feedback is mediated by the running computer system. The user's interaction stimulates the system and hence the resulting feedback offers more realistic information about the current states of performance of the system. On the one hand the proposed sonification can mimic the acoustical behavior of operating components inside a computer system, while on the other hand, new qualities can be synthesized that enrich interaction with the device. Different forms of sound effects and generation for the proposed auditory feedback are realized to experiment with the usage in an environment of silent computer systems.

1. INTRODUCTION

In the past various research has been done to extend the visual desktop metaphor for computer environments with audio feedback and thus to enrich the interaction with computers. Today, audio facilities are available in every standard desktop computer environment, i.e., a sound card is standard in personal computers and audio feedback is integrated into popular operating systems and applications. Different concepts were developed to map sound effects to user input events to enrich the user interaction with computers. For example, with the concept of Earcons an event is translated into a short musical sequence of tones, which has to be learned to understand their meaning by the listener [1]. While the concept of Auditory Icons introduced in [2] and [3] uses everyday sounds of the environment that are well-know by the user to convey information about events and states within a computer. Now, instead of adding sounds as a direct feedback to the interaction in a computer environment the emphasis and focus of this paper lies more on the sounds that the computer produces as a device itself and as a reaction to the input. The computer systems of the near future will loose their technically constrained noise aura and this can lead to more comfortable work atmosphere but also to irritation during the interaction. The imitation or a sort of a rebirth of the sounds of computer systems can help the user to monitor the state of the system and to fulfill learned expectations (see also related realizations [4]). In the following the context of this project and a typical situation of sound feedback during the interaction with a computer are described. Then, the future of noise-free computer systems is anticipated, followed by the description of a realized software prototype for the proposed sound feedback.

2. HYBRID ENVIROMENTS

On the continuum between the real world environment and a complete virtual environment are several approaches in between combining the properties and advantages of the two ends of the continuum. Milgram called these approaches along the continuum 'mixed reality' and build a taxonomy for the different visual displays, based on video and computer display techniques [5]. In the area of a general computer workplace environment the continuum starts with the traditional desktop computer environment and finishes in immersive, three dimensional environments, like described in [6]. Among these approaches so called hybrid environments combine on one hand more direct interaction and manipulation of the user with data represented by computers while on the other hand objects of the environment are still tangible and become augmented with information technology.

Figure 1: *An example for a silent computer system in a hybrid environment: the ConnecTable® is build upon computer components that emit no noise (Design: Fraunhofer IPSI, Wiege, Wilkhahn).*

8Mark Weiser coined for these kind of computer environments also the term 'ubiquitous computing' [7] emphasizing the aspect of the real space as an interface for the interaction with information. In a environment like described in [9] the objects within a room, like chairs, tables and walls become hybrid, i.e., they have a significant role in the real world and also function as an interface to interact with information in a virtual world in the computer. For cooperative work situations the hybrid environment acts as a traditional room which guarantees flexible and fast group interaction and at the same time free face-to face communication. The augmentation of the objects with information technology provides an additional virtual space in which the users can cooperate in parallel. In Figure 1 the ConnecTable is depicted as a typical example for a hybrid artifact. The small desk is designed to sit and to stand in front of it. The desktop is based on a computer display on which the user can interact with a pen. All other components of the computer are integrated in the case aside the column of the ConnecTable. The system works completely wireless and is entire free from typical computer noise from cooling fans, spinning hard disks and, of course keyboard clicks. Hence, the ConnecTable functions as a test object to experiment with sound effects for a hybrid artifact based on a silent computer system. The name ConnecTable refers to a mechanism that couples co-located displays of two desks to one homogenous workspace [8].

3. INTERACTION SOUND FEEDBACK

A common example of the sound feedback of a traditional computer system should illustrate the sound feedback processing triggered by an input event. The user presses the key combination 'Ctrl-s' on the keyboard and forces the currently focussed application to store the edited document.

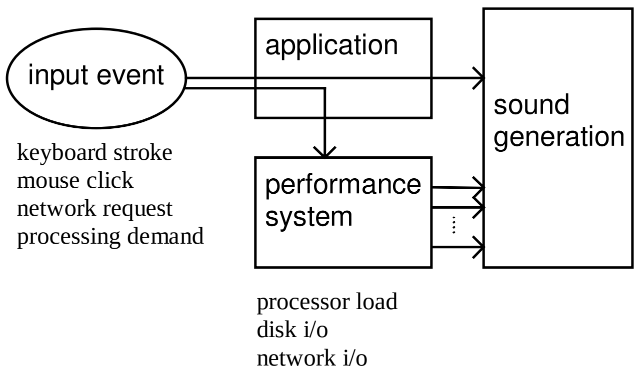

Figure 2: *The input event is processed by an application: In contrast to the direct call of the sound generation unit, the sonification mediated by the performance system is indirect and involves the characteristics of the underlying hardware system.*

The real computer system acknowledges the save-command with a transient noise burst that is caused by the positioning of the write head of the spinning hard disk during the save operation. This sound functions as a distinct hint for the users that really something is happening due to his command. The real operating components of the computer system emit sound, that has typical characteristics. The sound generation block in Figure 2 should comprise all these effects a standard computer system. In the chain of actions during this sequence also the click of the keyboard can be identified as an early feedback for the user that the key is/was pressed. In Figure 2 this is represented by the direct arrow (through the application) between the input event and the sound generation. This feedback does not give the user any hints about the states of the computer system, e.g. whether the command is executed or not. This is the same in the case of a synthetic sound feedback with a samples sound or musical motif assigned to the input event. This is currently accomplished by some system settings of popular computer operating systems and applications. Examples for this kind of feedback are the selection of the items for the pull-down menu or the opening and closing of applications. In the standard setting there is no sound feedback considered that represents a inherent state of the computer over time (expect perhaps for the situation when the wireless infrared connection temporally is broken down. This is illustrated by lopped sound that occurs during the time of the dropout). But currently the inherent states computer system that depends indirectly on the input event of the user, as shown in Figure 2 still bases on the sound generation that is the result of physical behavior of mechanical parts within the computers.

3.1. The disappearing sounds

In this paper, the assumption is made, that future computer systems become more and more inaudible and finally noise-free, as demonstrated with the ConnecTable [8][9]. Hence, the well known acoustical behavior will vanish and sound artifacts typically produced by a computer system will disappear. In the recent history of the computer industry two products are prominent examples with respect to the decreasing noise emission in computer environments. On one hand the Macintosh Cube is a computer system that is powered by a unit without an additional cooling fan. A chimney like construction of the central arrangement of the power supply unit allows a complete passive realization of the cooling of this unit. Passive or alternative methods of cooling are possible and applied for the central processing unit (CPU) in other standard computer systems by using a large heat sinks as well as liquid cooling techniques. On the other hand computer components like the latest hard disks of IBM can be controlled by a parameters for the acoustic management. The trade-off between high data access performance and low noise emanation (quiet seek mode) can be adjusted to meet on the requirements of the application context of this computer component in the work environment [10].
The consequences of the disappearing sounds are tow-sided: In a time of constantly increasing noise pollution in the environment [11] it is welcomed that noise can be dramatically reduced in the nearest surrounding of a computer workplace. But the lost of the acoustic aura of computer systems can also lead to irritation and uncertainty of the users during the interaction with the computer. In the context of product design for home appliances Heleen Engelen mentioned that the sound of devices should be designed to be more pleasent to the users than they currently are [12]. She states that „.by taking away the sound completely, the products lost a part of their character. They lost a part of their

communication to the consumer, which can, when not solved in another way, cause problems".

3.2. The reappearing sounds

In the same time in which the computer devices are getting more and more invisible or ubiquitous [13] also the audible properties and characteristics are getting lost or vanish. In some extreme cases there could be even no more a physical reason for the production and emanation of a sound. In the author's institute, examples of noise-free computer systems for the integration into future office environments [9] were built (second generation of the CommChairs and ConnectTables [14]) and allowed first experiences with noise-free computer systems.

Usually, the user ignores sound artifacts and understands them as waste, i.e., they are accepted as side products of the primary function or activity of the computer device. From the history of technology, however, there are examples that illustrate the persistence of sounds even when the physical reason does not exist anymore, because of certain improvements in technology. One example is the feedback of the dialed numbers on telephone devices with noise bursts due to the mechanical operation and the cross-talk between the sending and receiving channel. For these sounds there is no more technical reason anymore because of the improved digital technology in the area of telecommunication devices. The other example is the sound of the indicator in cars that originally was the sound of the mechanical relay that alternate between the on and off state of the indicator lights. Although, the mechanical relay is replaced by silent transistor technology the useful sound feedback still persists due to additional sound generation. These examples underline the importance of the sound feedback that emerge in a situation, where the technology development introduce new and more silent way of operation during the interaction.

The proposed reappearing sounds for computer systems can be understood and realized as a class of Auditory Icons, when the typical computer noise is imitated, or as a class of parameter mapping methods, where a one-to-one mapping between the points in the data and sound representation space exists [15]. Bill Gaver used Auditory Icons in his 'SonicFinder' to support the user's interaction of the 'desktop' of the computer screen with sound of the 'everyday listening' (e.g., deleting a file in the trash can) [2]. In contrast to this direct sound feedback of the user's interaction on the computer screen, like scraping sounds during dragging object over the desktop surface an analog sound feedback for the silent computer system is more indirect and emphasis the reaction of a 'system' to the user's input.

The original ambient character of the sound feedback should be retained when the sounds are the synthetically added and the offer to the perception should not attract the attention of the user constantly and so does not become unpleasant for the user/listener. Another possible feedback for the interaction with a hybrid artifact was demonstrated in [16]. The 'silent' interaction with stylus on a computer graphic tablet was acoustically modeled and the audible qualities of the surface textures trigger a cross-modal perception of different areas of interaction.

3.3. Performance parameters

To achieve the most realistic sound feedback for the performance states of a computer system, a low latency of the response of the parameters is important. For this case, the performance data are retrieved via kernel functions of the Windows operating system and mapped to the sound generation unit that allows sound synthesis in real-time. The currently chosen performance items represent the most interesting data items of the list of available items of the performance system under Windows 2000:

- Hard disk i/o in Bytes per second
- CPU load in percent
- Network i/o in Bytes per second

Other parameters like number of threads and mutex variables of a process can be also accessed by the programming interface but are less interesting for this proposed sound feedback.

The real sound emission of hard disks is a composite of a continuous part, due to the rotation of the drive, and a more transient part, e.g. created by data access operations. The CPU load represented here in percent is the sum of the demand of all running processes. Usually this parameter is not audible to the user in real computer environment, expect only indirect via an index (for semiotic classification see [1],[15]), like the increasing speed of the rotation of the cooling fan of a laptop. The number of bytes sent to or received by the computer is also a parameter that has no correspondence within the real computer environment, but it has certain correlation to other parameters, e.g., when downloading a file from the network to the local hard disk.

The programming infrastructure to access the parameter of the computer system via the Windows operating system (Performance Data Helper, PDH) allows also to retrieve the states of remote machines by simply modification of the performance query string. So non-standard sonification beyond real acoustical behavior of computer systems is possible so that the sound of a remote computer system, e.g. a file server could be transmitted and imitated on a local one.

3.4. Related Work

This work on the silent computer system is stimulated from different disciples and research areas, like computer science, human-computer interaction (HCI) and audio signal processing. In 1992 Jonathan Cohen presented in the ICAD community (international conference on auditory displays) the 'ShareMon' application that uses the audio channel as an alternative modality to convey to the user the states of the shared network resources of his computer [17]. Cohen used Auditory Icons like sounds of 'knocking on a door', 'foot steps' and a 'door slams' to map the remote logon and logoff procedure and the amount of file sharing activity on a Macintosh computer. His work was motivated by the limited visual display space on computer screens and the idea to convey background information about the computer via the audio medium. Another work by the artist Natalie Jeremijenko in 1995 at the computer science laboratory of Xerox PARC illustrates a more ambient and also hybrid approach to display the local area network activity. The so-call 'dangling string' was a plastic cable that hangs from a small electric motor from the ceiling. Each bit of information causes a tiny twitch of the motor, so that high network traffic made the cable twisting so fast that it got finally also audible [7]. In 1997 Ishii and Ullmer used also sound in an architectural space called ambientROOM to convey the hits on certain web pages on an internet server by mapping these events to single rain drops. The sound of a heavy rain indicates that the web pages is well visited and attracts the users attention [18]. The work of Beth Mynatt at Xerox PARC from 1998 is called Audio Aura and represents a personal mobile audio information system that delivers to the user peripheral information about arrival of e-mails, the presence of colleagues and their activity in the computer environment. These abstract or more high-level parameters of interaction with a computer system serve as events to build a 'sonic ecology' for each user. The different events are mapped into an auditory scene, e.g., an incoming e-mail is presented by seagull cries and various beach bird depending of the particular sender and the overall group activity are mapped to surf and volume and from hence a sonic background [19].

4. SOUND PRESENTATION

The presentation of sounds and sound effects for a silent computer system build upon standard audio facilities of traditional computer system. To achieve a maximum of coherence in the perception of the location of the 'object that sounds' and the location of the real sound emanation the loudspeaker should be as close as possible to the silent computer. The best solution would be to integrate the loudspeaker into the hybrid artifact. The alternative of a virtual sound projection with multiple loudspeakers always would lead to a particular optimal area of perception (sweet spot). This is only suitable for a static sound presentation like usually used in multi-media computer environments but not for a hybrid environment as described in section 2.

4.1. Sound generation

The generation of sounds for the inherent states of the computer system can follow different concepts and can vary between an analog and more abstract or symbolic auditory representation of the parameter from the performance system [20]. The goal of the analog sound generation would be to imitate the noise that is usually produced by the computer. These sounds are well-known by the users and are part of their 'everyday listening' in the workplace environment. More abstract and symbolic sound generation would use musical sequences, auditory scenes or effect on audio streams, that do not have any more a direct relation between the parameter of the computer system and the resulting sound. By using a metaphor an additional sign referent can create a link between the parameter of the computer system and the sound or sound effect that is presented to the user (for detailed descriptions see [21]). Like the desktop metaphor for the arrangement of graphical objects on the computer screen an auditory metaphor of a sounding device or an auditory scene can support the user's interaction and his mental model of the system activity. For the silent computer system two approaches are developed that follow on one hand a more analog representation and generation of sound for the inherent computer states with certain allusion to real noises. While on the other hand a metaphor of a audio device is used to convey the parameter via modulating an audio stream.

4.2. Analog representation

For the analog representation a white noise generator is modulated with a low frequency rectangular oscillator which speed is controlled by the percentage of the CPU load. Idle states of the CPU will sound like smooth swelling waves of water on the beach. Therefore an additional low pass filter reduces 'sharp edges' of the modulating rectangular function in the idle situation. A rising load of the CPU will increase the speed of the LFO so that finally the sound generator resembles to the rhythmic noise of a car engine. This sound will then be filtered by a recursive comb filter structure with a fixed resonance frequency. The amount of network traffic is mapped to the gain of the feedback coefficient of the comb filter structure so that higher activity on the network interface becomes audible by more harmonic filtering of the 'CPU load' sound (subtractive synthesis). While the CPU load parameter is more perceptible in the time domain, the network traffic is represented the frequency domain as a fixed resonance with variable gain. While the overall sound is not formed by an additive synthesis process of different sound generators the resulting sound of this generator appears more as one single sound object.

4.3. Metaphor representation

To convey the parameters of the CPU load and disk i/o activity to the user of the silent computer the metaphor of traditional record player is used. Therefore it is assumed that the computer user is listening to musical streams which then are manipulated by the performance parameters of the computer. The parameter of the CPU load is used to control the speed of the 'turntable' system so that the idle state is equivalent to the normal speed, while increasing load of the processes on the CPU leads to a decreasing of the rotation speed of the turntable. Only a few percent in the decrease of the speed are needed to be perceptible. The other parameter of the disk i/o performance affects the sound stream by additional artifacts in the playback of the 'record'. Small asperities on the record surface produce artifacts during the sampling of the record with a phonograph needle. This cracking influence is added to the sound stream to convey the read and write activity on the hard disk of the computer. Other standard sound effects can be used to convey this performance parameter like chorus, reverb or distortion effects [23][22].

5. IMPLEMENTATION

In a first version, a program was created that combines the monitoring of the performance states of a computer and the sound generation. The programming interface (performance data helper, PDH) of Windows 2000 was used to get access to the performance parameter. The resulting program was designed to run in the background on the system tray. The sound generation unit was integrated into the program to have as much as possible control of the parameter mapping and direct effectiveness in real-time. The PortAudio application programming interface was used to have access and control of the audio stream i/o in the computer environment [24]. A set of signal processing objects were written ANSI-C and used to build the basic filter operations and signal manipulations for the sound generation and effects. As nearly all programming environments and libraries this approach of signal processing objects also uses block-based signal processing. Well-known signal processing algorithms were implemented and applied to build a real-time controllable sound object and sound effects [25]. While including network based communication into the program it would be possible to remotely involve a more flexible and powerful sound processing environments, like e.g. Max/MSP [26] for the initial design phase of the sounds effects. The problem of the self-reference of the sound generation process has to be solved in future. The required processing capacity the sound generation has to be excluded otherwise the generation process produces sound that represents its own activity on the CPU. Some mappings of the parameter are extremely depended on the hardware configuration of the computer system and have to by adjusted individually. So for example the network traffic rate can vary from 1Mbps up to 100Mbps.

6. CONCLUSION

The described sound effects for a silent computer system are initial research activities in the context of future and emerging computer systems that will produce no more a noise at all. The disappearing sounds allow to make those sounds reappearing that are useful and important for the interaction with hybrid object in a hybrid environments. An analog representation and the use of a record player metaphor are used to demonstrate the variety of possibilities for a reappearing sound aura of a silent computer system. I would like to thank Steffen Halma for his programming work on the performance parameter and the integration of the all source code into one program.

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