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1 Introduction

This report is one of the deliverables of The Humanware Centre project *"Sound design for CE products"*. The goal of this project is to show that sound design can be used to great advantage for many CE products.

This report gives an overview of current research on the use of nonspeech audio at the user interface (UI).

Section 2 starts with some examples of everyday listening which demonstrate the potential of nonspeech audio for man-machine communication. Next, in section 3 some of the pros and cons of using nonspeech audio are discussed. The actual research overview is presented in section 4. Section 5 discusses the role sound can play in UIs for CE products. Section 6 concludes with some general remarks on the use of nonspeech audio at the user interface.

2 Examples of everyday listening

Examples of the use of nonspeech audio by humans in performing day-to-day tasks show the huge potential of the auditory input channel for man-machine communication. A striking example is given by Buxton (1989) who describes the use of nonspeech audio in driving a car:

> Consider that driving a car at 80 m.p.h. on a motorway is a critical task in which error could result in death. Nevertheless, one can perform the task, with the radio on, while holding a conversation with the passenger. Despite concentrating on the conversation, one can still

monitor what is on the radio and, if of sufficient interest, interrupt the conversation to point out a favourite melody. While all of this is going on, one could well be passing another car and, in the process, changing gears. A clicking sound confirms that the turn signal is working, and if the car has a manual transmission, audio cues (rather than the tachometer) will most likely determine when to shift. And throughout all of this, one is immediately aware if the engine starts to produce some strange noise, or if an ambulance siren is audible.

Other examples like crossing streets, playing video games, answering phones, listening to the sound of printers, modems, and disk drives to assess the state of the system, also illustrate that in daily life most people are using nonspeech audio cues to monitor what is happening in their environment.

3 Pros and cons

The *pros* for using nonspeech audio in products:

- As seen in the previous section, sound is a familiar and natural medium for users to obtain information from their environment. This means that the skills that users built up over a lifetime of everyday listening can be exploited by the UI designer (Gaver, 1989).

- Sounds convey very different kinds of information (Mountford & Gaver, 1990):

  Sounds tell something about *physical events.* Auditory feedback can give information whether or not a button on a touch screen is pressed (de Vet, van Deemter, Gerrissen & Kemp, 1991).

  Sounds give information about *invisible structures.* By using a stethoscope physicians can diagnose certain respiratory and heart diseases (Ballas, Dick & Groshek, 1987).

  Sounds provide information about *dynamic changes.* The sounds produced by a VCR enable users to estimate how long it will take for the VCR to rewind to the beginning of a video tape.

  Sounds convey information about *abnormal structures.* A malfunctioning product sounds different from a healthy one (Mountford & Gaver, 1990)

Sounds contain information about *events in space*. Somebody is approaching you and looks over your shoulder to get a glimpse of the report your reading.

Sound can be used to display the *status of processes* in multitasking environments. Your printer is still busy printing.

- Sound can be heard all around without the need to focus attention on an output device (Brewster, Wright & Edwards, 1993c), whereas a visual object can only be seen by looking at a certain location.
- Nonspeech audio reinforces visual views (Brown, 1992).
- As systems become increasingly complex visual displays become overly dense. Sound can be used as an alternative channel to reduce visual working load.
- The bandwidth of communication can be significantly increased by using both the audio and the visual channel.
- The human perceptual system does not remain conscious of steady-state sounds (Buxton, 1989). This means that continuous sounds do not have to be actively monitored by the user. These sounds will only draw attention when they change (Brewster *et al.*, 1993c).
- Users are able to simultaneously monitor a number of nonspeech audio signals while performing a motor/visual task (Buxton, 1989). This capability was clearly demonstrated by the example of driving a car.
- By using nonspeech audio interfaces can kept language free. This facilitates and maximizes the international exchange of products.
- There is much expertise on nonspeech audio in the world of music, film, and commercials. In these fields nonspeech audio is used in helping to realize the meaning of the pictures, and in stimulating and guiding the emotional response to the visuals (Jenkins, 1985; Blattner & Greenberg, 1992a).
- Adding sound to UIs may be relatively cheap as most of the time the required hardware is already present in the products.

There are also some *cons* for using nonspeech audio in products:

- If nonspeech audio products are used in environments in which more people are present, the sounds can become annoying or distracting. It should always be realized that users have no earlids. However, as argued by Buxton (1989):

  > ... there is no such thing as silence. In performing our day-to-day tasks, we are surrounded by sounds. Some help us, others impede us. The former are information; the latter are noise. ... By effective design, we can reduce the noise component and increase the information-providing potential of sound.

- Poorly designed auditory interfaces can be extremely annoying. The sounds themselves should be pleasing, but even more important, the sounds should be designed to be an integral part of the dialog between user and product.
- Sounds most of the time have a transient character. Once they have been played they're gone.
- Users in noisy environments, or those with hearing deficiencies may find it difficult to obtain information from sound (Mountford & Gaver, 1990).
- Although we can recognize and simultaneously monitor a number of different audio cues, we can normally only respond to one or two at a time (Buxton, 1989).

4 Research overview

This section presents the tour of nonspeech-audio research. General overviews on the use of nonspeech audio in user interfaces can be found in Buxton (1985); Buxton (1989); Buxton, Gaver & Bly (1990); DiGiano & Buxton (1993a); Gaver (1986); Mountford & Gaver (1990).

- **Sound quality of products.** The sound quality of a product may be used by the customer on an aesthetic level to qualify the acceptance of the product (Cann, 1993). The aim in this field of research is to come up with well-defined specifications for the sound quality of a product.

Sound quality of products is becoming a hot topic in acoustic research. For instance, at the upcoming conference of the Acoustical Society of America (Denver, Colorado) it will be presented as a hot topic in noise-control (Cann, 1993). In the automotive systems industry, Ford Motor Company is actively doing research on this topic (Wakefield, personal communication, July 6, 1993). Within Philips Research Laboratories, the Acoustics Research Group is addressing the problem (de Wit, Verbunt & Vael, 1993; Louwers, 1993). In fact, sound quality of products (also referred to as functional sound) is the focus of phase I of The Humanware Centre project "*Sound design for CE products*".

- **Soundscapes.** The word *soundscape* was coined from its visual equivalent *landscape*. "Soundscape studies investigate the effects of the acoustic environment or soundscape on the physical responses or behavioural characteristics of creatures living within it (Hiramatsu, 1993)". It is a topic which is a typical Japanese phenomenon. Recently, a special issue of the Journal of the Acoustical Society of Japan was completely dedicated to this subject. By analysing different soundscapes and taking personal and cultural (social) backgrounds into account, researchers hope to come up with rules which can be applied in the design of a comfortable acoustic environments (Hiramatsu, 1993; Namba & Kuwano, 1993; Sasaki, 1993).

- **Nonspeech audio in user-computer interfaces.** So far, three different types of nonspeech audio messages for the communication between user and computer have been explored. These audio messages provide users with information about computer objects, and events.

Earcons. Earcons are the auditory equivalent of visual icons (Blattner, Sumikawa & Greenberg, 1989). They are abstract, synthetic tones that can be used in structured combinations to create sound messages to represent parts of an interface. They are composed of motives, which are short, rhytmic sequences of pitches with variable intensity, timbre and register (Brewster, Wright & Edwards, 1993a). It has been shown that these earcons can be an effective method for communicating information between the user and the computer (Brewster *et al.*, 1993a; Brewster, Wright & Edwards, 1993b). They have also been applied in an educational context (Blattner & Greenberg, 1992a).

Auditory Icons. Auditory icons are caricatures of naturally occuring sounds. Auditory icons were introduced by Gaver (1986). The strategy behind auditory icons is that sounds provide information about the world, and as a consequence humans can use a source of sound to stand for a source of information. Auditory icons, thus, have a semantic link to computer objects and events (Gaver, 1986). For instance, the sound of a closing metal cabinet is used for closing a file.

Auditory icons have been used in different user interfaces: in the SonicFinder, an auditory interface for the Apple Macintosh (Gaver, 1989), in SharedARK, a large, shared, multitasking environment that serves as a virtual physics laboratory for distance education (Gaver, 1990), and in the ARKola simulation, a simulated softdrink factory in which users had to collaborate in a complex, and demanding simulation task (Gaver, Smith & O'Shea, 1991b). These studies suggest that auditory icons can play a significant role in man-machine communication. At the Institute for Perception Research, auditory icons have also been applied to UIs (Eggen, Haakma & Westerink, 1992; Haakma, 1993).

Genre Sounds. Cohen (1993) investigated whether it is possible to repurpose audio environments created for telling stories in film, television, and radio. His sound-to-event mapping uses sounds from the Star Trek television show. As yet, it is not clear whether these so-called genre sounds can be succesfully applied in UIs.

- **User interfaces for the visually impaired.** Window-based operating systems make access to computer-based equipment more difficult for visually impaired people. Research has been done on how to use nonspeech audio to adapt such interfaces for the blind or visually impaired (Edwards, 1988; Edwards, 1989a; Edwards, 1989b; Mynatt & Edwards, 1992).

- **Scientific audiolization.** In this field scientists investigate whether sound can be used for the exploration and analysis of data with very high dimensionality (Buxton, 1985; Smith, Grinstein & Bergeron, 1992; Flowers & Hauer, 1993). For instance, Blattner, Greenberg & Kamegai (1992b) have studied the audiolization of turbulence.

- **Algorithm animation.** The big question here is: are there tools like the doctor's stethoscope that can help programmers listen to the heart-beat of their software (DiGiano & Buxton, 1993b)? One approach is to associate nonspeech audio with program events. In this way, running the program generates sounds which can aid in the comprehension and analysis of the program's behaviour (Brown, 1992; DiGiano & Buxton, 1993b).

- **Audio enhancement of new interaction styles.** Various ways are explored how interaction styles can be enhanced by the use of nonspeech audio cues.

  Venolia (1993) uses sound to accentuate 3D direct manipulation of 3D images on an Apple computer screen. Almost every visual change in the interface and user action is accompanied by audio reinforcement.

  Riecken (1992) investigates adaptive auditory UIs. In such an interface, the system dynamically distribute and present to the user an ordered set of individual auditory signals without overloading a user's auditory channel.

  Karsenty, Landay & Weikart (1992) developed *Rockit*, a system that identifies the possible graphical constraints between objects in a two-dimensional scene and allows the user to choose and apply the desired constraints quickly and easy. Inferred constraints are indicated by graphical and sonic feedback objects.

  Laurel (1991) argues in her book "*Computers as Theatre*" that the tight linkage between visual, kinesthetic, and auditory modalities is the key to the sense of immersion that is created by many computer games, simulations, and virtual-reality systems.

  Cohen & Ludwig (1991) developed a multidimensional audio window management system. This is a spatial sound system (Wenzel, 1992) with hand gesture recognition and feedback based on so-called "filtears". *Filtears* are audio feedback cues that convey added information without distraction or loss of intelligibility. They applied this audio window management system to an audio server appropriate for a teleconferencing system.

- **Auditory warning signals.** Audio messages are received regardless of where one is looking (Buxton, 1987). Therefore sound can be used very effectively to warn users about unwanted or dangerous situations.

The literature on warning sounds addresses questions like what is the most effective signal for a given acoustic environment, or how can we construct sets of warning sounds that get one's attention reliably without startled reactions (Adams & Trucks, 1976; Fleisher & Blauert, 1989; Patterson, 1990)

- **Creation of nonspeech audio.** In order to be able to use nonspeech sounds for man-machine communication one has to create and manipulate sounds. Digital sampling is one of the easiest ways of using sounds in a system. Synthesizing sound by means of algorithms however is much more flexible. Algorithms allow attributes of the sound to be controlled by relevant computer events. Algorithms for parameterized auditory icons have been developed by Gaver (1993a). Expertise on algorithms and structures for the synthesis of nonspeech sounds can be found in the field of computer music (see for instance, Borin, De Poli & Sarti, 1992).

- **Psycho-acoustic and psychological research.** For a great many years psycho-acousticians have investigated how sound is perceived by humans. Psycho-acousticians study the physical correlates of perceived attributes of sounds (Houtsma, Rossing & Wagenaars, 1987; Rossing, 1990). Recently, there has been a growing interest into the perception of complex nonspeech sounds (Yost, 1989) and the way people perceive their auditory environment (Bregman, 1990).

  Ecological psychologists take a somewhat different approach by investigating sound in terms of sound-producing events, or sound sources (Warren, Jr. & Verbrugge, 1984; Jenkins, 1985; Gaver, 1991a; Gaver, 1993c). That these two approaches can be complementary is demonstrated by some recent studies on the perception of acoustic source characteristics (Repp, 1987; Tousman, Pastore & Schwartz, 1989; Freed, 1990; Li, Logan & Pastore, 1991).

5 Sound in UIs for CE products

So far, little has been said about nonspeech audio applications for CE products. The reason for this is that, besides the occasionally used 'roger' beep, nonspeech audio is not yet applied in CE products (some CD-I software forms an exception). This statement holds an opportunity for improving the UIs of Philips products and getting a competitive edge.

In this section two questions are addressed: which *CE products* might improve by using nonspeech audio at the UI, and what might be the *benefits for the user*? It should be noted that one can only speculate about answers to these questions, because the true answers can only come from user involvement throughout the R&D process. User involvement will allow one to make good predictions about nonspeech audio features or products which will be successful.

Within CE some trends are clearly recognized. *CE products* will become smaller, they will become more intelligent, will provide greater functionality, and above all future products should be easy-to-use and affect people's lives in a positive way.

These trends might give rise to problems. For instance, visual cluttering on small displays detoriates the comunication between the user and the product. The cognitive working load will increase, and users will get annoyed, and even worse they will give up using the product. Portable audio, video, and CD-I devices, or future personal communicators have to deal with these problems. But also the displays of advanced audio sets or televisions might suffer the same problems. Nonspeech audio could be one of the solutions.

Future television sets will feature advanced graphics and multitasking capabilities. Research has shown that nonspeech audio is essential to animate graphics, and that nonspeech audio is very effective in monitoring simultaneous processes.

As said earlier, one characteristic of sound is that you don't have to look at the source. This characteristic of sound should be exploited more. In conventional products like telephones, audio sets, and portable devices it is sometimes very hard, or even impossible, to view the display.

Of course, many more applications of nonspeech audio can considered. But the ones mentioned should suffice to point out the interesting possibilities of using sound at the UI.

At the Humanware Centre *user benefits* are measured in terms of effectiveness, efficiency, satisfaction, and pleasure. The contribution of nonspeech audio to the usability of CE products can be discussed according to these four criteria.

Research on nonspeech audio at the UI has clearly demonstrated that the effectiveness of users in reaching their goals is improved by using audio cues. For instance, Buxton (1989) has found that in video games that use sound effectively, the player's score is lower without nonspeech audio feedback than it is with nonspeech audio feedback.

At this moment, it has been shown that for certain tasks like multitasking or colloboration tasks the efficiency or effort needed to accomplish the tasks is increased by the use of nonspeech audio (Gaver, 1990; Gaver *et al.*, 1991b).

Informal observations made in the DRUID project have shown that users feel confident and show satisfaction the moment an auditory icon tells them that a certain command is being executed (Eggen *et al.*, 1992). One example is the use of the sound of a vacuum cleaner to indicate that a music track is removed from a DCC tape. Although when hearing the sound for the first time users were amused, later on in the experiments they heavily relied on the sound feedback. They did not look at the display to verify if the machine was really doing what they expected the machine to do. They felt satisfied in accomplishing their task, and went on with the next task.

If well designed, sound can increase the pleasure customers have in using the product. Good examples are video games.

6 General remarks

In this section some issues concerning the application of nonspeech audio at the user interface are mentioned. These issues deserve attention if we are going to apply nonspeech audio in products.

- The ultimate success of auditory icons depends on the development of good analogies between events in the product and sound-producing events in the world (Mountford & Gaver, 1990). When such analogies are hard to find, sounds can be giving meaning by design.
- Nonspeech audio information should be an integral part of the complete man-machine dialog. There should be a tight linkage between audio

and other input-output modalities used in the dialog between customer and product.

- What art is to icons is music to earcons. It should be stressed that not every implementer is a sound artist (Blattner *et al.*, 1989)! What is clearly needed in a team which designs an auditory interface is the presence of a sound designer.

- Nonspeech audio promises well for the future. However, we can only fill in this promise if we involve users throughout the product creation process. User involvement determines whether products which apply sound at the UI will be successful.

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