

“Informative auditory warning signals”: a review of published material within the HCI and Auditory Display communities

Fagerlönn, J¹

1. Interactive Institute, Sonic studio
Acusticum 4, SE-94128 Piteå, Sweden
E-mail: johan.fagerlonn@tii.se

Warning signals are used in a variety of settings to convey critical information, user environments are no exception. A clear trend for auditory warning signals in is that they become more and more informative. Their intention is not only to alert, but also to inform users about the nature of a critical incident. In this paper we focus on current research within this branch of sound design. A literature study has been conducted with the intention to map the progress which has taken place within the area of auditory display research, identify issues related to this research, and to point out new potential ways to design warning signals for user environments. The main results of this literature study are presented and discussed.

Warning signals, auditory display, auditory icons, earcons

1 Introduction

Sound as an information channel has distinct advantages over other methods of communication, making it widely-used for warnings and alerts in various contexts and environments. Auditory warning signals in user environments are, more often than not, very simple, monotone sounds. In application, they are often annoying and difficult for users to recognize and understand (Block et al., 1999; Ulfvengren, 2006) During recent time there has been an increasing interest to investigate new and more complex non-speech sounds to convey information in critical situations (Stevens et al., 2006; Ulfvengren, 2006; McKeown, 2005). The Sonic studio, part of the Interactive Institute in Sweden, is a research unit focusing on applied research within sound, interactivity and new technology. Sound for information-delivery is a recently started research project at the studio. One particular focus is to explore alternative methods to design warning signals for user environments. So far, a literature study has been carried to with the aim to investigate the progress which has taken place within this branch of sound design research, identify issues related to this type of research, and to point out some new potential ways to design warning signals. The objective of this paper has been to present and discuss the important findings of this study.

2 Speech and non-speech sounds

A common approach in auditory display research today is to distinguish between speech and non-speech sounds. General advantages and disadvantages of both categories of sound have been proposed. Speech-based signals may require minimal learning (Leung et al. 1997) and are suggested to have advantages over non-speech sounds in situations when the information to be conveyed is very complex, when the number of warnings in

a system is very large, or when the user is not required to make a particularly rapid response (Patterson 1982). On the other hand, non-speech based sounds may have advantages over speech in that they are both language independent and have the potential to be understood more efficiently and more rapidly. They can be better suited in environments that require other simultaneous verbal communication, or in environments with a high level of background speech and noise (Patterson, 1982; Edworthy, 1994). Research has so far been focusing primarily on two different categories of non-speech sound – abstract and representational sounds.

3 Abstract and representational sound icons

The concept of using more complex sounds to convey information and feedback in user environments derive primarily from HCI research in the 1980s. By that time, visual icons had been around for some time and there was an increasing interest to explore new ways to convey information using sound. Blattner et al. (1989) described how sound could be grouped or structured along principles similar to those of icons. These short sounds, which he called earcons, were defined as “*nonverbal audio messages used in the user-computer interface to provide information to the user about some computer object, operation, or interaction*”. He suggested that earcons, like icons, could be divided into the classes: representational, abstract, and semi-abstract. Abstract earcons would make use of the many possibilities offered by musical signals, to form unique sounds. By manipulation of parameters such as timbre, register and rhythm, hierarchical earcons with specific meanings could be created. Just as representational icons are recognizable pictures of objects, representational earcons would be sounds that are already familiar to the user. Gaver (1986) investigated representational earcons, although he called them auditory icons. He defined auditory icons as “*everyday sounds mapped to computer events by analogy with everyday sound producing events*”. He divided the mappings between data and their auditory representation into three different types: symbolic, nomic, and metaphorical.

4 Defining sound types

Ever since earcons and auditory icons were first introduced, authors have been investigating their potential, and how to make them more effective. Brewster and later also McGookin have done some important work evaluating earcons (Brewster et al 1993; Brewster et al.1996; Brewster 1998; McGookin 2004) and further developing design principles (Brewster et al. 1994). Their work clearly focuses on the kind of earcons which Blattner referred to as abstract earcons. Brewster has defined earcons as “*abstract, synthetic tones that can be used in structured combinations to create sound messages to represent parts of an interface*” (Brewster et al. 1996). Bussemakers et al. (1998) added mood to earcons by manipulating parameters such as loudness and intonation. Pirhonen et al. (2006) expanded the category of earcons to cover all non-speech audio signs that do not directly imitate sounds of real-world events. Jørgensen (2006) discussed the use of sound icons in both auditory displays and computer games and pointed out that the definitions of earcons and auditory icons in computer games generally covers a broader spectrum of sounds than in auditory displays. Speech might for instance be characterised as an auditory icon, if it does not present detailed linguistic information.

Auditory icons can be described as environmental sounds, non-abstract sounds, natural sounds which are common in the real world, every-day sounds, sounds that are simply

associated with real events, or generally non-musical sounds that have some resemblance to the thing they are representing (Gaver 1986; Pirhonen et al. 2006; Walker et al. 2006,). McKeown (2005) investigated candidates for within-vehicle auditory displays and separated auditory icons from environmental sounds in that the auditory icons were matched to particular outcomes. Ulfvengren (2006) investigated natural warning signals and suggested that: "*In the concept of natural warning sounds the interpretation of natural includes sounds that are natural for the users in their everyday environment.*" Conversy (1998) presented an alternative method for designing a form of abstract auditory icons based on sounds that do not exist in the real world, but which uses high-level attributes that naturally conveys the notion of speed and size and motion.

5 Finding the appropriate information carrier

An essential part of designing an auditory warning is to find an appropriate sound to represent the particular event. Quite a lot of studies, often carried out in controlled environments, have been focusing on identifying advantages and disadvantages with different types of sound. Auditory icons have proven more effective than abstract sounds both in terms of reaction time (McKeown 2005; Graham 1999; Stevens et al. 2006; Myra et al. 2000) and accuracy of response (McKeown 2005; Stevens 2006). McKeown (2005) proposed however that annoying and attention-getting abstract warning signals can be preferable in very urgent situations which occur infrequently. Smith et al. (2004) investigated in a study the ease of learning different sound types and found that abstract sounds were learnt and retained with far greater difficulty than both speech and representational sounds. Patterson (1982) investigated how auditory warning signals should be designed to lessen the likelihood of masking by noise and other warnings. He also recommended no more than 4-9 abstract alarms in a system. If the user is able to learn the intended rules of an abstract earcon hierarchy, abstract earcons can of course be used to represent numerous events in a system. An earcon with a specific timbre might for instance indicate an engine related error in a vehicle cab, whereas the rhythm can represent exactly what kind of problem it is. Brewster (1996) proposed that earcons can be a powerful when representing large hierarchies. Although, given the training required and problems retaining or retrieving associations between abstract sounds and events, it has been questioned whether earcons are appropriate in very important situations, or when there is a high cognitive load (Stevens et al 2004). There are a number of issues associated with auditory icons. Several relates to finding appropriate sounds for specific events. In many cases sounds that are recognizable can be tricky to find (Walker 2006). An alternative when designing auditory icons is to use metaphorical or symbolic mappings (Gaver 1986). But auditory icons are suggested to have the potential to cause inappropriate user actions (Graham 1999), which have verified the importance of using comprehensible auditory icons. Another proposed issue with auditory icons is that they can be annoying after prolonged use (Sikora et al. 1995).

6 Discussion

In the previous chapter some of the advantages and disadvantages, which have been proposed for different sound types, were presented. Using very familiar auditory icons (in those cases when such sounds can be found) might be a very effective way to convey critical information. Stevens et al. (2004) showed how systematic manipulations of acoustic parameters of auditory icons can be used to convey properties of a sound

source such as location, distance and motion. Adjusting certain of the sound attributes of auditory icons, to provide valuable information about an object, is interesting for the future development of warning signals.

However, it is important to realize that no single type of sound previously described, can possibly be the best information carrier for all situations. Which type of sound to use may be influenced by a number of parameters such as the number of potential sounds, the information to be conveyed, environmental conditions, the urgency and importance of the situation, concurrent task demands, desired user action and the user background. Previous studies which have been carried out in controlled environments can give us indications about what kind of responses we can expect from different types of sound when designing warning signals, but more studies performed in realistic environments are necessary to verify how these sounds perform in real-world settings. Effective warnings might be achieved by combining different types of sounds into new types. Such as Spearcons (speech based earcons), a concept recently proposed by Walker et al. (2006). One can imagine combining other types of sounds to create new kinds of warning signals. A future application for abstract warning signals can be to present them concurrently with auditory icons. This may be an interesting way to make auditory warnings more redundant and decrease the risk of unexpected user actions. Whereas the auditory icon gives the driver associational information (what it is that we hear) the abstract sound carries complementary information about urgency level (how important it is). The abstract sound could further be used to help drivers distinguish warning messages from each other. Like musical parameters are used to make earcons distinguishable, timbres and melodies can be used to build families of warning sounds, and make warning sounds part of more overall theme.

Also, sound is an important means of communication in the everyday world in many ways, and research on auditory displays is still a relatively young field. There are still many aspects of sound and mapping methods which have not been investigated or considered.

Much of the research carried out within the area of auditory displays has had a strong “sound-focus”. The sounds that are examined are often described and defined on the basis of the qualities of the sound itself and/or how the sound was designed. If the sound imitates some real event or object – then it will probably be referred to as an auditory icon. If it is a musical sound, then it will most likely be defined as an earcon. What may be of more interest is how users perceive and interpret the sounds in specific environments and under particular conditions. The sound of children’s voices can for instance be an iconic representation of children playing, but it might also be perceived as speech or even music by a listener. The sound of a loud car alarm might convey an extremely high level of importance, but it may also be a naturally occurring sound in that environment, and people will perhaps not even look in that direction. The loud sound of a Harley Davidson motorcycle engine might be perceived as sweet music by some people. It is important to understand that one particular sound can easily be perceived and processed in many ways, depending on both the user and the context. Existing knowledge about non-speech sounds in human-computer interaction provide valuable support to sound designers. But auditory display researchers and sound designers would probably benefit from taking a more user-oriented approach, utilizing sound design methods that do not focus on specific sound types, and their limitations.

Ulvengren(2007) recently presented a more user-oriented approach to the design of natural warning signals.

Auditory display research has so far primarily been focusing on improving functional aspects of sound, such as making earcons easier to distinguish from each other, or to determine whether auditory icons are easier to recall than abstract sounds. Not much work has been focusing on issues such as how to design sounds that are beautiful to listen to or to make them fit well into a context or a specific environment. An exception is the work that has been carried out on earcons for computer games (Jørgensen 2006). The idea of further exploring musical signals for use in auditory interfaces is interesting. Music is used to create atmospheres, express emotions and enhance experiences in various areas such as film and computer games (Fagerlönn 2007). In a computer game a short musical motive can be used to represent hostile presence (Jørgensen 2006). The work which has been carried out on earcons in auditory display research have given us some idea of the potential of using musical signals in user interfaces, but there is much to find out about how to make use of musical expression and meaning when designing sounds for auditory displays. Gaver (1997) outlined that auditory interfaces had so far utilized only a limited amount of the inherent potential in music. In a recently published pilot study Fagerlönn (2007) explored and promoted the potential of using expressive musical earcons, similar to those used in computer games, in user environments.

In previous chapters definitions of different sound types used in auditory display research has been presented. The research area has developed fast, and definitions have been reshaped as ideas have grown and new areas of use have been entered. How the sounds are described, defined and used may differ between authors and type of research. Commonly used terms such as earcons, every-day sounds or musical sounds, which may appear to be obvious at a first glance, can in fact span over very large spectrums of sounds. It is therefore of importance that authors who are working with sound to convey information, and use these terms, are clear about exactly what they stand for in their particular work.

Conclusions

In this paper we have presented the results of a literature study examining some of the currently developing approaches to the design of auditory displays and auditory warning signals. The intention of this study was to look into the progress which has taken place of this branch of sound design research, identify issues related to this type of research, and to point out some new potential ways to design warning signals. Most work which has been done in this area has been carried out in controlled environments, focusing on advantages and disadvantages with specific sound types. Although the concept of using very familiar environmental sounds might be a very effective way to convey critical information, one conclusion is that no type of sound can be the best information carrier in all situations. Also, this is still a young research field, and there are several potential ways to map information to sound which have not been investigated. Further exploring the potential of musical signals has been proposed in research and is definitely interesting from various aspects, especially when one considers how music is used in other areas such as movies and computer games. New effective and redundant warning signals might also be achieved by combining sound types and mapping methods into new kinds of sound. The study further proposes that there exists a uncertainty regarding

definitions of working terms that are used in this branch of research, and that auditory display researchers and sound designers would probably benefit from taking a more user-centred approach, utilizing sound design methods that do not focus on specific sound types, and their limitations.

7 References

- Blattner, M., Sumikawa, D. & Greenberg, R. 1989. Earcons and Icons: Their Structure and Common Design Principles, *Human-Computer Interaction*, 4, 1, 11-44.
- Block, F.E., Nuutinen, L., Ballast, B. 1999. Optimization of alarms: A study on alarm limits, alarm sounds and false alarms intended to reduce annoyance. *J Clin Monit Comput*, 15, 2, 75-83.
- Brewster S.A. 1994. Providing a structured method for integrating non-speech audio into human-computer interfaces. University of York, UK.
- Brewster, S, Raty, V.P. Kortekangas, A. 1996. Earcons as a Method of Providing Navigational Cues in a Menu Hierarchy. In *Proceedings of the Eleventh Conference of the British Computer Society Human Computer Interaction Specialist Group - People and Computers XI*, London, UK. pp. 169-183.
- Brewster, S. Wright, P.C. Edwards, A. 1993. An Evaluation of Earcons for Use in Auditory Human-Computer Interfaces. In *Proceedings of the ACM CHI 93 Human Factors in Computing Systems Conference*, Amsterdam, The Netherlands. pp. 222-227.
- Bussemakers, M.P. De Haan, A. 1998. Using Earcons and Icons in Categorisation Tasks to Improve Multimedia Interfaces. In *Proceedings of ICAD 1998*. Glasgow. UK.
- Bussemakers, M.P. De Haan, A. 2000. When it Sounds like a Duck and it Looks like a Dog... Auditory icons vs. Earcons in Multimedia Environments. In *Proceedings of ICAD 2000*. Atlanta. USA.
- Conversy, S. 1998. Ad-hoc synthesis of auditory icons. In *proceedings of ICAD 1998*. Glasgow, UK.
- Edworthy, J. 1994. The design and implementation of non-verbal auditory warnings. *Applied Ergonomics*, 25, 202-210.
- Fagerlönn, J. 2007. Expressive musical warnings signals. In *Proceedings of ICAD 2007*. Montreal. Canada.
- Gaver, W.W. 1986. Auditory icons: Using sound in computer interfaces. *Human-computer Interaction*, 2, 2, 167-177.
- Gaver, W. W. 1997. Auditory interfaces. In M. G. Helander, T. K. L. Landauer & P. Prabhu. *Handbook of Human-Computer Interaction*. Amsterdam: Elsevier Science. Second Edition.
- Graham, R. 1999. Use of auditory icons as emergency warnings: evaluation within a vehicle collision avoidance application. *Ergonomics*, 42, 1233-1248.
- Jørgensen, K. 2006. On the Functional Aspects of Computer Game Audio, In *proceedings of Audio Mostly 2006*. Piteå. Sweden.
- Leung, Y.K., Smith, S., Parker, S., Russell, M. 1997. Learning and retention of auditory warnings. In *Proceedings of ICAD 1997*. Palo Alto. USA.
- McGookin, D. 2004. Understanding and Improving the Identification of Concurrently Presented Earcons. University of Glasgow. UK.
- McKeown, D. 2005. Candidates for within-vehicle auditory displays, In *proceedings of ICAD 2005*, Limerick, Ireland.
- Patterson, R. D. 1982. Guidelines for auditory warning systems on civil aircraft. Paper No. 82017. Civil Aviation Authority. London.

- Pirhonen, A. Murphy, E. Graham, M. Wai, Y. 2006. Non-speech sounds as elements of a use scenario: a semiotic perspective. In Proceedings of ICAD 2006. London. UK.
- Sikora, C.A. Roberts, L.A. Murray, L. 1995. Musical vs. Real world feedback signals. in Proceedings of CHI'95, Denver, pp 220-221
- Smith S.E., Stephan K.L., Parker, S. 2004. Auditory Warnings in the Military Cockpit: A Preliminary Evaluation of Potential Sound Types. Technical report, Department of defence, Defence science and technology organisation, Edinburgh, Australia.
- Stevens C., Brennan D. & Parker S. 2004. Simultaneous manipulation of parameters of auditory icons to convey direction, size and distance. In Proceedings of ICAD 2004. Sydney. Australia.
- Stevens, C., Perry, N., Wiggins, M. & Howell, C. 2006. Design and Evaluation of Auditory Icons as Informative Warning Signals. ATSB transport safety report. Sydney. Australia.
- Ulfvengren, P. 2007. Design of Natural Warning Sounds. In proceedings of ICAD 2007, Montreal, Canada.
- Walker, B. N., Nance, A., Lindsay, J. 2006. Spearcons: Speech-based Earcons Improve Navigation Performance in Auditory Menus. In Proceedings of ICAD 2006. London. UK.