SOUNDSCAPES FOR IN-VEHICLE TECHNOLOGIES

KatieAnna E. Wolf

Princeton University
Princeton, NJ, USA
kewolf@princeton.edu

Michael A. Nees

Lafayette College
Easton, PA, USA
neesm@lafayette.edu

ABSTRACT

Auditory displays have been implemented with some success in a variety of in-vehicle technologies. Most of these applications have used discrete alerts and warnings, which present complications with false alarms and annoyance. Some research has suggested that on-going, continuous information displays may mitigate some of the problems with discrete alerts and warnings. We argue that well-designed naturalistic soundscapes offer a potentially useful means of continuous auditory display for in-vehicle technologies. We present examples of use scenarios and demonstrations of candidate sound manipulations for conveying information with soundscapes. We argue that soundscapes could be used in a variety of in-vehicle technologies, including displays of vehicle and driver conditions, collision and hazard warnings, infotainment systems, and automated systems.

1. INTRODUCTION

Auditory displays have been deployed with some success in various in-vehicle applications, most commonly in the form of auditory warnings and alerts (for a review, see [1]). Warnings and alerts are usually distinct, brief sounds that direct attention to a discrete system event that requires an immediate response (e.g., an impending collision).

A number of design complications emerge with discrete auditory alerts and warnings. Annoyance is a serious concern with auditory displays [1], [2]. Discrete alarms maybe especially problematic in this regard (see [3]). In high numbers, warnings can interfere with other audio communications and induce negative affect and stress [3][4]. Warnings are appropriate for infrequent events, as a proliferation of warnings, especially for noncritical events, results in annoyance and disuse—characterized by disabling or ignoring the warnings [5][6]. The primary source of overuse of alarms seems to be false alarms—alarms that are triggered frequently in the absence of a critical event that requires immediate action [7].

Consider, for example, a crash avoidance system that alerts the human operator to potential dangers. Given that crashes have extremely negative consequences, the designer may choose to err on the side of triggering alerts liberally at the hint of a possible collision rather than risk failing to alert the driver to a possible collision. We know, however, that the base rate of accidents is low, so most alerts will be false alarms (see [8]). Sorkin and Woods argued that false alarms result in less than optimal human monitoring strategies whereby the operator either (1) samples—or attends to—only some of alerts; or (2) attends to all alerts, but with reduced attention. Sorkin and Woods suggested providing the human operator continuous information about the system status rather than binary information triggered by a preset status criterion. Later research [9][10] found benefits of such approaches, dubbed *likelihood alarm systems*. As such, some of the shortcomings of discrete warnings triggered by system failures could be overcome with displays that provide on-going, information to the user [11].

The auditory modality is well-suited for presenting on-going peripheral displays that provide continuous information about the state of the system processes [12]. Data sonification, soundscapes, and ambient auditory displays are tenable candidate approaches to continuous auditory displays. Watson and Sanderson, for example, demonstrated the value of continuous sonification for monitoring variables relevant to anesthesiology during simultaneous secondary tasks [13], and Seagull et al. [14] showed that continuous auditory displays allowed for adequate monitoring performance. Though auditory monitoring performance was worse than conditions monitoring visual displays, the auditory monitoring condition allowed for considerably better performance on a concurrent visual tracking task that overshadowed the advantages of visual monitoring.

Annoyance, however, remains a major concern with continuous auditory displays. As Kramer [2] described, "…it is a familiar experience of people working in AD that a sonification will be running and it becomes sufficiently annoying that we just turn it off to take a break. Likewise, overly simple, intrusive, or simply unpleasant auditory computer interfaces are turned off, even if they have some utility" (pp. 52). This concern may be particularly relevant for in-vehicle technologies. It is unclear whether drivers and passengers would accept on-going sonifications, and this problem may increase to the extent that continuous auditory displays are perceived to be artificial and intrusive. Sanderson, Anderson, and Watson [15] presented a simple model that related possible system and operator states to outcomes with continuous auditory displays. Ideally, system states and operator states align to accomplish system goals in two ways: (1) the continuous auditory display is relegated to peripheral attention during normal or routine system operations, and this backgrounding (see [2]) of the auditory display allows the human operator to proceed with secondary cognitive tasks with little interference; and (2) the continuous auditory display attracts the focus of attention during abnormal system states that require intervention. Problems arise if: (1) the auditory display remains in the background or periphery of attention during abnormal system states; or (2) the auditory display attracts the focus of attention and interferes with other cognitive tasks during routine or normal system states. With continuous auditory displays, a delicate balance must be achieved such that the sounds are subtle enough to be relegated to peripheral attention, yet pronounced enough to call attention to themselves during critical events. To this end, continuous auditory displays that synthesize more naturalistic sounds warrant consideration for use for in-vehicle technologies.

2. THE CASE FOR SOUNDSCAPES

Mauney and Walker [16] presented a prototype system that represented stock data continuously by modulating changes in synthesized natural sounds such as rain, cicadas, and crickets. These artificial *soundscapes* were designed to display on-going feeds of data in the auditory periphery (also see [17]). Vickers et al. [18] supported soundscapes as a viable auditory interface for process monitoring and situational awareness of networks, primarily because they have the potential to communicate information while also being less fatiguing than other auditory interfaces. Work continues in this area toward developing models for translating data to customizable soundscapes [19], but perceptual and usability evaluations seem to have been limited to the brief initial interviews conducted by Mauney and Walker.

3. PROTOTYPE SOUNDSCAPES AND USE SCENARIOS FOR IN-VEHICLE TECHNOLOGIES

Similar to Wolf et al. [19], we conceptualize soundscapes as a hierarchy of sounds where each soundscape is broken into groups that contain all of the sound samples (i.e. recordings) from the same acoustical source. For instance, all of the recordings from a frog would be in the frog sound group. Additionally, they used terminology such as interval and instant sounds to represent sounds that are played continuously throughout a soundscape and those that occur at discrete intervals respectively. We will refer to these sounds as continuous and event-based. Using this terminology, we present design ideas and prototypes of natural soundscapes that could be used in the varying scenarios for in-vehicle technologies.

3.1. Alerts for Vehicle and Driver Conditions

When alerting a driver of vehicle and driver conditions (i.e. speed alerts, energy consumption, etc.), a system might only seek to inform the driver of an ongoing process, which may or may not require the driver to take immediate action (or any action at all). We can present the display in the form of a continuous soundscape that can be brought to the attention of the driver when they are interested in the information, but that can also fade into the background when not needed.

We present a number of soundscape examples that demonstrate the continuous passive conveyance of information. At a very basic level, a soundscape might include only a sound group or two to represent information. For example, changes in speed could be represented by changes in the gain of a recording (streamGainDemo.wav), changes in the number of layers of a recording to adjust the density of a sound (streamLayersDemo.wav), or changes in the playback rate of a recording (streamRateDemo.wav). Additionally, we can include multiple layers of a soundscape by adding sounds groups that do not convey information, but are there simply to create a more aesthetic appeal (cricketsWithOtherSounds.wav). On the other hand, these layers could be used as alerts to augment the information represented by the continuous sounds. In example (cricketsWithAlerts.wav), we use increasing gain of the stream to represent continuously updating data (e.g. speed), while specific events in the data (e.g. going above target speeds) trigger different event-based sound groups to play, such as the thunder, birds, and flies. When we include these alerts, we can randomize the selection of the sample used (if there are multiple samples from the same sound group), to allow for less predictability in the soundscape, making it potentially less fatiguing. These types of alerts differ from the discrete auditory alerts discussed in Section 1 as they fit into the context of the soundscape (assuming that the sound groups are taken from the same environmental location) and may therefore be less annoying.

The main goal with using soundscapes in this scenario is to provide information to the driver that they can passively observe without having their attention negatively drawn to the sounds in an obtrusive manner. It would be interesting to explore whether these sounds could positively affect the driver by creating a more relaxed driving environment.

3.2. Collision Avoidance and Hazard Warnings

Warnings used for collision avoidance and driving hazards typically indicate an unsafe driving scenario that requires the driver to take immediate action [1]. We can use the continuous feedback in the form of soundscapes to provide users with a passive, non-fatiguing way to monitor their situation, yet confront them with urgent information when the risk of a collision or a driving hazard becomes great.

We propose a few methods for presenting this urgent information using soundscapes. First, the sounds could gradually take on an unnatural aesthetic that we believe would bring the soundscape to the forefront of a user's attention. In one of our examples (frogsHighRate.wav), the playback rate of a recording of a frog is adjusted higher than the typical range to produce an unnatural pitch. There are several other ways in which we can create these "unnatural" sounds in order to bring the soundscape to the users attention (e.g. applying filters and other modulations). In addition to unnatural sounds, we can introduce sounds that are out of place in that sound environment to indicate to the driver that conditions are changing. For instance, in a forest soundscape with a stream and crickets, the sound of a dolphin is out of place (cricketsWithDolphin.wav). One concern with this type of alert is similar to the concerns of the discrete auditory alarms presented in Section 1, mainly that they may be annoying and the user will turn them off.

Another way we can present urgent information using soundscapes is by adding more layers to the soundscape to give an indication that the risk of a hazard or collision has increased. Example (cricketsWithFrog.wav) demonstrates the addition of the frog sound on top of the crickets to indicate a change in the data. We can even have these added sounds be "unnatural", as in example (crickets-WithUnnaturalFrog.wav).

In this scenario, the main focus is to provide clear information to the driver in moments of high urgency, while otherwise being unobtrusive and potentially relaxing, as in the previous scenario. While soundscapes have great potential for passive monitoring, there are many ways that we can use sound to intrude on that passivity and alert users that they need to take immediate action. It will still need to be investigated whether these manipulations and intrusions for this scenario work better than other sounds presented in previous work.

3.3. Infotainment

Similar to alerts for vehicle and driver conditions, alerts for various infotainment sources (e.g. email and social network) should allow for passive monitoring of information to allow the driver to focus on the primary task of controlling the vehicle. Wolf et al. [19] have presented a prototype for sonifying data from the social network Twitter using soundscapes, with a particular focus on allowing the end-user to play a role in the design of the sonification. Their examples include having a particular event-based sound group represent a specific person (i.e. the nightingale bird chirp representing a tweet or an email from a particular colleague), or continuously monitoring a particular trend in the data. Examples for this scenario are very similar to those in Section 3.1. For instance, instead of monitoring the speed of the vehicle, we could monitor the volume of tweets for a particular trending topic.

This leads to another interesting application of soundscapes for in-vehicle technologies, which is that they can provide a way to encrypt and anonymize the data. The driver may know that the nightingale means that an email was received, but others in the vehicle may simply perceive it as an aspect of the soundscape.

3.4. Monitoring Automation Status

Finally, we suggest that soundscapes may be able to promote situation awareness during periods of automation in self-driving vehicles. Even during highly automated driving scenarios, the vehicle operator may need to resume manual control from the system in the event that automated systems falter (see, e.g., [20]). Norman [21] argued that difficulties with automation could be alleviated by "continual feedback about the state of the system, in a normal natural way" (pp. 8). Indeed, research has shown that continuous feedback about the status of the system results in better performance in resuming control from automation. Helldin et al. [22] displayed a global measure of the autonomous driving system's uncertainty using a visual meter. Performance metrics suggested that participants with knowledge about the automation status were better able to resume manual control of the vehicle and also better able to safely engage in secondary tasks (also see [23]). Seppelt and Lee [24] observed similar performance benefits when adaptive cruise control (ACC) systems—an example of partial automation—provided users with on-going information about the automation's status. Further, people seem to be more forgiving and willing to continue to use imperfect automation if they are aware of the reasons for automation failures [25]. Research also has shown that human operators are more trusting and accepting of automation that provides them with feedback and information about the actions being executed by the automation [26]. As such, various combinations of the soundscape examples described above could be implemented to display data from sensors and algorithms in automated driving systems to keep the driver "in the loop" regarding the status of automated systems.

4. CHALLENGES WITH USING SOUNDSCAPE FOR IN-VEHICLE TECHNOLOGIES

While soundscapes offer a possibility for a continuous auditory display that could be useful for in-vehicle technologies, there are some unique aspects of soundscapes that should be considered in the development of these displays. As soundscapes consist of "real-world" sounds, there could be an intersection between the sounds in the soundscape and informative incidental sounds in the real world. For example, rainfall representing in-vehicle data could be difficult to perceive if it was actually raining outside. This is a difficulty of using soundscapes for any auditory display, and work by Wolf et al. [19] seeks to over come these sorts of difficulties by allowing users to play a more direct role in the creation of auditory displays. Additionally, as with any in-vehicle auditory display, it is important that the sounds in the soundscape do not interfere with a user's ability to detect potential problems with the car itself.

5. FUTURE DIRECTIONS AND CONCLUSIONS

Soundscapes may offer a useful approach to auditory display for in-vehicle technologies, as they may be able to overcome some of the limitations of discrete auditory alerts and warnings as well as other, less naturalistic forms of continuous sonification. More research is needed, however, as perceptual-cognitive and usability of evaluations of soundscapes have been limited to this point. Direct comparisons of soundscapes to other forms of display, including visual displays, discrete auditory displays, and other forms of continuous auditory display are warranted. Further, given the dearth of research on soundscapes, more research is needed to determine best practices in the design of soundscapes.

6. REFERENCES

[1] M. A. Nees and B. N. Walker, "Auditory displays for in-vehicle technologies," in *Reviews of Human Factors and Ergonomics*, P. Delucia, Ed. Thousand Oaks, CA: Sage Publishing/Human Factors and Ergonomics Society, 2011, pp. 58–99.

[2] G. Kramer, "An introduction to auditory display," in *Auditory Display: Sonification, Audification, and Auditory Interfaces*, G. Kramer, Ed. Reading, MA: Addison Wesley, 1994, pp. 1–78.

[3] J. Edworthy and E. Hellier, "Auditory warnings in noisy environments," *Noise and Health*, vol. 2, no. 6, pp. 27–39, 2000.

[4] J. Edworthy, "Does sound help us to work better with machines? A commentary on Rautenberg's paper 'About the importance of auditory alarms during the operation of a plant simulator,'" *Interacting with Computers*, vol. 10, pp. 401–409, 1998.

[5] R. Parasuraman and V. Riley, "Humans and automation: Use, misuse, disuse, abuse," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 39, no. 2, pp. 230–253, Jun. 1997.

[6] R. D. Sorkin, "FORUM: Why are people turning off our alarms?" *The Journal of the Acoustical Society of America*, vol. 84, no. 3, pp. 1107–1108, Sep. 1988.

[7] C. Meredith and J. Edworthy, "Are there too many alarms in the intensive care unit? An overview of the problems," *Journal of Advanced Nursing*, vol. 21, no. 1, pp. 15–20, 1995.

[8] R. Parasuraman, P. A. Hancock, and O. Olofinboba, "Alarm effectiveness in driver-centred collision-warning systems," *Ergonomics*, vol. 40, no. 3, pp. 390–399, 1997.

[9] R. D. Sorkin, B. H. Kantowitz, and S. C. Kantowitz, "Likelihood Alarm Displays," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 30, no. 4, pp. 445–459, Aug. 1988.

[10] R. Wiczorek and D. Manzey, "Supporting Attention Allocation in Multitask Environments Effects of Likelihood Alarm Systems on Trust, Behavior, and Performance," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 56, no. 7, pp. 1209–1221, Nov. 2014.

[11] Y. Xiao and F. J. Seagull, "An Analysis of Problems with Auditory Alarms: Defining the Roles of Alarms in Process Monitoring Tasks," *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 43, no. 3, pp. 256–260, Sep. 1999.

[12] P. Vickers, "Sonification for process monitoring," 2011.

[13] M. Watson and P. M. Sanderson, "Sonification helps eyes-free respiratory monitoring and task timesharing," *Human Factors*, vol. 46, no. 3, pp. 497–517, 2004.

[14] F. J. Seagull, C. D. Wickens, and R. G. Loeb, "When is less more? Attention and workload in auditory, visual, and redundant patient-monitoring conditions," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 2001, vol. 45, pp. 1395–1399.

[15] P. Sanderson, J. Anderson, and M. Watson, "Extending ecological interface design to auditory displays," in *Proceedings of the 10th Australasian Conference on Computer-Human Interaction*, 2000, pp. 259–266.

[16] B. S. Mauney and B. N. Walker, "Creating functional and livable soundscapes for peripheral monitoring of dynamic data," 2004.

[17] B. N. Walker, M. T. Godfrey, J. E. Orlosky, C. Bruce, and J. Sanford, "Aquarium sonification: Soundscapes for accessible dynamic informal learning environments," 2006, pp. 238–241.

[18] P. Vickers, C. Laing, M. Debashi, and T. Fairfax, "Sonification Aesthetics and Listening for Network Situational Awareness," *arXiv:1409.5282 [cs]*, Sep. 2014.

[19] K. E. Wolf, G. Gliner, and R. Fiebrink, "End-user development of sonifications using soundsacpes," in *Proceedings of the International Conference on Auditory Display (ICAD2015)*, Graz, Austria.

[20] N. Merat, H. A. Jamson, F. Lai, and O. Carsten, "Human factors of highly automated driving: Results from the EASY and CityMobil Projects," in *Road Vehicle Automation*, G. Meyer and S. Beiker, Eds. Springer International Publishing, 2014, pp. 113–125.

[21] D. A. Norman, "The 'Problem' with Automation: Inappropriate Feedback and Interaction, not 'Over-Automation,'" *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, vol. 327, no. 1241, pp. 585–593, Apr. 1990.

[22] T. Helldin, G. Falkman, M. Riveiro, and S. Davidsson, "Presenting system uncertainty in automotive UIs for supporting trust calibration in autonomous driving," in *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 2013, pp. 210–217.

[23] J. M. McGuirl and N. B. Sarter, "Supporting trust calibration and the effective use of decision aids by presenting dynamic system confidence information," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 48, no. 4, pp. 656–665, 2006.

[24] B. D. Seppelt and J. D. Lee, "Making adaptive cruise control (ACC) limits visible," *International Journal of Human-Computer Studies*, vol. 65, no. 3, pp. 192–205, 2007.

[25] M. T. Dzindolet, S. A. Peterson, R. A. Pomranky, L. G. Pierce, and H. P. Beck, "The role of trust in automation reliance," *International Journal of Human-Computer Studies*, vol. 58, no. 6, pp. 697–718, Jun. 2003.

[26] F. M. F. Verberne, J. Ham, and C. J. H. Midden, "Trust in Smart Systems Sharing Driving Goals and Giving Information to Increase Trustworthiness and Acceptability of Smart Systems in Cars," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 54, no. 5, pp. 799–810, Oct. 2012.

All of the sound samples are from freesound.org. The full attribution is listed in the table below.

Sound	Sound Title	User	URL
stream	Distant stream 1	Adam_N	https://www.freesound.org/people/Adam_N/
nightingale	nightingale	viaaico2013	https://www.freesound.org/people/viaaico2013/
frog	Frogs	juskiddink	https://www.freesound.org/people/juskiddink/
thunder	Distant Thunder	sean.townsend	https://www.freesound.org/people/sean.townsend/
wolf	Wolf Howl	Gorgoroth6669	https://www.freesound.org/people/Gorgoroth6669/
owl	Tawny Owls 2	Benboncan	https://www.freesound.org/people/Benboncan/
fly	flys-l	galeku	https://www.freesound.org/people/galeku/
crickets	crickets	FreethinkerAnon	https://www.freesound.org/people/FreethinkerAnon/