Report on the In-vehicle Auditory Interactions Workshop: Taxonomy, Challenges, and Approaches

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AutomotiveUI '15 Adjunct, September 1-3 2015, Nottingham, UK

http://dx.doi.org/…

Abstract

As driving is mainly a visual task, auditory displays play a critical role for in-vehicle interactions. To improve in-vehicle auditory interactions to the advanced level, auditory display researchers and automotive user interface researchers came together to discuss this timely topic at an in-vehicle auditory interactions workshop at the International Conference on Auditory Display (ICAD). The present paper reports discussion outcomes from the workshop for more discussions at the AutoUI conference.

Author Keywords

Auditory displays; Automated driving; Collision warnings; Fuel-economic driving; Infotainment

ACM Classification Keywords

H.5.2. [Information interfaces and presentation (e.g., HCI)]: User Interfaces; Sound and Music Computing – methodologies and techniques.

Introduction

The advance of technology has opened a new era of vehicles, such as connected, electrical, and automated vehicles. Given that driving is a visually demanding task, auditory displays have provided clear advantages and have been adopted in vehicles. However, we can improve in-vehicle interactions to a more advanced level in order to offer better driver experience in rapidly

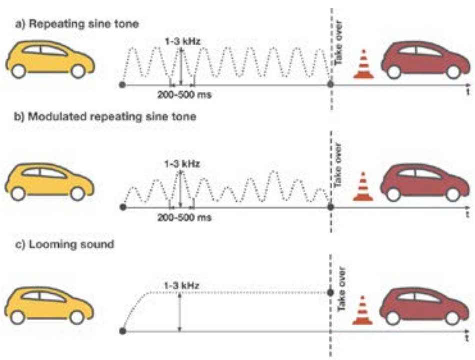

Figure 1. Proposed designs of auditory displays for TOR in HAD.

Table 1. Proposed designs of auditory displays for TOR in HAD.

A. Repeating hann-enveloped sine tone notes ("pleasant");
B. Repeating hann-enveloped sine tone notes (A) with longer overall hann envelope ("pleasant");
C. Repeating hann-enveloped sine tone notes with longer overall hann envelope (B) and triangle wave ("annoying");
D. Modulated repeating feedback sine tone with hann envelope ("annoying");
E. Modulated repeating feedback sine tone with hann envelope (D) with sudden cutoff ("annoying");

changing vehicle environments. To this end, researchers of two communities – auditory display experts and automotive user interface experts – jointly hosted the first workshop on in-vehicle auditory interactions on July 6th, 2015 in the 21st International Conference on Auditory Display (ICAD2015) in Graz, Austria. This full day workshop attempted to intermingle participants, present conceptual in-vehicle auditory displays, discuss challenges and issues, and integrate ideas. In total, 30 organizers and participants attended the workshop from nine countries. Workshop papers brought up various discussion topics on in-vehicle auditory interactions, including a taxonomy of in-vehicle auditory interactions, sonification strategies (e.g., continuous soundscapes, implicit auditory displays, and target matching auditory displays), specific application areas (e.g., infotainment menu navigation, augmentation of drivability in electric vehicles, take-over requests in automated vehicles), and research frameworks for implementation (a software library for in-vehicle auditory displays) and evaluation (questionnaire factors). For more details of the workshop papers, see the workshop proceedings [1].

In the present paper, we report the outcomes of the workshop with a focus on discussion results. We had two successive discussion sessions at the workshop. In the first session, participants tried to identify taxonomies and structure of in-vehicle auditory interactions and in the second session, participants had in-depth discussions about sonification strategies and design the actual auditory displays for specific situations. There were four discussion tables according to topics: 1) auditory displays for electric/automated driving, 2) auditory displays fuel efficiency, 3) auditory displays for infotainment, and 4) collision warnings.

Discussion Outcomes

Auditory Displays for Electric/Highly Automated Driving

Most electric vehicles produce little noise, and many of such vehicles employ artificial engine sound. In the discussion, a more advanced interface was suggested, where the sound is amplified as a function of the environment around the vehicle. Next, we focused more on (semi-) automated driving. In the discussion on the use of auditory interfaces for highly automated driving (HAD), auditory interfaces for low criticality ("friendly" interfaces) and high criticality, such as take-over requests or TORs ("urgent" interfaces) were discussed. Figure 1 shows three possible designs for such interfaces as outlined in the discussion: a) repeating sine tone; b) modulated repeating sine tone, with gradual increase of pitch followed by gradual decrease of pitch; and c) looming sound, in which pitch increases and stays at a maximum level until the end of the TOR. The yellow car is the vehicle where a TOR is received while the red car represents a stationary vehicle, a reason for generating a TOR. The length of one message in cases *a* and *b* was set to be 200–500 ms. All three kinds of interfaces were said to be in the range 1–3 kHz, with the loudest point of the looming sound at 3 kHz. It was defined that the sounds should in principle be non-directional. However, we also discussed the possibility of implementing spatial sounds, which can carry information on the relative location of the reason for receiving a TOR. The intensity of the interface received a lot of attention during the discussion and a number of concepts of such sounds were created. The prototypes, available in the supplementary material, feature amplitude of both "pleasant" (low criticality) and "annoying" (high criticality) intense sounds (see Table 1). Next, we discussed the location of the reason for generating a TOR (e.g., an exit from the highway or a traffic accident) as a parameter for the design of the interface. It was suggested that auditory cues generated behind the driver are ambiguous, and that they may result in unpredictable actions.

Auditory Displays for Fuel Efficiency

The discussion on sonification for supporting fuel-economic driving yielded extensive outcomes about new approaches for the creation of interactive soundscapes. The participants weighted ecological arguments stronger than economic arguments. A 'free wish from the participants' brainstorming resulted in manifold ideas, including: a) using the existing soundscape of a car (e.g. the sound of the engine or the music the driver listens to) as a basis for a (blended) sonification; b) sonification could enhance the experience of sportiveness of the car, so that the need for an agile driving style is already satisfied at a less energy-wasting driving style; c) the music playback quality could be enhanced in episodes of "good" driving behavior or subliminally degraded in episodes of high fuel consumption, providing an incentive to drive more economically; d) front/rear spatial cues in the sound could provide indices to reorient the drivers, e.g., for indications of appropriate speed; e) trying to manipulate the perception of the engine sound so that higher consumptions sound less 'healthy'; and f) the 'running out' / loss of fuel would manifest in a sonic movement of emptying / loss, e.g., decreasing pitch. In a design focus session, we defined in more detail a novel sonification type, provisionally called "Interactive Music Filtering for continuous eco-driving feedback," which elaborates the second approach above. An approach in this line will be tested and published elsewhere. However, the core ingredients are four types of manipulations: a) changing the spectrum (low/highpass filter), b) adding degradation cues (such as gramophone needle cracking), c) spatial cues (such as shifting from the center to front or rear), and d) modulations (e.g., amplitude modulations that has a stuttering as extreme manifestation). Careful inspection of the sonic parameters in light of the available data led us to the initial choice to us a) for gearshifts, b) for the (temporary) display of high energy use, c) for speed recommendations, and d) for instantaneous fuel consumption.

Auditory Displays for Infotainment

For secondary or tertiary tasks, our discussions revolved around three different themes: the data to be displayed, the people doing the listening, and the sounds used to convey the data. In terms of the data, we discussed variations on navigation and route finding that use non-speech auditory cues to assist and remind the driver of future directions, while considering driver preferences and utilizing auditory beacons and spatial audio. We considered data about the driver including driver experience level, sound and driving preferences, and driver condition (e.g., health issues, tiredness, and hydration). We also discussed infotainment data about a driver's social network feed, emails, etc. In the end, we wondered how we might be able to influence people to take the proper action when they receive notifications that need direct attention. If the vehicle includes smart technology to limit a driver's actions, then we need to consider how to balance the system to keep it from being an over-protective "nanny" system. The people that are listening to the auditory displays may be various types of drivers (e.g., car drivers, truck drivers, public transit drivers, inexperienced drivers, etc.) or they might be passengers (e.g., other adults, children, etc.). Typically, auditory displays have been built for the drivers, but we also considered how passengers might be able to convey information about himself or herself to the driver or assist them in driving. If the passengers (or those who we might be on the telephone with) are informed about the driving conditions, they may be able to assist the driver in keeping their attention on the road when it needs to be. Additionally, there may be cases where a driver would find it useful to have an auditory display about the state of the passengers, especially if they are very young children or if there are a large number of them (i.e., public transit). Finally, we discussed sounds. The use of time, space, and motion could be used to represent data of varying degrees of importance. Sounds that are "close" to the driver or in the front may be more important since they might be a bit more intrusive and attention grabbing. Similarly, moving sounds could convey information based on the velocity of their movement. The sounds could be used to navigate the driver by using spatial information about where the driver should be, or a continuously sounding beacon could use spatialization to convey the final location of the destination.

Auditory Displays for Collision Warnings

We also brainstormed a taxonomy of relevant issues and characteristics of in-vehicle auditory warnings for collision hazards. Types of auditory warnings can include: a) discrete sonification – earcons, auditory icons (AI), and speech; and b) constant sonification – soundscape or interactive sonification. The constant sonification, however, could be annoying, and possibly difficult to understand. Perhaps, it would be best if it is only used when the driver shows intention to change or merge lanes. Multiple vehicle speakers can display a localized auditory warning with directional (and distance) information about the hazard's location in reference to the driver's vehicle: in front, either side (left or right), and rear. Situations that would benefit from auditory displays include parking, lane change or merging into another road (intended), lane departure (unintended), other vehicle encroaching in the driver's lane, city driving (densely populated area), highway driving (less eventful, but more deadly due to fatiguing vigilance and higher speeds), approaching a turn or exit at unsafe velocity, any loss of control of the car (wet or snowy roads, or low visibility), etc. The object of the hazards (different hazards call for different responses in driving behavior) was also discussed: animals, pedestrians, bicycles, motorcycles, cars, large 18 wheelers, trains, and physical barricades. Next, we discussed what information the warning should convey. Most accidents require driver attention and action in fractions of a second. Ideally, a single sound could describe both the specific nature of the hazard and the recommended course of action to avoid the hazard. Possible auditory warnings were suggested: a) one short warning: (urgent sounding earcon or AI, or speech e.g., "STOP!") from the direction of hazard). It is intended to inform the driver to reduce speed immediately. This type of warning can work in a wide variety of situations; b) one short warning from the rear of the vehicle to urge the driver to speed up. This is only displayed if stopping or slowing down is not appropriate, as in a case of someone running a red light or hazard coming from the rear of the vehicle; and c) an additional "beacon" (of a more pleasant sound) could be provided to suggest a direction the driver should travel towards to avoid the hazard/collision. We can also convey the distance of hazard with a presentation rate of an earcon, or low pass filter on either the earcon or the AI. The farther away, the larger frequency band is filtered to imitate a faraway hazard. Taxonomy of AIs to describe the type of hazard was also discussed: train horn, 18 wheeler horn, tire screeching, car horn, footsteps, and bicycle bell.

Conclusion

We tried to model driver-vehicle (and vehicle contexts) interactions from the perspective of auditory displays. We believe that intermingling of the two separate communities will contribute to designing better in-vehicle auditory interactions theoretically and practically. The next step could be prioritizing the signals among auditory displays for a number of situations and constructing an optimal layout of the various displays across different modalities (e.g., visual, tactile/haptic, and auditory).

Acknowledgements

This workshop was partly supported by Michigan Tech Transportation Institute. We also thank Daria Nikulina for designing Figure 1.

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