"SLOWIFICATION": AN IN-VEHICLE AUDITORY DISPLAY PROVIDING SPEED GUIDANCE THROUGH SPATIAL PANNING

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ABSTRACT

We present a novel in-vehicle sonification for providing immediate feedback about the current vehicle speed in consideration of prescribed speed limits and common driving practices. The key conceptual idea of our "Slowification" auditory display is to assume that the sound of the car (i.e. the car's audio system) travels with the allowed resp. expected speed and to virtually position the driver into this space according to the car's current speed, resulting in a sound which moves to the back as one drives faster than allowed and catches up on slowing down. Further changes of the sound for excessive deviations complement this design.

We evaluated the Slowification system in a virtual reality based car simulator delivering realistic soundscapes of both engine and media sound placement, showing that it indeed helps the user to drive within speed limits and additionally provides less distraction than a conventional visual speed display. Questionnaire results furthermore indicate that users easily accepted this novel auditory display as an unobtrusive in-vehicle user interface.

1. INTRODUCTION

Especially when considering the mostly rather hectic urban traffic, car driving is not only a visually demanding task, but also one that is safety-critical for both the driver and other road users. Additionally, more and more in-vehicle systems are being integrated into the car, which almost exclusively rely on visual indicators for interacting with the driver.

For this reason, recent research efforts have targeted the *auditory* domain for in-vehicle interaction (e.g. [1, 2]). The soundscape of a car, however, is also a difficult environment to deal with, as we have to take into account a wide variety of background noises coming from the engine, the wind, and the tires. Additionally, many people are listening to music or utilize a navigation system, which guides the driver using speech notifications. In consequence, the majority of auditory cues used in the car are of rather salient nature, e.g. the sounds used in parking assistance systems or the distinct but admittedly fairly unpleasant noise to indicate that the driver should fasten the seatbelt. Similarly, indication that a driver is exceeding a prescribed speed limit, provided for example by a navigation system, is commonly conveyed by quite salient auditory notifications.

Based on these observations, we propose to use the existing soundscape as much as possible when developing auditory interfaces in the car, which in this paper will be realized within our framework of blended sonification [3]. As a concrete application, we present a novel in-vehicle auditory display for indicating the exceeding of a prescribed speed limit based on spatial panning of the car's audio system's sound signal: When a driver has missed a speed sign and is driving too fast, the sound signal of the car's audio system will gradually move from a centered position towards the back of the car. Conveying this information in such a way has three distinct advantages: a) Panning of a sound signal is rather easily perceived and rather difficult *not* to notice, which matches the importance and urgency of the information. b) The meaning of the sound design should quite intuitively be understood, as you get the feeling of driving away from "your" sound (which can be expected to move at the appropriate speed). c) As the composition of sounds is not changed at all by this auditory display, it is very unobtrusive and thus should be easily accepted, which is of major importance when dealing with a sonic environment that so many people are exposed to as it is the case for automobiles.

Similarly, the driver can be notified by a subtle pan towards the front of the car, if he or she is driving (significantly) slower than the current speed limit would suggest. Such a notification will of course only be triggered if there is no vehicle in front preventing to drive faster and could also be made dependent on whether there are any following cars being hindered by the reduced speed.

2. RELATED WORK

2.1. Spatial panning to guide users

Although certainly not used in lots of systems, there are a few instances where spatial panning has been incorporated in user interfaces to inform about an event or point of interest in a certain direction.

Holland and colleagues, for example, developed a GPS navigation system with the goal to allow users to be engaged in different activities while being guided by the system [4]. To this end, they decided to use a non-speech audio interface to encode distance and direction of a location. In their prototype, the direction was represented by spatial panning of a tone based on the current moving direction of the user. Although seemingly coarse, this method yielded good enough results to discern the principal direction in an informal user trial.

In the context of automotives, Fagerlönn et al. evaluated different ways of guiding drivers at the early stage of a dangerous driving situation like an imminent collision with another vehicle [5]. In a study with 24 people, they compared using 1) a mild warning sound, 2) reducing the volume of the vehicle's radio, and 3) panning the radio's signal. The authors conclude that panning the radio led to the lowest response times and, at the same time, was significantly better rated by users than the volume reduction.

2.2. Dynamic Speed Assistance Systems

Although currently the vast majority of speed limits are static (i.e. consist of fixed signs that do not change in terms of position or limit), there are efforts to introduce more dynamic Speed Assistance Systems, which take into account road geometry and vehicle characteristics [6], or upcoming traffic signal information [7].

These systems will make the use of a traditional visual speed display far more difficult, as the drivers will have to deal with constantly changing and non-standarized speed limits, which, in turn, would require the drivers to use another (or additional) interface such as the one presented in this paper.

3. INTERACTION DESIGN

Keeping the speed is an important issue when driving and too often the visual focus of attention is shifted to the speedometer and thus distracted from the outside traffic situation where it should remain. However, speed limits are frequent: in cities, on country roads, close to railway crossings, and speeding is controlled and penalized. Obviously, the existing visual means for providing feedback about the speed via a speedometer is not an optimal choice, as it leads to frequent visual distractions. An interaction design for providing this non-critical yet highly relevant information needs to take the drivers' primary task and required focus into account.

3.1. Auditory Displays

Using an auditory display would be an intuitive choice to approach this monitoring task. And indeed, some navigation systems already signal the exceeding of a speed limit by auditory alerts. These can, however, be experienced as annoying and don't add to the driver's satisfaction (at least subjectively, according to one of the author's experience). Furthermore, these sounds don't represent details about the amount of deviation or significance. Finally, they can't inform drivers about the opposite condition (i.e. driving too slow), for instance when the following traffic is unnecessarily delayed.

Symbolic auditory displays generally require a cognitive processing of information, which in most situations should not pose a problem, since the task of driving can become quite automated and would not require permanent cognitive control. Symbolic communication, however, is necessarily interrupting and risks to be annoying and to create resistance or reactance, which might result in users experiencing these cues as disturbing or paternalizing.

Analogous representations, in contrast, keep users informed at all times, provide an, in most cases less accurate, yet continuous cue about the underlying condition and leave the decision making in the hands of the user/driver. The reason why continuous auditory displays (or sonifications) have not yet been considered for the speedometer is that a continuous sound would most likely be rather annoying in itself (even if we readily accept permanent engine sounds and would even object if they were removed). One might also argue that we already have such a (physical) auditory speedometer in form of the rolling sounds of the wheels. These, however, are not gauged and depend on the street surface. Furthermore, they are masked by other sounds like the car's audio system and the sound of the engine and don't provide information relative to the context, i.e. the prevailing speed limits.

Figure 1: Picture of the car simulator.

3.2. Conceptual idea

The preceding analysis provides the ground for our new innovation: a sonification that works with the existing in-car audio system as source sound to be modified according to the available information. The fact that, in most cases, a car's audio system is quadrophonic in order to allow a fine balance of sound between left/right and front/rear to meet the driver's preferences and that most users listen to music, audiobooks or radio while driving is the technical and conceptual basis for our sonification.

Imagining that the sound of your audio system is not fixed within the car, but instead travels at its own speed, the central idea is that, unlike the car itself, the sound travels exactly as fast as allowed (resp. as recommended), while still being elastically attached to the car's center of mass. One would further assume that the sound would be represented as a "sound bubble", which naturally encompasses the car and the driver. With this (metaphorical) setup, the following conditions can arise:

- If the driver exceeds the speed limit, the sound bubble would fall back and be dragged by the car behind the user by means of the elastic attachment. This situation would naturally lead to the perception of the audio system's sound panning to the rear.
- On the other hand, if the driver goes slower than the allowed tempo and there is both traffic behind and no traffic in front (which certainly can, yet only with additional sensors, be registered), then the sound bubble would travel faster than the driver and lead to a spatial shift of the sound towards the front.
- Finally, if the car's speed is the same (or within tolerance) as recommended, the bubble would be perfectly centered, leading to no audible modification of the sound.

The metaphor would not only allow to determine the spatial location (which, in terms of feedback signals, is an analogous relative corrective cue). It would also allow to coherently manage a number of coupled features, such as decreasing the sound level as the car's distance to the sound bubble's location increases, or to add reverberation, delay or other filtering plausible for distant sound sources. Such subtle cues might add to an enhanced sense of realism in this auditory display and thus improve its perception and also lead to an increased acceptance.

3.3. Prototype implementation

As a first prototype, we implemented a rather straightforward version of the concept described in the previous section. For this, we first defined a measure for driving faster (or slower) than a recommended speed:

$$d(\Delta_v, v_{\text{ref}}, \tau) = \max\left(\alpha \cdot |\Delta_v| + (1-\alpha) \cdot \frac{|\Delta_v|}{v_{\text{ref}}} \cdot v_n - \tau,\ 0\right),$$

where $\Delta_v = v - v_{\text{ref}}$ is the (absolute) difference between the current and a reference speed, α is a weighting factor balancing relative and absolute speed difference, and v_n is a predefined neutral speed, where the (unweighted) relative and absolute speed differences would be the same. In our study (cp. Section 4), we used $\alpha = 0.8$ and $v_n = 70$ kmh. τ is a measure for the tolerated deviation from the reference speed and is used to define a 'speed channel' around v_{ref}, with a lower and and upper bound for going too fast (τ_u) or too slow (τ_l). In our current implementation, we have defined $\tau_l = 3$ and $\tau_u = 5$.

Driving faster than v_{ref} would lead to a gradual spatial shift of the sound towards the back, while driving slower to a shift towards the front of the car. The amount of panning is determined by

$$P_{u/l} = \Phi\left(d(\Delta_v, v_{\text{ref}}, \tau_{u/l})\right) \quad \text{with} \quad \Phi(d) = \rho \cdot \sqrt{d},$$

where $\Phi(d)$ leads to a more noticeable spatial shift after crossing the threshold. In our quadrophonic speaker setup, we pan each stereo channel separately with Supercollider's[1] *Pan2* UGen. Furthermore, if $P > 1$, the volume of the audio signal will be reduced by $\nu_{\text{db}} \cdot (P - 1)$, indicating a further movement of the sound bubble towards the respective direction (cp. Section 3.2). For the study, $\nu_{\text{db}} = 25$ and $\rho = 0.2$.

Finally, when dealing with changing speed limits or even traffic lights, the bounds of the speed channel further deviate: As it is common practice for a driver to 'coast' (i.e. only slowly decelerate) when encountering traffic lights or a slower speed limit, the lower bound v^l_{ref} will drop by a deceleration constant $a_d = 0.1\ ^{\text{kmh}}/_{\text{m}}$ well before passing the sign, meaning that there will be no panning to the front if the driver chooses to do so. In contrast, the upper bound v^u_{ref} will drop rather near the sign by a braking constant $a_b = 0.8\ ^{\text{kmh}}/_{\text{m}}$ to indicate the upcoming speed limit, if the driver has not reduced the speed by then.

4. STUDY

In order to assess the efficacy of our design in terms of a) drivers adhering to the prescribed speed limit, b) the subjective and measured distraction by the panning, and c) the acceptance of the general design, we have developed a simulator environment specifically tailored to evaluate in-vehicle auditory displays.

4.1. A Virtual reality car simulator

The core of our evaluation system is a car simulator conveying a virtual reality 3D environment with the help of an Oculus Rift[2] for a realistic driving experience (also cp. Figure 1). It is written in three.js[3] (i.e. it can be run in any browser), which makes the system a very portable one.

Figure 2: Hardware setup for the study. Two additional loudspeakers (not seen in the picture) were placed behind the participant. The computer monitor on the right was used only for controlling the application and could not be observed by the participants during the experiment. The head tracking sensor of the Oculus Rift can be seen between the two loudspeakers in the front.

The car simulator features a physics based engine model, including a torque map to model the engine's varying torque responses depending on the input throttle. Furthermore, it has a dedicated interface to SuperCollider via OSC[4], which is also used to create the engine sound. For the study, we implemented a way to stream (internet) radio into Supercollider via a virtual soundcard in order to simulate listening to the radio while driving and as input for our Slowification system.

4.2. Study Design

With the help of our simulator environment, we conducted a study to evaluate the prototype implementation of the Sonislowcation system discussed in Section 3.3. To reduce the number of necessary participants, we employed a within-subject design. For each condition, the participants had to drive the same test track three times in order for them to familiarize with the the respective display. Controlling for ordering effects, we employed a counterbalanced measures design, where both condition sequences were evenly distributed among the study participants.

For the study, we designed a circular track, with speed limits ranging from 30 kmh to 130 kmh. The lengths m_i of the individual segment belonging to a particular speed limit l_i were chosen in such a way that the time needed to drive through them was approximately the same, i.e.

$$t_i \approx t_j, \quad i, j \in [1..n], \quad \text{with } t_i = \frac{m_i}{l_i}$$

Furthermore, the curve radius was adjusted depending on the respective speed limit so that segments with a high speed limit have a

[1]Supercollider: A real-time audio synthesis language (`http://supercollider.github.io`)

[2]Oculus Rift: A virtual reality headset (`https://www.oculus.com`)

[3]three.js: A JavaScript 3D Library (`http://threejs.org`)

[4]OSC: Open Sound Control (`http://opensoundcontrol.org`)

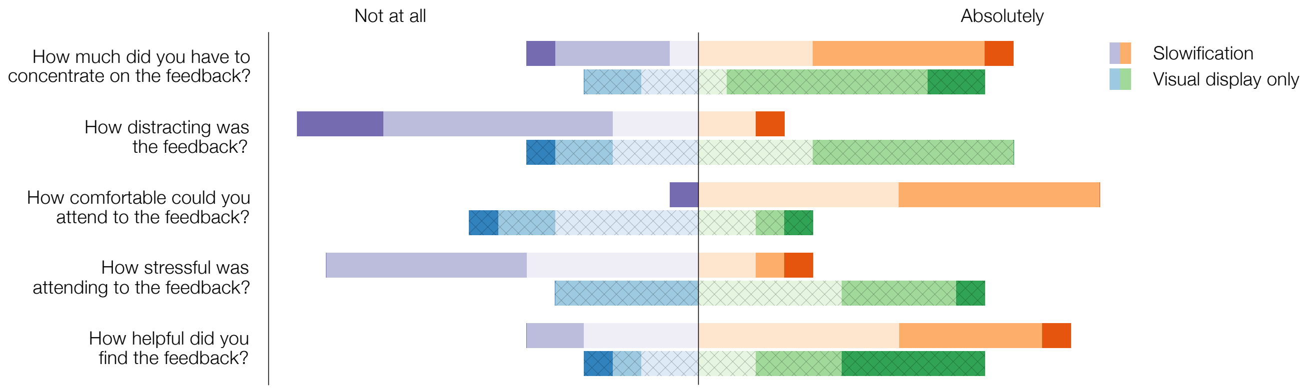


Figure 3: Main results from the questionnaire of the study. Answers could be given on a 7-point Likert-type scale indicating the level of agreement with the statements that were given. For this visualization, only the responses that were not "neutral" are displayed.

wider radius than segments with a lower one. The time to complete one lap is approximately 2 minutes.

4.2.1. Attention task

In order to compensate for the comparably distraction-free simulator environment, we also introduced an attention task for the participants to simulate the usual distractions (e.g. other cars, bicycles, and a lively surrounding) that are present when driving a car. In the spirit of the time, we designed a Pokémon-themed task that was both simple and engaging: While driving on the street, there will appear different kinds of Pokémon that you can catch – true to the original game – with a Pokéball (also cp. Figure 1). This works simply by looking at the Pokémon and pressing a button located on the steering wheel.

4.2.2. Hardware setup

In Figure 2, we can see the actual hardware setup used in the experiment. Four loudspeakers (Genelec 8020A) were placed in a quadrophonic setup around the user. As a virtual reality headset, we used the consumer version of the Oculus Rift. As input devices, we used a consumer-grade steering wheel (Logitech Wingman Formula GP), which also has pedals included.

4.3. Procedure

At the beginning, all participants signed a written consent that the data obtained during the experiment could be used in this study and completed a short introductory questionnaire dealing with general questions about personal preferences and previous experiences.

They were also given a short written introduction explaining the basic concept behind the feedback provided by the Slowification system and telling them what they were expected to do during the experiment.

Specifically, they were told to 1) keep on their lane, 2) not to drive through red traffic lights or ignore stop signs, and 3) to comply to the speed limits – i.e. to follow the common traffic rules. As the last (secondary) assignment, they were told to capture as many Pokémon as possible, including how to do so (cp. Section 4.2.1).

For the actual experiment, all participant were told to first familiarize with their "real-world" environment in order for them to be able to easily reach the pedals and the steering wheel. Only in some cases it was necessary to adjust the position of the pedals.

Moreover, the participants were told that they could select any (internet streamable) radio channel so that they could adjust their soundscape to what they were accustomed to when driving a car. All of them, however, were satisfied with the default selection of 1Live[5], which is a quite popular and known German radio channel.

Then, after familiarizing with the Oculus Rift and the car simulator, the participants had two driving sessions – one with and one without the Sonislowcation system – where they would independently complete three laps of the track (also cp. Section 4.2).

After each session, they completed a questionnaire about the preceding driving session, followed by several comparative questions

4.4. Goals and Hypotheses

The primary goal of the experiment was to evaluate the described design under the following aspects:

- **Adhering to the prescribed speed limit**: As the participants are given the secondary task of catching Pokémon and the speed limit changes several times while driving the track, it can be expected that there is a certain amount of time where the respective speed limit will be exceeded.

  Our main hypothesis is that the Slowification system will help the participants to better adhere to the prescribed speed limits than without it (H1).

- **Distraction**: We furthermore assume that, in comparison to keeping an eye on the visual speed display, the participants will be less distracted by the panning of the radio's sound.

  We assume that this will, on the one hand, be measurable by the amount of time the participants will deviate from their lane (H2), but will also lead to the participants *feeling* less distracted, as should be reflected by the answers in the questionnaire (H3).

[5] 1Live: A German radio channel (`http://www1.wdr.de/radio/1live`)

- **Helpfulness**: Although the helpfulness of the Slowification system should as well be reflected by H1, we also expect the *perceived* helpfulness to be something that can be confirmed by the questionnaire (H4).
- **Acceptance**: A final important aspect of a user interface design that is meant to be installed in an automotive context is the user acceptance.

  Although most of the participants can be expected to be accustomed to the conventional speed dial and to the routinely glance to the dashboard, we hope that the Slowification system will at least be as comfortably to use for the participants as the speed dial (H5).

5. RESULTS

In total, we invited 22 people to try out the Slowification system within our simulation environment. Three of them, however, had to abort the experiment as they were very soon feeling sick because of the VR environment (this is a common problem with VR Devices such as the Oculus Rift and has nothing to do with the Slowification system), leaving a total of n=19 fully evaluable data sets. The participants were 21-30 years old and balanced in terms of gender (9 male and 10 female participants). If not otherwise noted, we used a conventional t-test for comparing values from different conditions. For calculating the effect size, Cohen's d was used.

5.1. Measured data

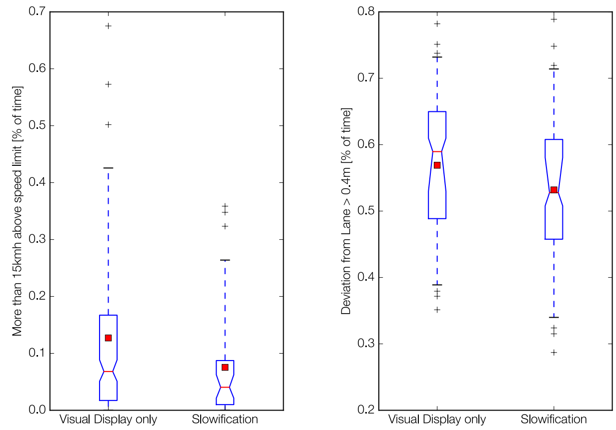
In order to evaluate to what extent the prescribed speed limits were adhered to, we analyzed the percentage of time for each lap that a participant was driving more than 15 kmh too fast. As can be seen in Figure 4a, this was considerably less the case for the panning condition ($7.5\% \pm 9.5$) than for the baseline condition ($12.7\% \pm 15.7$), which confirms our hypothesis H1 ($p < 0.05$, $\text{Cohen's d} = 0.39$).

Furthermore, as a measure for being distracted, we compared the amount of time the drivers deviated from their own lane by more than 40 cm (Figure 4b). Although the differences are not as striking, there is a significant difference when considering our one-sided hypothesis ($p/2 < 0.05$, $\text{Cohen's d} = 0.34$) between driving with ($53.2\% \pm 11.0$) and without ($56.9\% \pm 10.6$) the Slowification system, confirming H2.

5.2. Questionnaires

This result is supported by the responses to the question how *distracting* the participants found the respective feedback. As can be seen in Figure 3, when being supported by the Slowification system (2.79 ± 1.54), the users felt significantly less distracted ($p < 0.05$, $\text{Cohen's d} = 1.01$) than when not (4.42 ± 1.6), which clearly confirms H3.

Being asked about *helpfulness*, however, participants rated the two conditions almost the same ($p > 0.7$), which obviously cannot support our H4. Our interpretation of this result is that the participants, in the short amount of time they had to become accustomed to the system, could not *consciously* "grasp" it in a way that they could assess it as useful. This is also reflected by the answers to the question, how much the participants had to *concentrate* on the feedback, where no significant differences between using the Slowification system and only the speedometer could be



(a) (b)

Figure 4: (a) Percentage of time that a person was driving more than 15 kmh faster than the prescribed speed limit. (b) Percentage of time that a person deviated too far from the street resp. the correct lane.
The whiskers denote the 5% and 95% percentiles of the data, while the notches represent the 95% confidence intervals of the median. The mean values of the data are illustrated by the red boxes.

found, i.e. although they were (at least partly) able to process the provided information (cp. Section 5.1), the participants still tried to consciously attend to it. However, this seemed to be less *stressful* (3.32 ± 1.45) than when attending to the speedometer (4.32 ± 1.59) and further supports H3 ($p/2 < 0.05$, $\text{Cohen's d} = 0.64$).

Finally, as a measure for how well such a system would be accepted as an additional in-vehicle user interface, the participants stated that they could attend to the Slowification more *comfortably* (4.95 ± 1.19) than to the speedometer (3.74 ± 1.37), which confirms H5 ($p < 0.05$, $\text{Cohen's d} = 0.92$).

6. DISCUSSION AND CONCLUSION

The conducted study gives a first indication for the efficacy of the Slowification concept (Section 5). We are, however, aware that the chosen implementation as well as the subjective choice of parameters (cp. Section 3.3) might not necessarily be the best possible one. Nonetheless, this study provides a baseline for the efficacy of the concept and space for future refinements of the implementation.

Although the majority of participants (67%) indicated that they would prefer the Slowification over the speedometer, we argue that in its current form, it cannot replace the visual display: When actively being attended to, the speedometer offers a rather precise way to determine the car's speed and we think that this *possibility* should remain (besides the legal complications that would arise when completely removing the speedometer). However, it is one possible direction of future work to evaluate how well the Slowification works as the *only* available feedback.

Several users reported that they could barely perceive the spatial shift of the sound while, at the same time, apparently reacting to it. Although this certainly needs further investigation, it is insofar remarkable, as that, even after only a very short time of getting accustomed to it, some participants were apparently able to subconsciously perceive and react to the subliminal changes of the sound. Seen from a different perspective, the result of users immediately feeling rather comfortable with the system leaves some room for making the indication of driving too fast (or too slow) more distinct, which is something that should be evaluated in future studies. Another way to further evaluate our speed indicator would be to compare it with a different type of (auditory) display, e.g. an alert-based system, which we would assume to be rated as far more annoying than the Slowification.

During the study, one participant stated that "the panning is a really good idea" but felt that she needed more time to get accustomed to it and suggested "more time for test drives". Another way to give users more time to get accustomed to it would be to install the system in a small number of cars for people to experience the feedback over a longer period of time. While certainly more difficult to evaluate as we would be dealing with a completely uncontrolled environment, this would give insight into how users would be using the system after really becoming accustomed to it and how well it is usable in real-life situations.

Finally, it would be interesting to extend the use cases of the system by integrating an adaptive speed assistance system based on traffic light predictions [7], which we think would make the advantages of the Slowification even more distinct than with static speed signs only.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] M. A. Nees and B. N. Walker, "Auditory Displays for In-Vehicle Technologies," *Reviews of Human Factors and Ergonomics*, vol. 7, no. 1, pp. 58–99, Aug. 2011.

[2] Myounghoon Jeon, Jan Hammerschmidt, Thomas Hermann, Pavlo Bazilinskyy, Steven Landry, and Katie Anna E. Wolf, "Report on the in-vehicle auditory interactions workshop: Taxonomy, challenges, and approaches," *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - Automotive'UI 15*, 2015.

[3] René Tünnermann, Jan Hammerschmidt, and Thomas Hermann, "Blended Sonification: Sonification for Casual Interaction," in *The 19th International Conference on Auditory Display (ICAD-2013)*, 2013.

[4] Simon Holland, David R Morse, and Henrik Gedenryd, "Audiogps: Spatial audio navigation with a minimal attention interface," *Personal and Ubiquitous computing*, vol. 6, no. 4, pp. 253–259, 2002.

[5] Johan Fagerlönn, Stefan Lindberg, and Anna Sirkka, "Graded auditory warnings during in-vehicle use," in *Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '12*, New York, New York, USA, Oct. 2012, p. 85, ACM Press.

[6] F Jimenez, F Aparicio, and J Paez, "Evaluation of in-vehicle dynamic speed assistance in spain: algorithm and driver behaviour," *IET Intelligent Transport Systems*, vol. 2, no. 2, pp. 132–142, 2008.

[7] Behrang Asadi and Ardalan Vahidi, "Predictive cruise control: Utilizing upcoming traffic signal information for improving fuel economy and reducing trip time," *IEEE transactions on control systems technology*, vol. 19, no. 3, pp. 707–714, 2011.