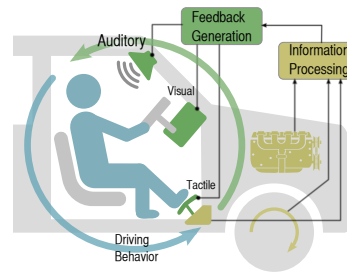

EcoSonic: Auditory Displays supporting Fuel-Efficient Driving

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Abstract

In this paper, we present our work towards an auditory display that is capable of supporting a fuel-efficient operation of vehicles. We introduce five design approaches for employing the auditory modality for a fuel economy display. Furthermore, we have implemented a novel auditory display based on one of these approaches, focussing on giving feedback on the engine's optimal rpm range, which is a major factor for eco-driving. Finally, we report on the development of a simple but physically realistic car simulator, which allows for a reproducible evaluation of prototype auditory displays as well as a comparison to state-of-the-art visual fuel efficiency indicators.

Author Keywords

Eco-Driving, Auditory Display, Feedback, Sonification

ACM Classification Keywords

H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces.

Introduction

The transportation sector is the second-largest contributor of greenhouse gas emissions in the European Union and the United states, accounting for around one fourth of the total CO₂ emissions in these countries [3, 4]. Among



Figure 1: Basic Fuel Economy display [1].

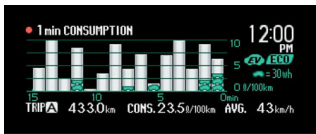


Figure 2: Detailed history of the fuel consumption of a hybrid car [2].



Figure 3: Active acceleration pedal (Eco Pedal). When pressing the pedal beyond the dotted red line, the pedal actively exerts counter-pressure [10].

other measures, research has identified *eco-driving* as a particularly promising and often-overlooked element to reduce both fuel consumption and greenhouse gas emissions especially for personal vehicles: Multiple studies have shown that eco-driving has the potential for reductions of approximately 10% [5]. For hybrid and electronic vehicles, driving style seems to have an even greater impact on energy consumption [14]. Describing several ways to engage car-drivers in eco-driving, Barkenbus [6] specifically recommends the use of feedback-systems to support users in changing their driving habits. Currently, there exist three different types of – also commercially available – feedback systems:

Visual online feedback of fuel consumption: These systems provide direct feedback to the driver on the vehicle's fuel economy. They show either instantaneous consumption data (cp. Figure 1), accumulated values (e.g. aggregated over a couple of minutes, one whole trip, the time between fuel stops), or a more detailed history of the fuel consumption (cp. Figure 2).

Offline Feedback: For this type of feedback, the driving behavior is first logged during operation of the car and then saved onto a flash-drive. Later, this data can be analyzed and reviewed on an external computer [12].

Haptic Feedback (Eco-Pedal): When being pressed down, an *active acceleration pedal* can increase its resistance in order to indicate excessive or wasteful acceleration and by this improve fuel economy. Also, it can be used to help enforcing speed limits [16].

Although research on auditory fuel economy displays is merely in a nascent state [11], we argue that an auditory system is a viable alternative to using a visual display, since it is exactly during fuel-consuming behaviors that

drivers should not divert their attention away from what is happening on the street.

Design Approaches

Based on existing research literature, we propose five design strategies for auditory displays that are applicable for supporting a fuel-efficient driving style:

First, the *direct sonification of the current fuel consumption* can be seen as conceptually closest to the majority of visual fuel economy displays. It can either be continuous or event-based, e.g. with auditory icons signaling fuel spikes or when the driver has achieved a comparatively good fuel economy. For a continuous one, a concept like blended sonification [15] should be applied in order to keep the sound as unobtrusive as possible.

The second approach is the *sonification of secondary parameters that affect fuel consumption*: This might be the driver's braking behavior or the rpm range that is being used.

Third, *using elements of gamification* [7] can help to more effectively motivate users to change their driving habits, e.g. by emphasizing and reinforcing the progress towards a fuel-efficient driving style by using virtual (auditory) rewards.

Fourth, *sonifying advanced support information* can help in anticipatory driving, which is an important element of eco-driving. This could be hints for speed reductions, stop signs, or traffic light information (e.g. [13]). We argue that in those safety-critical situations – i.e. when approaching a crossing or traffic lights – an auditory display is the best option to convey such support information.

Finally, *supporting specific qualities of driving*, like subliminally enhancing the feeling of safety or calm, can indirectly have a positive effect on the driving style. This approach of course comprises a wider range of aspects of

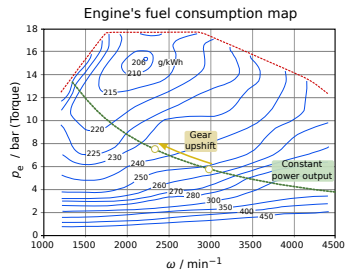


Figure 4: Typical fuel consumption map of a combustion engine. The dashed red line represents the maximum torque that the engine can provide at a given rpm. The green line represents one possible, constant power output (which is proportional to the product of rpm and torque).

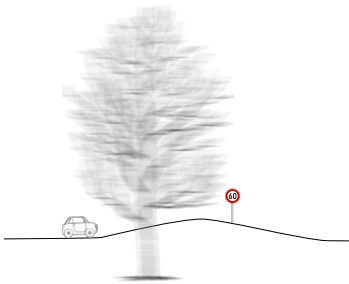


Figure 5: Screenshot of the driving simulator, utilizing a 2,5D side-view with parallax scrolling.

car-design, but we argue that sound could play a major role in establishing such a feeling. These design strategies are obviously not mutually exclusive and can be combined for best effectiveness.

Sonification Design

Based on the second design approach (sonification of secondary parameters), we have developed a prototype auditory display that gives feedback on the (usually rather low) rpm range that is best for a fuel efficient operation of the engine¹: Although the driver generally has less ability for acceleration when driving with a low rpm, as the engine is already operating with an increased torque in that case, the engine's internal friction naturally increases with higher rpm, which directly leads to higher energy losses. This is also reflected in the fuel consumption map of the engine (cp. Figure 4), which shows that fuel efficiency typically *increases* with lower rpm. To make this audible, we have decided to use an event-based sonification, which is triggered when the driver leaves an "optimal" rpm range. Although for simplicity, this range can be fixed, it can also be based on the engine's specific characteristics or modified on preliminary eco-driving performance of the user. For an easily recognizable auditory icon, we have chosen to use a slurping-like sound as an indicator for increased fuel consumption, which already has been proven effective for jet-fighter pilots [8]. Furthermore, how much the driver is outside the optimal rpm range is used as input for the sonification: In our prototype display, this parameter controls the loudness of the produced sound. Also, we have identified the time that a driver *remains* outside of the optimal rpm range as an important additional input parameter for the sonification, which currently controls the sampling rate (and thereby perceived speed) of the auditory icon.

¹<http://bit.ly/sound-example>

Evaluation Approach

In order to allow for a meaningful evaluation of our auditory fuel economy displays, we have developed our own car simulator (cp. Figure 5). Although its graphics are deliberately kept simple, it aims to be physically realistic, as the simulation not only takes into account the car's air drag, rolling and gradient resistance, but also the engine's internal friction and incorporates a model of the fuel consumption map and a torque map of the engine. While the driving itself is simplified insofar as the user doesn't need to steer, we tried to include all aspects of the driving experience that are relevant in the context of a fuel efficient driving style, including street elements like speed signs and traffic lights as well as other cars and an (easily perceivable) height profile of the street. The throttle is controlled with an actual acceleration pedal. With a track editor, we are able to create reproducible driving scenarios, which obviously is of high importance when comparing different designs. Finally, the simulator incorporates an integrated interface to Supercollider [9], i.e. an environment for real-time audio synthesis, which we use to develop our prototype auditory displays. With this setup, we are able to (a) benchmark user performance, (b) assess adaptation and learning effects on repeated tracks, (c) conduct basic research on the ability of sonification to affect (driving) habits and inform users in continuous interaction, and (d) compare different designs of auditory and visual fuel economy displays. While we plan to conduct a quantitative study to evaluate the impact of our auditory display, our subjective observation so far is that the system should be able to support users in avoiding the fuel-inefficient high-rpm range and thus to reduce the overall consumption. We want to prove this hypothesis by measuring the total amount of fuel that was consumed when driving through a specific driving scenario (a) without any support, (b) with

our rpm range auditory display and (c) a visual fuel efficiency indicator.

Future Work

Based on our proposed design approaches, we plan to develop further auditory displays and evaluate and compare them in terms of (a) effectiveness, i.e. how well it can help to reduce fuel consumption, (b) driver distraction, i.e. if the driver is still able to react quickly enough in safety-critical situations, and (c) user acceptance, i.e. if the user feels annoyed by the system.

Acknowledgements

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