ECOSONIC: TOWARDS AN AUDITORY DISPLAY SUPPORTING A FUEL-EFFICIENT DRIVING STYLE

Jan Hammerschmidt
Ambient Intelligence Group
CITEC, Bielefeld University
jhammers@techfak.uni-bielefeld.de

René Tünnermann
Ambient Intelligence Group
CITEC, Bielefeld University
rtuenner@techfak.uni-bielefeld.de

Thomas Hermann
Ambient Intelligence Group
CITEC, Bielefeld University
thermann@techfak.uni-bielefeld.de

ABSTRACT

In order to support drivers in adopting a more fuel efficient driving style, there currently exists a range of fuel economy displays, providing drivers feedback on instantaneous and long-term fuel consumption. While these displays rely almost completely on visual components for conveying relevant information, we argue that there are significant benefits in using auditory interfaces for providing feedback while driving,.
We review existing literature and discuss various design strategies for auditory displays that are applicable for supporting a fuel-efficient driving style. Exploring one of these design strategies, we furthermore introduce several prototypical sonification designs.

1. INTRODUCTION

Greenhouse house gas emissions resulting from the energy consumption and pollution from conventional and electric cars is still a major global issue in spite of attempts to curb such emissions through technological improvements and regulation.

Based on the observation that an aggressive driving style can effectively cancel out the positive effects of an efficient engine, manufacturers install vehicles with visual fuel efficiency displays designed to give feedback on instantaneous and long-term fuel economy in order to influence or support drivers to adopt a more fuel efficient driving style.
A visual display, however, is prone to distracting a driver from their main task, i.e. safely operating and steering the car. This is particularly true for a fuel efficiency display: It is precisely in those situations, when drivers should keep their eyes on the road (e.g. when quickly accelerating) that the information from such a display becomes most relevant.
Nevertheless, eco-driving is a highly promising way for car drivers to reduce both fuel consumption and carbon dioxide (CO_2) emission: Vandenbergh et al. have estimated that 32% to 41% of the total CO_2emissions of the United States are directly caused by individual behavior, including household energy use and, most prominently, personal transportation [1]. Based on these findings, Barkenbus recently surveyed a range of possible measures to reduce greenhouse gas emissions for individual transportation, including the use of public transportation, carpooling, and the purchase of more fuel efficient vehicles [2].

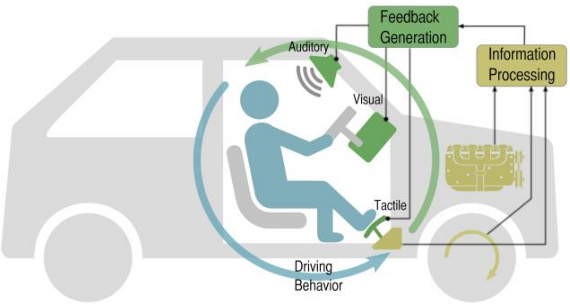

Figure 1: Feedback loop. The driver controls the (acceleration of the) car, which in turn controls the feedback display. The feedback is perceived by the driver and gives supports in improving driving behavior.

Apart from these measures he argues that a more efficient operation of vehicles is an often overlooked opportunity with a potentially large impact on CO_2 emissions. Among a range of interventions to support eco-driving – including public education policies, economic incentives, and regulatory initiatives – Barkenbus specifically recommends the use of feedback systems to help drivers gain an awareness of their fuel consumption and eco-driving performance in dependence of their respective driving behavior [2].
With the uptake of hybrid and electric cars, this aspect is becoming increasingly important, as these cars are far more sensitive to driving behavior than those with a combustion engine. While there are several studies showing that eco-driving has the potential to reduce CO_2 emissions by approximately 10% already for conventional cars [3,4], aggressive driving can cause the fuel efficiency of hybrid vehicles to decrease by more than 30% [5].
Furthermore, it has been shown that eco-driving contributes to a safer driving style as it encourages a steady and moderate speed as well as gentle acceleration. On the other hand, first research results indicate that (visual) fuel economy driver interfaces may lead to a distraction that has a negative impact not only in terms of driving performance [6], but also relating to safety issues [7].

In this paper, we first review existing eco-driving systems, which leads us to propose sonification-based systems as solving

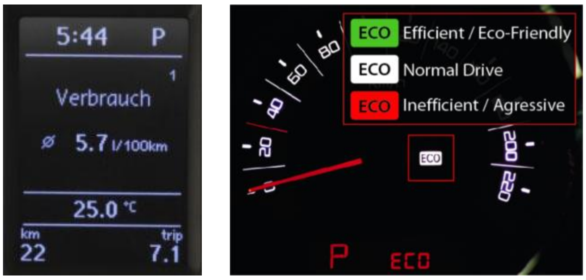

Figure 2: (a) Basic display of instantaneous fuel consumption, measured in L/100km [8]. (b) Eco-driving indicator, which is integrated into the speedometer and can differentiate between three levels of fuel economy [6].

major problems in Section 2.4. We propose various design strategies for auditory-based eco-driving-systems in Section 3 and present several prototypical sonification designs in Section 4.

2. OVERVIEW OF EXISTING ECO-DRIVING SYSTEMS

Driven partly by developments in the hybrid-sector, there currently exists a number of commercially available eco-driving systems, which help the driver in achieving a fuel-economic driving style.

2.1. Visual Online Feedback of fuel consumption

The majority of the available eco-driving systems provide feedback to the driver on the vehicle's fuel economy and thus allow the driver to gain an awareness of how this variable is affected by a specific driving behavior. The devices are usually mounted in the dashboard, allowing the driver to get immediate feedback *while* driving.

A very basic example for a fuel economy display can be seen in Figure 2(a), which shows the current consumption as a plain number, typically in terms of MPG for the United States, and either L/100km or km/L for other parts of the world, depending on cultural preference. A slightly more advanced display is shown in Figure 2(b), which differentiates between three levels of fuel economy: Normal, Inefficient, and Eco-Friendly. This simplified way of displaying levels of consumption allows the driver to more easily perceive this information, but obviously lacks in precision, which is also something that was criticized by study participants who were asked about such a display in a recent study of Lee et al. [6].

In addition to the instantaneous consumption, there are displays showing accumulated consumption, where information is aggregated over a longer period of time. This can either be a couple of minutes, one whole trip, or the time between fuel stops. Typically, consumption is averaged over the time period and displayed in a similar way to instantaneous consumption. A more complex form can be seen in Figure 3(a), which displays a quite detailed (but at the same time also more difficult to perceive) history of the consumption.

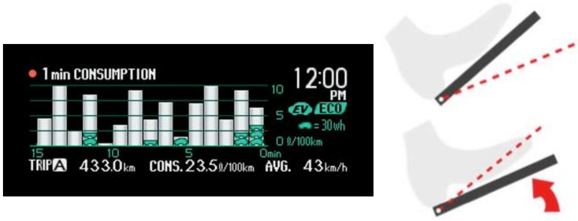

Figure 3 (a) Consumption monitor of the Toyota Prius [9]. This display offers a detailed view on the fuel consumption over the last 15 minutes. (b) Active acceleration pedal (Eco Pedal). When pressing the pedal beyond the dotted red line, the pedal actively exerts counter-pressure [10].

2.2. Offline Feedback

A second type of feedback can be seen in Figure 4. Here, driving behavior and consumption data is first being monitored and logged during operation of the car and recorded onto a flash drive. Later, the driver can download the data to a PC, where it is analyzed and presented to the user with an additional piece of software. An example of such a system is Fiat's eco:drive [11].

The analysis of the gathered data is somewhat more sophisticated than for online feedback systems, as the software takes into account not only fuel consumption and emissions, but also acceleration, breaking and gear shifting patterns and is able to suggest specific changes to the driving behavior [12].

The obvious disadvantages, however, are that the user is required (a) to dedicate extra time, and (b) to do it *outside* the vehicle for this feedback system to have any effect, i.e. the feedback is decontextualized, in time and place, from the act of driving the car.

Thus, while it may not be ideal for private use, it can be a great review tool for professional transport companies.

2.3. Haptic Feedback (Eco Pedal)

A third type of feedback exists in form of an active acceleration pedal (cp. Figure 3(b)). When being pressed down, the pedal can actively increase its resistance, which might either be related to the current speed limit [14] or the fuel consumption in order to avoid excessive and wasteful acceleration [15].

This form of feedback is certainly a promising direction of research and it seems to be effective in increasing the compliance with speed limits [16]. However, in a recent study that compared different types of feedback systems designed to support a fuel-efficient driving style, the concept of an eco pedal was rated significantly lower than other systems – both in terms of user acceptance and perceived usefulness [10].

Figure 4: Screenshot of the Fiat eco:drive software [13]. The software uses data that was captured while in the car and assesses various aspects of driving behavior.

2.4. The use of auditory feedback

To our best knowledge, there currently exists no system that uses auditory feedback as means to support the user in achieving an improved fuel economy.
We argue, however, that especially for the scenario of providing feedback *while driving*, there are significant and considerable benefits in using this modality:

- Research has suggested that in order to be most effective, feedback should be given as "close" to the respective action as possible [17]. The auditory channel is perfectly suited to make this possible, as the driver can actually perform the act of driving (with the hands on the steering wheel and the eyes on the road), and at the same time attend to the given feedback.
- Looking at specific driving behavior, it has been shown that braking and acceleration processes are crucial for determining fuel economy, which is also why feedback on fuel consumption would become of increased relevance in these situations. On the other hand, drivers would be ill-advised to shift their focus from what is happening on the street to a visual indicator of fuel consumption in the dashboard, as those situations are also highly critical in terms of safe driving. With auditory feedback, a driver can be "in the loop" concerning fuel consumption (cp. Figure 1), while at the same time keeping the eyes on the road.
- Finally, an auditory feedback system would be comparatively easy to install and implement, as it would basically require no additional hardware and can utilize the loudspeakers that are already installed in the vast majority of cars anyway.

3. Related work

By now, a multitude of studies clearly show a positive effect of eco-driving on fuel economy: Johansson et al., for example, evaluated, how the recommendations of eco-driving instructors influenced the driving behavior of 16 driving school teachers and found that both fuel consumption and the emission of carbon dioxide were reduced by an average of 10.9% as a result of the instructions [4]. Vangi et al. developed a method for automatically assessing driving behavior of bus drivers and found that economical driving can provide direct savings in fuel consumption of up to 25% [18].
Although the variance of found fuel efficiency improvements are rather large, they are in the majority of cases highly significant and warrant the effort to support eco-driving behavior for a broad range of people.

Manser et al. compared a broad selection of "fuel economy driver interface concepts" (FEDICs) in three different stages, including a usability study and a driving simulation evaluation [19]. Among other results, the authors found out that *simple* representations of fuel economy information were generally the most usable and that study participants also had a preference for those types of feedback, as compared to textual representations. Also, they observed that, when using a (visual) FEDIC display, drivers made more glances away from the road, indicating that there are "potential safety implications due to FEDIC use".

While the majority of feedback displays use rather conventional methods of displaying fuel consumption, there are also more creative propositions, like for example in [29] (cp. Figure 5) where the curve of the speedometer needle displays the deviation from the most fuel efficient driving speed.

3.1. The importance of unobtrusiveness

Tulusan et al. analyzed, which aspects of eco-feedback systems are beneficial for drivers to accept them as meaningful support for achieving an efficient driving behavior [20].

They found that unobtrusive feedback systems were most preferable for the users and state that the car industry should "enhance and promote the notion of interaction cultivated between feedback technologies and drivers, firstly by developing unobtrusive systems, not posing additional workload and frustration to drivers and being seamlessly interweaved into driving".

In another study, Lee et al. evaluated a commercial eco-driving system [21] and found that the increased cognitive load might even lead to an *increased* fuel consumption in some circumstances [6].

3.2. Auditory displays

While auditory fuel economy displays are virtually non-existent in the commercial sector, there already has been (albeit very little) work within the sonification community:

Nees and Walker included the topic of energy conservation systems in a survey paper on auditory displays for in-vehicle technologies [22], and very recently Nees et al. reported on planned research on how to best use auditory displays in a fuel efficiency driver interface [23].

Figure 5. Curvy Speedometer [29]. The tip of the needle indicates the current speed of the car while its curvature indicates, how far the current speed is from the most fuel-efficient speed.

4. DESIGN STRATEGIES FOR AN AUDITORY DISPLAY TO SUPPORT ECO-DRIVING

4.1. Direct sonification of current fuel consumption

This first conceptual approach to creating auditory displays to influence driver behavior is similar to the one for visual displays, i.e. to directly sonify the data on current fuel consumption. The design is based on a number of decisions, which are important for the system to be accepted. First, the sonification can be either continuous or event-based: For an event-based sonification, one then would have to decide, how and when a sound is triggered. This might simply be on each kilometer driven or on the expenditure of a specific amount of fuel. Another possibility could be the occurrence of a peak in fuel consumption or when the driver manages to achieve a comparatively good fuel economy. Ultimately, it must be decided, which sound is produced; if one should use, for example, auditory icons [30] or earcons [31] – and which ones would be appropriate.

For a continuous sonification, it must be decided, how the input data is mapped onto a specific characteristic, e.g. pitch, loudness, or brightness of a sound. This also introduces the question of polarity [25], i.e. if a rising fuel consumption should, for example, go along with a rising or falling pitch of a sound.

Finally, as it has been shown in user studies, it is crucial for the acceptance of a fuel economy display that it is rather unobtrusive. We propose to make use of the concept of *blended sonification* [26] in order to achieve this, i.e. to create a sonification that blends into the user's environment by working with pre-existing sounds – e.g. the sound of the engine – and manipulate (e.g. augment) this sound in a way that it conveys additional (fuel consumption) information.

4.2. Sonification of secondary parameters

Another design approach for an auditory fuel economy display is the sonification of specific aspects of driving that are known to significantly affect the fuel consumption.
One of these aspects is certainly the driver's braking behavior, which obviously has a direct impact on how much energy is wasted while driving. An auditory display could help in creating an awareness for the negative effects of too frequent or unnecessarily hard breaking, which can occur due to an aggressive or insufficiently anticipatory driving style.

4.3. Gamification

Creating an awareness for the car's fuel consumption and providing feedback on how it is affected by driving behavior is a necessary (or at least very important) part in
achieving wide-spread adoption of eco-driving habits.
However, we also have to think about how to *motivate* drivers in achieving this goal over a longer period of time.

In the context of eco-driving, we propose to make use of an gamification-like approach in order to do so: Gamification is an emerging area of research, which deals with improving user experience and user engagement by using game elements in non-gaming contexts [27].

In contrast to a fuel economy display that neutrally conveys consumption data or even tries to point out situations where the driver is wasting energy,

a gamification approach emphasizes and reinforces the progress the driver makes towards a fuel-efficient driving style, e.g. by using virtual rewards like badges or achievement points.

To the best knowledge of the authors, the concepts of gamification have yet to be applied to an (exclusively) auditory display, which is most likely due to the fact that they have originated from a *video* game context and as such are naturally difficult to translate to an auditory display.

We argue, however, that this is a promising research direction, which would contribute both to increasing the driver's motivation and to improving the user acceptance for a fuel economy display, and we are currently working on a first concept of such an *auditory gamification display*.

4.4. Sonifying advanced support information

Another approach for supporting a fuel economic driving style with the help of an auditory display is to sonify more advanced support information, such as hints for speed reductions or stop signs.

Bär et al., for example, have proposed a system that can calculate – based on detailed information on the position of stop signs, speed limits and a height profile of the road – when to freewheel, i.e. when the driver can completely stop accelerating [28]. Similarly, Raubitschek et al. examined, how a driver can make use of predictive traffic light information [29].

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.

4.5. Supporting specific qualities of driving

A final possibility for an auditory display to help to establish a fuel economic driving style for a broad range of people is by subliminally supporting a feeling of *safety* or *calm*, which in turn might have a positive effect on the driving style.
The hypothesis here is that such feelings will also lead to a calmer way of driving – just as for example a more sportive feeling would lead to a slightly more aggressive driving style.
Although this approach comprises a wider range of aspects of car-design, sound could play a major role in achieving such a feeling.

5. SONIFICATION DESIGN

The focus of this paper is to approach eco-feedback systems from a conceptual side and to propose and elaborate on design directions for connecting different data types with auditory feedback. All our aforementioned approaches are subject of our ongoing sonification developments. Our first prototype illustrates the direct sonification of fuel consumption (cp. Section 3.1).
For this approach, the first possibility is to make the absolute consumption audible. The information reflects the instantaneous use, which correlates (to some degree) with the RPM of the engine and the perceived speed of the vehicle. However, the sound complements the other cues as it makes the fuel use explicit. We present a sonification example where fuel consumption is represented by a sequence of grains, each grain signaling the expenditure of a small amount of fuel. Comparable with a Geiger counter, which ticks faster at higher radioactivity, the rate of grains here signals the instantaneous consumption (listen to sound example S1 on our website[1]).
A second possibility, which reduces the correlation with the RPM and perceived speed and is also more in line with the majority of visual fuel economy systems is to base the direct sonification on the relative consumption, i.e. the instantaneous fuel consumption per metre. As this is a variable that does not integrate in the same way as fuel drops do, we propose as sonic representation a sharp bandpass-filtered noise signal, where the cutoff frequency is controlled by the input data, so that a wind-like sound emerges. In consequence, strong accelerations, or for instance driving fast on low gear becomes highly salient as high-pitched noise (cp. sound example S2).
As a combination of these two approaches, our third sound example signals the expenditure of a small amount of fuel with a grain, whose pitch is controlled by the relative consumption, providing a continuous awareness for both variables (cp. sound example S3).
Obviously, these few sonification examples scratch only the surface of what is possible to represent the fuel economy while driving. More comprehensive sound designs and evaluations for how these sonifications affect drivers in their driving style will be reported in our future papers.

[1] http://www.techfak.uni-bielefeld.de/ags/ami/publications/HTH2014-ETA/

6. SUMMARY

In this paper we presented our work in progress on auditory interfaces to support fuel efficient driving. We highlighted important design aspects such as unobtrusiveness, directness and gamification. Furthermore, we presented a first prototype, which is illustrated by examples of the sonifications.
With the presentation of various design strategies, we hope to motivate diverse future work that might lead to better fuel economy displays and want to encourage discussions on the use of auditory displays for in-vehicle usage.
As next steps, we plan to evaluate the proposed sonification designs and compare them to visual fuel economy displays: We have developed a driving simulator that reduces the complexity of a driving task to the aspects that are relevant in the context of a fuel-efficient driving style, thus allowing for a meaningful and reproducible evaluation of different approaches and sonifications.

7. ACKNOWLEDGMENT

We thank the German Research Foundation (DFG) and the Center of Excellence 277 Cognitive Interaction Technology (CITEC) who funded this work within the German Excellence Initiative.

8. REFERENCES

[1] M. P. Vandenbergh, J. Barkenbus, and J. M. Gilligan, “Individual carbon emissions: The low-hanging fruit,” *UCLA Law Review*, vol. 55, pp. 08–36, 2008.

[2] J. N. Barkenbus, “Eco-driving: An overlooked climate change initiative,” *Energy Policy*, vol. 38, no. 2, pp. 762–769, Feb. 2010.

[3] *Workshop on Eco-Driving: Findings and Messages for Policy Makers*, 11 2007.

[4] H. Johansson, P. Gustafsson, M. Henke, and M. Rosengren, “Impact of EcoDriving on emissions and fuel consumption,” in *International Scientific Symposium on Transport and Air Pollution*, Avignon, France, no. m, 2003.

[5] J. J. Romm and A. A. Frank, “Hybrid vehicles gain traction,” *Scientific American*, vol. 294, no. 4, pp. 72–79, 2006.

[6] H. Lee, W. Lee, and Y.-K. Lim, “The effect of eco-driving system towards sustainable driving behavior,” in *Proceedings of the 28th of the international conference extended abstracts on Human factors in computing systems - CHI EA ’10*. New York, New York, USA: ACM Press, Apr. 2010, p. 4255.

[7] V. L. Neale, T. A. Dingus, S. G. Klauer, J. Sudweeks, and M. Goodman, “An overview of the 100-car naturalistic study and findings,” *National Highway Traffic Safety Administration, Paper*, no. 05-0400, 2005.

[8] “*Basic fuel consumption monitor*,” http://partner.volkswagen.de/content/medialib/vwd4/global/mom/new_sharan/content/sharan_mfa_verbrauch/_jcr_content/renditions/rendition.570.270.file/sharan_mfa_verbrauch.jpg, [last accessed: 30.07.2014].

[9] "*Toyota Prius Consumption Monitor*, "http://www.toyota.com.au/static/images/16lin-toyota-prius-gallery-prius-multi-information-display-940x529.jpg, [last accessed: 30.07.2014].

[10] A. Meschtscherjakov, D. Wilfinger, T. Scherndl, and M. Tscheligi, "Acceptance of future persuasive in-car interfaces towards a more economic driving behaviour," *Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '09*, no. AutomotiveUI, p. 81, 2009.

[11] "*Fiat eco:drive*," http://www.fiat.com/ecodrive/, [last accessed: 17.07.2014].

[12] L. Orofino, L. Cilimingras, and E. Morello, "Eco-drive: Driver behaviour evaluation system to reduce co 2 emissions," in *World Automotive Congress*, 2010.

[13] "*Screenshot of Fiat's eco:Drive*," http://www.fiatusa.com/deprecated/en/mobile_apps/images/apps/fiat-ecodrive/FiatEcoChallenge.jpg, [last accessed: 30.07.2014].

[14] A. Varhelyi, M. Hjälmdahl, R. Risser, M. Draskóczy, C. Hydén, and S. Almqvist, "The effects of large scale use of active accelerator pedal in urban areas," in *Paper presented at the ICTCT workshop on ISA–Intelligent Speed Adaptation*. ICTCT, 2002.

[15] "*Nissan Eco Pedal*," http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/eco pedal.html, [last accessed: 17.07.2014].

[16] A. Várhelyi, M. Hjälmdahl, C. Hydén, and M. Draskóczy, "Effects of an active accelerator pedal on driver behaviour and traffic safety after long-term use in urban areas," *Accident Analysis & Prevention*, vol. 36, no. 5, pp. 729–737, 2004.

[17] J. Froehlich, L. Findlater, and J. Landay, "The design of eco-feedback technology," in *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*. New York, New York, USA: ACM Press, Apr. 2010, p. 1999.

[18] D. Vangi and A. Virga, "Evaluation of energy-saving driving styles for bus drivers," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 217, no. 4, pp. 299–305, Jan. 2003.

[19] M. Manser, M. Rakauskas, J. Graving, and J. Jenness, "Fuel economy driver interfaces: Develop interface recommendation. report on task 3," *Fuel economy driver interfaces*, May 2010.

[20] J. Tulusan, L. Soi, J. Paefgen, M. Brogle, and T. Staake, "Which eco-feedback types prefer drivers most ?" pp. 1–8, 2011.

[21] "*KIA Eco-Driving System*," http://kia-buzz.com/eco-driving-system/, 2008, [last accessed: 22.07.2014].

[22] 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.

[23] M. A. Nees, T. Gable, M. Jeon, and B. N. Walker, "Prototype auditory displays for a fuel efficiency driver interface," in *The 20th International Conference on Auditory Display (ICAD-2014)*, 2014.

[24] B. N. Walker and G. Kramer, "Mappings and metaphors in auditory displays: An experimental assessment," *ACM Transactions on Applied Perception (TAP)*, vol. 2, no. 4, pp. 407–412, 2005.

[25] R. Tünnermann, J. Hammerschmidt, and T. Hermann, "Blended Sonification: Sonification for Casual Interaction," in *The 19th International Conference on Auditory Display (ICAD-2013)*, 2013.

[26] S. Deterding, M. Sicart, L. Nacke, K. O'Hara, and D. Dixon, "Gamification. using game-design elements in non-gaming contexts," in *Proceedings of the 2011 annual conference extended abstracts on Human factors in computing systems - CHI EA '11*. New York, New York, USA: ACM Press, May 2011, p. 2425.

[27] D. Vangi, A. Virga, T. Bar, R. Kohlhaas, J. M. Zollner, and K.-U. Scholl, "Anticipatory driving assistance for energy efficient driving," in *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 217, no. 4. IEEE, June 2003, pp. 1–6.

[28] C. Raubitschek, N. Sch, E. Kozlov, B. Bernard, N. Schutze, and B. Baker, "Predictive driving strategies under urban conditions for reducing fuel consumption based on vehicle environment information," *Integrated and Sustainable Transportation System (FISTS), 2011 IEEE Forum on*, pp. 13–19, June 2011.

[29] M. Sohn, T. Nam, and W. Lee, "Designing with unconscious human behaviors for eco-friendly interaction," *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems - CHI EA '09*, p. 2651, 2009.

[30] E. Brazil and M. Fernström, "Auditory icons," in The sonification handbook, T. Hermann, A. Hunt, and J. G. Neuhoff, Eds. Logos Publishing House, Berlin, Germany, 2011, pp. 325–338.

[31] D. McGookin and S. Brewster, "Earcons," in The sonification handbook, T. Hermann, A. Hunt, and J. G. Neuhoff, Eds. Logos Verlag Berlin, 2011.