Impact of a visual and haptic driver advice and preview system on a range optimized way of driving in electric vehicles

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Abstract

Today one of the disadvantages of electric vehicles is still the lower driving range in comparison to conventional vehicles resulting in subjective fear of drivers not to reach their destination. One approach to extend the driving range is to change the driver behaviour to a more efficient and intelligent way in terms of energy usage in certain driving situations. To realize a change in driver behaviour it is necessary to support and motivate drivers by means of driving advice and situation preview. This paper introduces a visual and haptic on-trip Human Machine Interface (HMI) for electric vehicles, developed with the purpose to lead drivers to a range optimized way of driving, and the results of the associated driving simulator study about the impact of that HMI on such a range optimized way of driving in electric vehicles.

The HMI presented in this paper is the result of an iterative development process with several sub studies and consists of many elements to support the driver in a range optimized way of driving. Central element of the visual HMI is a preview and advice system that provides drivers with information about the current and upcoming situation and advice. It is complemented by visual feedback elements that e.g. rate the efficiency of the current driving style. The visual advice is supported by haptic advice elements like a continuous haptic feedback on the acceleration pedal, when the driver exceeds the speed limit respectively an eco friendly speed, and a “recuperation” advice that provides a pulsation of the acceleration pedal at the time of an optimal start of recuperation manoeuvres regarding energy efficiency. The haptic advice is provided by a force feedback pedal.

The impact study was conducted in ika’s static driving simulator with twenty-seven subjects. Beside an objective evaluation of the driving parameters, an introductory interview on demographic data and driving experiences as well as questionnaires on the acceptance of three different HMI versions (no advice, visual advice & preview, visual & haptic advice & preview) are evaluated. The evaluation shows a positive impact of the developed visual as well as visual & haptic advice and preview system.

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on a range optimized way of driving in electric vehicles. Hereby the visual-haptic advice system showed compared to a baseline (without advice) and a visual advice system the biggest impact on the driving behaviour.

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1. Introduction

The IPCC Working Group III Fifth Assessment Report (“Mitigation of Climate Change”) from April 2014 shows once more the necessity to reduce CO₂ emissions in order to mitigate climate change [IPCC (2014)]. A possibility to reduce CO₂ emissions in the automotive sector is to roll out more electric vehicles in combination with an expansion of renewable energies, because an advantage of electric vehicles is that they do not have direct CO₂ emissions [Zimmer et al. (2011)]. Another advantage of using electric engines is the possibility to reuse the kinetic energy of the vehicle in deceleration situations to fill the energy storage [Helms et al. (2010)]. In conventional vehicles this energy will be converted in heat and is lost during braking.

As a bottleneck of today’s electric vehicles the high cost of purchase, the limited number of charging points and the limited range are mostly urged as arguments [Sommer (2011)]. Even if usual driving distances are far below the possible ranges of electric vehicles, many customers are afraid of not reaching their destination [Sommer (2011)]. To meet these fears several strategies are possible. One is to extend the range by improving the energy storages. It is foreseen that significantly optimized batteries will not be available before 2020 [Bernhart et al. (2013)]. Another strategy is to use the available energy more intelligently and efficiently. An intelligent and efficient usage of the available energy in an electric vehicle covers measures before (pre-trip), while (in-trip) and after driving (post-trip) [Hof et al. (2013)].

Several studies for conventional vehicles showed already that an energy efficient way of driving can lead to lower energy consumption [Neunzig (2002)], [Gonder and Sparks (2011)], [Christen and Töpler (2009)], [Zlocki (2010)], [Wengraf (2012)]. In addition, electric vehicles have the advantage that the kinetic energy of the vehicle can be used in recuperation manoeuvres to recharge the battery during deceleration so that recuperation increases the potential for extending the range by appropriate driver behaviour [Helms et al. (2010)]. Further technical differences between electric and conventional vehicles lead to other demands of information for drivers of electric vehicles. As shown in [Sommer (2011)] many customers are afraid not to reach their destination, so that e.g. displaying the current range must have a higher priority than in conventional vehicles. As a result special Human Machine Interface (HMI) concepts have to be developed for electric vehicles.

Ika has developed a concept for this purpose. Main part of this concept is visual and haptic driver advice and a preview system that will be introduced hereafter.

2. Visual and haptic driver advice and preview system

An efficient way of driving can only be realized with efforts and cannot be taken for granted. According to [Campbell and Pritchard (1976)] effort is a function of skills and motivation.

\[
\text{Effort} = f(\text{Skills, Motivation})
\]

In this context, skills will be used synonymously with the knowledge on how to drive energy efficiently. Depending on the driver, skills for an energy efficient way of driving are available or not. If those skills are not available, the HMI has to support the driver with advice. If the skills are available, the HMI has to support the driver with information to enhance performance. Advice in this context is for example a hint when the driver has to release the acceleration pedal to start an energy efficient deceleration manoeuvre. Drivers that already know how to perform an energy efficient deceleration manoeuvre need e.g. information about the status and distance of the next traffic light or a non-visible speed limit to use their skills to save as much energy as possible. Such support can be provided by a situation preview.
This means that to realize a change in driver behaviour it is necessary to support and motivate [Gonder and Sparks (2011)] drivers. This can be done by providing feedback, explicit driving advice and a preview in relevant situations. This paper focuses on advice and preview elements that support drivers of electric vehicles. The used motivational elements of the HMI concept are introduced in [Kotte et al. (2014)]. An overview about different approaches to support drivers in an energy efficient way of driving for mainly conventional vehicles can be found in [Hof et al. (2013)].

To use the whole potential of recuperation manoeuvres in electric vehicles it is necessary to leave the acceleration pedal in the right moment so that the car has the aimed speed at the aimed location (in the following place of speed change) without using the breaks. The moment when the driver has to leave the acceleration pedal (in the following optimal start of recuperation manoeuvre) depends on many factors like current speed, distance to the speed change, slope, etc.. Advice on timing of the optimal start of the recuperation manoeuvre can help drivers to use the whole potential to save energy in these situations. This advice is called recuperation advice in the following.

Advice can be given in different ways. State of the art is to provide in-trip advice visually in the instrument cluster [Hof et al. (2013)]. Since today 80-90 % of all driving relevant information is already perceived visually, new forms of information transfers to the driver have to be considered in the conception of new systems, especially if they provide additional information [Winner, Hakuli and Wolf (2009)]. For recuperation advice, where the target reaction of the driver is that he leaves the acceleration pedal, advice can be given haptically with a pulsation on the acceleration pedal. Furthermore this has the advantage that the place of advice and the place of reaction are same what should lead to a faster reaction of the driver.

Active acceleration pedals for different purposes have already been assessed in different studies with promising effects on the driver behaviour. [de Rosario and Louredo (2010)] for example used a pulsation on the acceleration pedal for a distance warning. They studied different designs of pulsation with the result that a pulsation with a frequency of 5 and 10 Hz and a maximal amplitude of 1.6 Nm has the biggest impact on the driver behaviour. [Adell et al. (2008)] used haptic advice for distance and speed warnings. In [Lange et al. (2010)] and [Lange et al. (2008)], a system is introduced that uses a pulsation on the pedal to provide gear change advice and a pressure point that guides the driver to hold the current speed limit. For the design of gear switch advice the authors studied different pulsation designs with the result that a twice double twitch of pressure with a gap of 3 s between the two repetitions leads to the best results [Lange et al. (2010)]. Also, continuous feedback designs to guide drivers to an optimized pedal position were investigated in different studies. [Jamson et al. (2011)], for example, figured out that especially feedback where a driver feels a step change in acceleration pedal stiffness leads to a better acceleration pedal usage.

![Fig. 1. Studied feedback forces as a function of the deviation between aimed speed (eco speed or speed limit) and driven speed (Δv).](image)
Based on the results of [Lange et al. (2008)], [Lange et al. (2010)] and [de Rosario and Louredo (2010)] the here used recuperation advice was designed as a twice double twitch (frequency 10 Hz) of pressure with a gap of 3 s. In addition, a continuous haptic feedback system was integrated with the aim to guide the driver unconsciously to a smoother speed profile. For that purpose, the continuous feedback has to be designed in contrast to [Jamson et al. (2011)] in a way that the driver does not recognize a step change in acceleration pedal stiffness. Such design was chosen because the system should not annoy the driver. For the design of such feedback, a pre-study was conducted in which twelve subjects drove three different feedback designs (linear, degressive, progressive as a function of the deviation between aimed speed (eco speed or speed limit) and driven speed (Δv)) (Fig. 1) in a static driving simulator. The result of this pre-study was that a degressive design leads to the best performance regarding a smooth speed profile and driver acceptance. Based on comments of the pre-study subjects the degressive feedback design was afterwards slightly adapted for the final version with a continuous offset of 10% of the maximal pedal stiffness and a lower gradient shown in Fig. 1.

[Lange et al. (2008)] showed in their study that a combination of haptic feedback on the acceleration pedal together with visual information elements in the instrument cluster had the most promising impact on driver behaviour for their system. In addition, recuperation advice sometimes has to be given several seconds before the reason for the advice is visible for the driver (e.g. speed limit change after a curve). To keep acceptance of the haptic advice system even in these situations on a high level it is necessary to give drivers an explanation for the pulsation on the acceleration pedal (i.e. haptic advice). Due to this reasoning a visual advice system was developed as well. This system shows drivers oncoming and current advice on dedicated positions in the instrument cluster. In addition, it provides the driver with a situation preview so that it is easy to understand why the advice (visual and haptic) is given. The driver should also be able to deactivate the haptic advice system. In this case the preview system supports the driver in using its own skills for energy efficient deceleration manoeuvres by displaying information about not-yet visible situations, like traffic light status changes or speed limit changes after curves. The complete visual support system is shown in Fig. 2. Advice and preview elements are highlighted in orange.

![Fig. 2. Visual driver support system for a range optimized way of driving in an electric vehicle with advice and preview elements (orange).](image)

**3. Impact evaluation of the visual and haptic advice and preview system**

In the previous chapter a visual and haptic in-trip advice and preview system for an electric vehicle, developed with the purpose to lead drivers to a range optimized way of driving, was proposed. Target of the system is to influence the drivers’ behaviour in a way to drive in a more energy efficient way. Based on this system a study was conducted to address the following research questions:
• Does the advice provided significantly increase the advised behaviour?
• Is the impact on the driver behaviour significantly higher with a combined system of haptic and visual advice?
• Does a continuously given haptic feedback on the acceleration pedal guide drivers to a better control of the vehicle speed without losing drivers acceptance for the system?
• How do subjects rate the usefulness and acceptance of the visual and combined visual and haptic system?

The method and results of this study are introduced in the following.

3.1. Methodology

The study was conducted with twenty-seven participants in Ika’s static driving simulator, which is presented in Fig. 3. The simulator was built to evaluate HMI concepts. Its modular construction enables a free and easy adjustment of the car cabin dimension and HMI elements. To give drivers a realistic steering feedback a Sensodrive SENSO-Wheel is integrated. As instrument cluster a freely programmable full colour TFT display is used, which enables an easy switching between different visual clusters. For the purpose of this study the visual advice and preview strategy proposed in Fig. 2 is implemented in this cluster. To provide haptic feedback on the acceleration pedal the 1. Gen. Acceleration Force Feedback Pedal (AFFP) from Continental is integrated. For recuperation advice the above described pulsation (twice double twitch of pressure with a frequency of 10 Hz and a gap of 3 s) instead of the implemented jitter was used.

![Various Car Cabins Representable](image)

![Full TFT Color Instrument Cluster](image)

![Force Feedback Pedal](image)

![CAN Bus Simulation](image)

![Head Up Display](image)

![Senso Wheel](image)

Fig. 3, Ika’s static driving simulator for HMI evaluation.

The used test route has a length of approximately 15 km and consists mainly of rural roads and a small segment of city as well as a small segment of motorway with a construction zone. For the objective evaluation the following situation specific characteristic values are defined:

Deceleration situations:
• \( \Delta t_{\text{recuperation}} \): Time between optimal start of recuperation manoeuvre regarding energy efficiency and the drivers start the recuperation manoeuvre (driver releases the acceleration pedal without using the braking pedal).
• \( t_{\text{followed}} \): Ratio of time the recuperation advice was followed to the recuperation advice was active

Constant driving situations:
• \( \phi \Delta v \): Average absolute deviation between speed limit and driven speed
• \( \sigma_{\Delta v} \): Standard deviation of absolute deviation between speed limit and driven speed

In general, only recuperation manoeuvres longer than 2 s were considered. In earlier studies of this project, differences in driving behaviour depending on the length of the deceleration situation were observed. Thus, for the current evaluation a distinction between situations to a standstill (e.g. stop signs) and upcoming speed limits higher than 0 km/h were made. Upcoming situations to standstill are called standstill deceleration situations in the
following and all other deceleration situations are called dynamic deceleration situations. The test route consisted of two different types of standstill deceleration situations (speed limit changes from 70 km/h respectively 50 km/h to 0 km/h) and two different types of dynamic deceleration situations (speed limit changes from 100 km/h to 70 km/h and 100 km/h to 50 km/h).

Besides the objective evaluation of the driving parameters, an introductory interview on demographic data and driving experiences as well as questionnaires on the acceptance of the HMI versions are evaluated. The acceptance evaluation reported here is done via the nine item scale developed by [Van Der Laan et al. (1997)], which measures satisfaction as well as the usefulness of the system using semantic differentials.

Altogether the test persons performed an introduction drive (to get familiar with the simulator) and three test drives with three different versions of the developed HMI:

1. Baseline: No visual and haptic advice activated
2. Visual: Visual advice activated. No haptic feedback and advice on the acceleration pedal
3. Visual & haptic: Visual and haptic advice are activated

All three versions used the situation preview to announce the next driving situation in advance. The order of the versions on test drives was randomized to balance practice effects on the three versions alike. For all three test-drives, the battery status was set to a low level indicated in red to provide a plausible reason for energy efficient behaviour. However, motivation in this study can be assumed to be lower than the motivation to reach a self-selected destination in real life. Before the first test drive the introductory interview was conducted. In addition, interviews with test specific questionnaires were undertaken before, between and after the drives to receive ratings on acceptance.

### 3.2. Evaluation results

The sample consisted of twenty-seven (8 female, 19 male) participants. Seven of the test persons were in the age between 62 and 70 (M = 65 years) and twenty in the age between 20 and 28 (M = 25 years). The age groups are not be evaluated separately in this paper. Subjects had different driving experiences between 100 km/year and 60,000 km/year. For the objective evaluation in deceleration situations only subjects that recuperated in all deceleration situations (N= 23 subjects for standstill deceleration situations; N= 15 subjects for dynamic deceleration situations) were evaluated to create an equal basis for the comparison.

The results of the acceptance evaluation [Van Der Laan et al. (1997)] are shown in Fig. 4 a. The systems were evaluated before and after the drives contrary by the subjects. While the visual-haptic system received higher ratings after the drive for “satisfying” [visual-haptic: t(25) = 2.59, p < .05], but not for usefulness [t(25) = 1.3, p = .2], the visual system received significantly lower ratings after use than beforehand on both scales [satisfying: t(25) = 2.25, p < .05; usefulness: t(25) = 2.94, p < .01]. A comparison of all three systems after the drives shows significant differences regarding “usefulness” [F(2.50) = 16.51, p < .01]. A post-hoc pair wise comparison shows that the visual system (MD = 0.7, p < .05) and the visual-haptic system were rated significantly better than the baseline (MD = 1.24, p < .05). In addition, the visual-haptic system was rated better than the visual system (MD = 0.54, p < .05). For the factor “satisfying”, no significant differences were found between the three systems [F(2.50) = 1.62, p > .2].

Next to the subjective evaluation, three objective driving parameters as described above were evaluated to compare the impact of the developed systems on driving behaviour. The comparison of the time between optimal start of recuperation manoeuvre regarding energy efficiency and the drivers’ start of the recuperation manoeuvre Δt_{recuperation} (Fig. 4 b) shows significant differences between the three systems for both kind of deceleration situations [standstill: χ² (2) = 19.91, p < .001; dynamic: χ² (2) = 20.93, p < .001]. A post-hoc pair wise comparison shows that the subjects meet the optimal time to start a recuperation manoeuvre regarding energy efficiency significantly better with the visual (standstill: p < .005; dynamic: p < .05) and the visual-haptic (standstill: p < .001; dynamic: p < .001) system compared to the baseline system. Between the visual and visual haptic system no significant differences can be observed (p = .13).
To investigate if people only improve the timing when to begin a recuperation manoeuvre or if they also use more of the recuperation potential by recuperating as long as possible, the ratio of time recuperation advice was followed to the recuperation advice was active, $t_{\text{followed}}$, was evaluated. The results are shown in Fig. 5 a. A comparison over all three systems shows a significant difference between them [standstill: $\chi^2 (2) = 18.00, p < .001$; dynamic: $\chi^2 (2) = 8.4, p < .05$]. A post-hoc pair wise comparison for standstill deceleration situations shows equivalent results to the evaluation of $\Delta t_{\text{recuperation}}$ with significant differences between baseline and both systems (compared to baseline: visual: $p < .05$; visual-haptic: $p < .001$). Between the visual and visual-haptic system no significant difference can be observed ($p = .231$). For dynamic deceleration situations the post-hoc pair wise comparison shows a significant difference between the baseline and the visual-haptic system (visual-haptic: $p < .05$), but neither between the baseline and the visual system nor the visual and the visual-haptic concept ($p > .08$). This evaluation shows that the subjects with the visual-haptic system not only meet the optimal starting point of a recuperation manoeuvre better but use in addition more potential of the recuperation manoeuvre to save energy and to extend the range of their electric vehicle.
In constant driving situations a smoother speed profile and lower speeds lead to a more efficient way of driving. To investigate the effect of the developed system on that, the average and standard absolute deviation between advised speed and driven speed ($\Delta \nu$ and $\sigma_{\Delta \nu}$) have been evaluated. The deviations are shown in Fig. 5 b. The overall comparison shows a significant difference between the systems [$F(2.48) = 8.5$, $p < .005$]. A post-hoc pairwise comparison shows a significantly enhanced performance of the subjects with the visual-haptic system compared to both other systems (compared to baseline: $MD = -1.8$, $p < .001$; compared to visual: $MD = -1.5$, $p < .05$).

Overall, the objective evaluation of the driving simulator study shows that the visual-haptic system has a positive impact on driver behaviour regarding energy efficiency compared to a baseline system in all investigated situations. The visual system enhances performance in all situations except dynamic deceleration situations when compared to the baseline. In constant driving situations, the results show additionally a significantly enhanced performance of the subjects with the visual-haptic system compared to the visual system.

4. Summary

This paper presented an on-trip visual and visual-haptic advice and pre-view system, developed with the goal to guide drivers to a range optimized way of driving electric vehicles. It is part of an overall HMI concept and it addresses one of the two key points of effort based on [Campbell and Pritchard (1976)], i.e. skills. The other key point – motivation – is addressed by further elements of the developed HMI, which are not introduced in this paper.

The results of an impact study for the evaluation of the visual and visual-haptic advice and pre-view system are given.

The developed visual system in the instrument cluster consists of a situation preview and advice elements. The advice elements mainly focus on recuperation situations and provide information about the best time to start a recuperation manoeuvre regarding energy efficiency so that the vehicle will reach the next situation with the aimed speed without using the brakes. For that purpose the system shows the driver a recuperation symbol when he has to initiate a recuperation manoeuvre. This symbol is also shown in advance in the situation preview to prepare the driver. At the time visual advice is given, additional haptic advice by a pulsation on the acceleration pedal is provided. Next to prepare drivers for advice the situation preview shall support driver skills by providing information about upcoming situations (type and distance) like e.g. speed limit changes after a curve. The preview therefore further supports the advice elements by providing reasons for them.

To investigate the impact of the developed elements on driving behaviour a study with twenty-seven participants was conducted with three different configuration levels of the HMI in a static driving simulator. A baseline version, with no advice at all, a visual version with visual but no haptic advice, and a visual-haptic version with both types of advice, visual and haptic, was investigated. The situation preview was part of all versions.

The results of the acceptance evaluation using the nine item scales by [Van Der Laan et al. (1997)] show that drivers rated the visual-haptic version significantly better regarding “satisfying” after the drives than before and the visual version significantly worse regarding “usefulness” after the drives. The evaluation of all three systems after the drives shows significant differences regarding “usefulness”. It also shows that the visual-haptic system was rated best. The objective evaluation shows that the developed visual-haptic version has a significant positive impact on driver behaviour regarding energy efficiency compared to the baseline version in all investigated situations. In constant driving situations the results show in addition a significantly enhanced performance of the subjects compared to the visual system, although the effect seen in this study is small. The behaviour of drivers using the developed visual system was significantly better in almost all investigated situations, except dynamic deceleration situation, compared to driving with the baseline system.

In conclusion, a positive impact of the developed advice and preview system on a range optimized way of driving in electric vehicles could be shown by the conducted study. The better performance of the subjects with the visual-haptic advice system compared to the visual system has to be proven in real-world studies. Follow-up activities are ongoing.
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