Influence of a Multimodal Assistance Supporting Anticipatory Driving on the Driving Behavior and Driver's Acceptance

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Abstract. This work presents an investigation of a multimodal human-machine interface (HMI) of an anticipatory driver assistance system. The HMI of the system consists of visual indicators displayed in the digital instrument cluster and discrete impulses of an active gas pedal (AGP). The assistance recognizes the upcoming driving situation, informs the driver about its emergence, and suggests a driving action, which execution assures significant reduction in fuel consumption. The experiment is performed in the fixed-base driving simulator. Results show that during assisted drives an average reduction in fuel consumption amounts to 7.5%, in comparison to the drives without assistance. In 50% and 80% of all the cases, participants release the accelerator correspondingly within 1.2 and 2 seconds after receiving the first information. Two thirds of the test subjects grade the concept as "good" and "very good". The participants appreciate AGP discrete feedback especially in rare, unexpected, and potentially critical situations.

Keywords: Advanced driver assistance system, multimodal human-machine interface, anticipatory driving, active gas pedal.

1 Introduction

Due to the continuing development of traffic information sources, advanced driver assistance systems (ADAS) gain the possibility to inform drivers about an upcoming traffic situation before it becomes visible. These sources are e.g. detailed digital maps, far-field radar systems, car-to-car (C2C), and car-to-infrastructure (C2X) communication systems [1], [2]. This early information via ADAS can help to reduce fuel and increase safety, i.e. by supporting coasting[1] phases and alerting the driver about upcoming safety-critical situations.

The objective of this study is to investigate the effect on driving behavior of a multimodal assistance system, which expands the driver's natural anticipation horizon on the maneuvering level [3] by presenting information about upcoming deceleration situations and suggesting beneficial driving action even if the situation cannot be seen

[1] Coasting a vehicle – exploitation of motor torque during deceleration phases via releasing the accelerator and not depressing the brake pedal.

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yet. The benefit is defined in this work as increase in efficiency (reduction in fuel consumption), comfort (reduction of strong decelerations), and safety (reduction of extreme decelerations and collisions).

2 Experimental Design

In the following, information about the investigated assistance concept, test subjects, hardware and software tools used for the implementation of the test course and analysis, as well as descriptions of all investigated deceleration situations are provided.

2.1 Investigated Assistance Concept

The concept consists of a visual assistance based on a bird's-eye view perspective on the situation (in the following called as "visual Bird's-Eye View HMI concept"), and discrete impulses of the accelerator. The visual part of the HMI is presented to the driver in the instrument cluster. It is based on the preceding work of [4]. A similar concept of a discrete AGP is also investigated in the work of [5].

The so called Bird's-Eye View HMI depicts a virtual road scenery including the ego vehicle, and the emerging deceleration situation. This HMI possesses continuous characteristics: the presentation of the ego vehicle on the occupied lane is permanently displayed in the instrument cluster. The deceleration situation is superimposed on the virtual road when such is detected, e.g. in Fig.1 a situation involving a slower preceding vehicle and a traffic light.

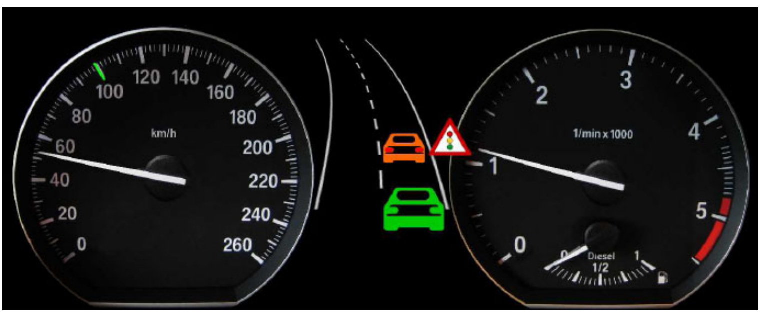

Fig. 1. Bird's-Eye HMI

The legitimate traffic sign corresponding to the deceleration situation is shown at the side of the virtual road to enhance the comprehensibility of the emerging situation. This information appears at the point of time when the so-called beginning of the optimal coasting phase should start. It is an efficiency optimized action, which assures sufficient reduction of speed solely via engine braking. Also the color coding of the displayed driven vehicle from white to green suggests the start of coasting.

If pure coasting is not sufficient to reach the required lower speed, the color of the ego vehicle changes to orange to suggest active braking by depressing the brake pedal. It is left to the driver to decide with which strength to brake. Further information about the visual concept can be found in [6].

Simultaneously with the activation of the Bird's Eye HMI the driver receives a discrete impulse of the AGP (see Fig.2). This haptic component of the multimodal assistance indicates an oncoming change of the current traffic situation and it encourages the driver to release the gas pedal. As it is shown in [7], the AGP activation helps drivers to react more rapidly in comparison to a HMI concept, which only consists of the described visual interface without AGP support (reviewed in [8]).

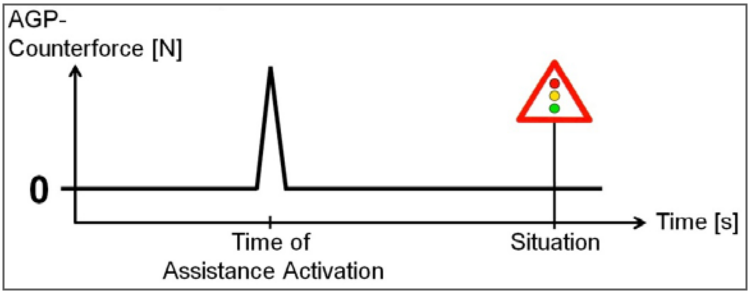

Fig. 2. Operating mode of the Active Gas Pedal

2.2 Subjects

Thirty participants (twenty five male and five female) took part in the experiment. All of them hold valid category B German driving licenses. The average age of the test subjects is thirty seven years (standard deviation, sd = 15.2 years). The driving experience varies: nine participants drive less than 10.000 km per year, fourteen – between 10.000 km and 20.000 km, and seven – more than 20.000 km per year.

2.3 Hardware and Software Tools

The experiment is performed at the fixed-base simulator located at Lehrstuhl für Ergonomie, Technische Universität München. A field of the driver's front view of 180° is used. The landscape and driving environment are simulated using SILAB software [9], which allows flexible and precise creation of the driving situations including the control over simulated traffic. The driving data of the test vehicle as well as relevant situational data, e.g. distance and speed of other traffic participants, are recorded at 60 Hz within the SILAB framework. The descriptive analysis of the driving data is done with MATLAB and Excel, the statistical analysis is performed using SPSS.

2.4 Simulated Test Course

Each one of the test subjects drives the simulated test course two times in permuted order: without the assistance (in baseline condition) and with the multimodal assistance. The goal and functionality of the visual and haptic assistance is explained to the test subject by a handout before the experiment starts. Moreover all questions concerning the assistance concept are answered. The test subjects pass an introductory drive before the experiment starts. One experiment drive lasts between seventeen and twenty minutes, during which the test subjects cover a 24.5 km long drive and are confronted with twelve different deceleration situations: Seven situations on a rural road (RR), three on a highway road (HR) and two urban situations (UR). The situations systematically differ in the length of the suggested coasting phase and their criticality. The order of deceleration situations and surrounding landscape is changed in the two drives to avoid recognition effects. In the following the description of all investigated deceleration situations is provided.

Situations on a Rural Road. "RR Construction site behind a curve on a straight segment". This situation occurs on a two-lane rural road, where the permissible speed is 100 km/h if not explicitly changed by other speed limit signs.

The test subject has to decelerate in front of a construction site located on the driven lane in order to let the oncoming cars pass. The site is located 200m after a right curve. The situation becomes visible at the distance of 200m-250m before the construction site, while the optimal coasting phase assuring efficiency benefit lasts 600m.

"RR Construction site in a right curve". The difference to the previously described situation is that the construction site is located directly in the curve. The driver is able to see the situation at the distance of 450m before the site.

"RR Speed limit". The driver has to decrease the driven speed down to 70 km/h due to an incoming sharp curve in this situation. The sign becomes visible approximately 170-200 m before it is reached, while coasting from 100 km/h down to 70 km/h lasts 500 m.

"RR Speed limit and slower lead vehicle". The driver has to decrease the driven speed down to 70 km/h. The speed limit sign becomes visible approximately 100 m before it is reached, because the sign is located in a curve. At the time when the driver sees the sign he also recognizes a slower leading vehicle driving also at 70 km/h.

"RR Town entrance". The driver has to decrease speed to 50 km/h when entering an urban area according to German traffic regulation rules. Even though this investigated situation is well-visible at larger distances, it is still unclear if the driver without assistance starts coasting early enough to perform the efficient deceleration maneuver. Coasting from 100 km/h to 50 km/h lasts 800 m.

"RR Slower preceding vehicle in the vicinity of prohibited overtaking". On a two lane rural road, the driver is confronted with a slower vehicle driving 80 km/h in the vicinity of prohibited overtaking. The situation is well-visible, optimal coasting lasts 110 m.

"RR Slower preceding vehicle and oncoming traffic". Drivers approach a vehicle driving 60 km/h on a rural road. Optimal coasting lasts 220 m. They are allowed to overtake it after the opposite lane is free from the oncoming traffic.

Situations on a Highway. "HR Speed limit". The allowed speed before this highway segment is 130 km/h. In the situation, the allowed speed is set down to 100 km/h. The Situation becomes visible about 300 m after the beginning of the optimal coasting phase (which is 450 m long) should have taken place.

"HR Stagnant traffic". The driver approaches a traffic congestion moving at 60km/h on the highway. This situation is well-visible and occurs shortly after "Speed limit on the highway". Optimal coasting lasts 220 m.

"HR Highway jam". This is the most critical situation investigated in the experiment. Drivers are driving on the highway with a speed of 130 km/h. They approach a curve behind which idle vehicles are located on all of the lanes. This jam tail becomes visible 250-300 m before the driver has to come to a stop.

Situations in Urban Environment. "UR Parking car and oncoming traffic". The permissible speed limit is 50 km/h in a town. In this situation, the driver has to decelerate because of a parking car occupying the driven lane. After the oncoming traffic on the opposite lane has passed, the driver can overtake the obstacle. The situation becomes visible at the distance of 140 m, so the driver has to brake slightly.

"UR Red traffic light". The traffic lights are in red phase before the driver approaches them. So he has to stop in front of them before he can pass. The suggested coasting phase lasts around 450 m.

2.5 Dependent Variables

The focus of the presented analysis is put on the reduction of the estimated fuel consumption and reaction times in the investigated situations.

The estimated fuel consumption is calculated for the entire drive course, and situation segments. An analyzed situation segment starts where the optimal coasting should begin when driving the permissible speed plus 100 m to take faster driving test subjects into account. It ends when the situation is bypassed.

In a safety critical situation, the analyzed segment begins 1000 m before it, which is the point at which an early comfortable braking not exceeding $-3m/s^2$ [10] should take place in order to avoid collisions.

The reaction time is defined as the time gap between the activation of the multimodal system and the point of time at which the driver steps of the accelator.

3 Results

This chapter presents the summary of the efficiency benefit reached during assisted drives and reaction times of the drivers on the assistance suggestions. Furthermore the general user acceptance of the haptic feedback via AGP, as well as detailed description of the results in every of the investigated deceleration situations is presented.

3.1 Situational Analysis of the Driving Behavior

Generally the release of the gas pedal after the corresponding multimodal advice is being issued by the system follows within the next 0.8 s[2] to 4.0 s[3]. In nine out of the twelve situations the 75% percentile of the reaction time is 1.75 s. These nine situations cover all highway and rural situations except "RR Slower preceding vehicle in the vicinity of prohibited overtaking". In this situation the 75% percentile is 3.99 s while the 50% percentile is 1.04 s. The slower preceding vehicle is visible to the

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[2] Minimum of 50% percentile.

[3] Maximum of 75% percentile.

driver for a long time so the driver is able to react proper in this common situation without assistance. In the two urban situations the reaction takes place within 2.3 s in the 75% percentile.

The fast reaction times and, as a consequence, the long coasting phases lead to a significant reduction in fuel consumption. So throughout the entire drive, the test subjects are able to reduce fuel consumption on average 7.5% with activated assistance (estimated fuel consumption during baseline drives: Ø=100.0%, sd= 16.2%; assisted drives: Ø=92.4%, sd= 12.0%).

The visual distraction due to the proposed visual concept of the assistance system is investigated in a previous study and does not possess any critical or driving endangering character [6].

In most of the analyzed situations, the average reduction of the fuel consumption while driving with assistance ranges from 15% to 35%. This occurs due to the longer coasting phases which are being proposed by the assistance system, and, as a general rule, are reflected by the driver's corresponding actions as it is shown above. Exceptions are the situations which are visible to the driver before the optimal beginning of a coasting phase should take place and its length is below 200 m, and therefore also without the assistance drivers act efficiently: "RR Slower lead vehicle in the vicinity of prohibited overtaking", "HR Stagnant traffic", and "UR Parking car and oncoming traffic".

A noticeable benefit is established in situations, in which drivers get the coasting suggestion before they are able to perceive the situation on their own. 30-35% of fuel is saved in the situations "RR Construction site behind a curve on a straight segment", "RR Speed limit", "RR Speed limit and slower lead vehicle". Approximately 25% of the fuel is reduced due to the system's advice in "UR Red traffic light" situation, 20% - in "RR Construction site behind in a right curve", 15% - in "RR Slower preceding vehicle and oncoming traffic".

The greatest reduction of 60% by following the system's advice is achieved in the situation "RR Town entrance". The town is visible to the driver from larger distances, but during the baseline drives nobody prefers to decelerate to the target speed purely through coasting. The experienced coasting phase with the activated system of 800 m is subjectively perceived by test subjects as extremely prolonged, and AGP feedback has a vast patronizing character (discussed further in this paper). However, the test subjects decide to follow the advice in the experiment drive.

The results regarding "HR Speed limit" are following: baseline drives Ø=100%, sd=50%, assisted drives Ø=47%, sd=118%. Eleven test subjects decide to accelerate during assisted drives again after initially performing the coasting phase, which is reflected in standard deviation.

Detailed explanation of the driving behavior can be found in [7].

3.2 Results Regarding the Drivers Acceptance

In Fig. 3, the number of participants who evaluate the influence of the multimodal assistance system in particular situations as helpful, neither helpful nor irrelevant, and irrelevant are provided. In the very critical situations "HR Highway jam" none of the drivers evaluates the system negative. Other critical situations like the construction sites on the RR, the "HR Stagnant traffic" situation and the noncritical situations with

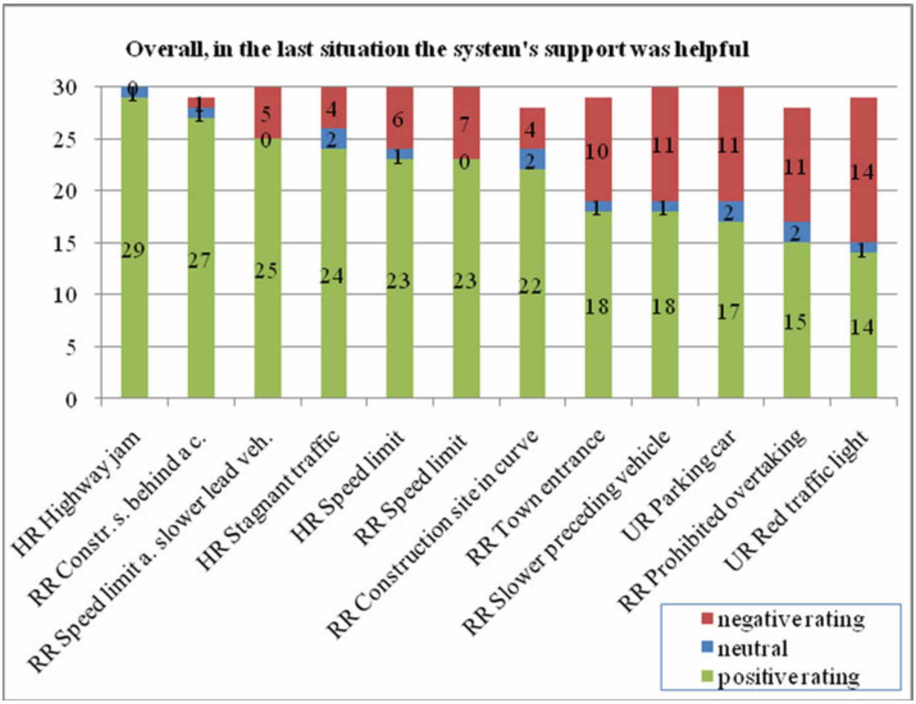

Fig. 3. Results regarding helpfulness of AGP activation in different deceleration situations

speed limits are also assessed very positive by the majority of the drivers. More than half of drivers estimate the system as helpful in "RR Town entrance" and "RR Slower proceeding vehicle and oncoming traffic". The acceptance of the system declines in the two analyzed urban situations and "RR Slower leading vehicle in the vicinity of prohibited overtaking". In the urban situation with a parking car and the prohibited overtaking on a rural road the suggested coasting phases are less than 200 m and the drivers are able to perform these well by their own without assistance. The situation "UR Red traffic light" suggests a very long coasting phase of 450 m and therefore the acceptance drops down.

The results regarding AGP appeal to the test subjects in deceleration situations are following: eight test subjects do not show any interest in the currently proposed concept of AGP assistance (two of whom clearly state their dissatisfaction), 21 participants find the concept as "good" or "very good", and one test subject cannot decide. However, the comments of four test subjects which do not like the current AGP activation strategy show that they could imagine great benefit of the discrete AGP assistance in very rare, critical situations. This also complies with the summary of the rest of the comments, in which the participants value the AGP activation especially in seldom, unexpected, and critical situations. Overall, it can be stated that test subjects perceive haptic assistance in form of discrete impulses of the gas pedal in deceleration situations rather as a warning, than as information indications for a fuel saving strategy. However, inter-subjective opinion on which situations one should be warned and AGP is “not patronizing” differs. Almost in every situation the majority of test subjects admit the helpfulness of the AGP feedback for reduction of fuel consumption, though in urban situations this number considerably decreases.

An important factor influencing the acceptance of AGP is the negative feeling the user gets when feeling patronized by the system (Fig. 4.). In urban situations and situations which can be seen early enough to undertake an efficient deceleration strategy without any assistance the negative patronizing effect of AGP is especially obvious (“UR Parking car and oncoming traffic”, “RR Town Entrance”, “UR Red traffic light”, “RR Slower preceding vehicle in the vicinity of prohibited overtaking”, “RR Slower preceding vehicle and oncoming traffic”). The majority of the test subjects in these situations either explicitly stated their dissatisfaction, or never experienced the assistance activation because they themselves were taking the optimal course of driving actions. The presence of urban situations in this category should not lead to a conclusion that no assistance would be accepted in the investigated situations.

A high quota of participants felt patronized by AGP when approaching speed limit signs: 14 test subjects in both situations “RR Speed limit and slower lead vehicle” and “HR Speed limit”, 13 – in the situation “RR Speed limit”.

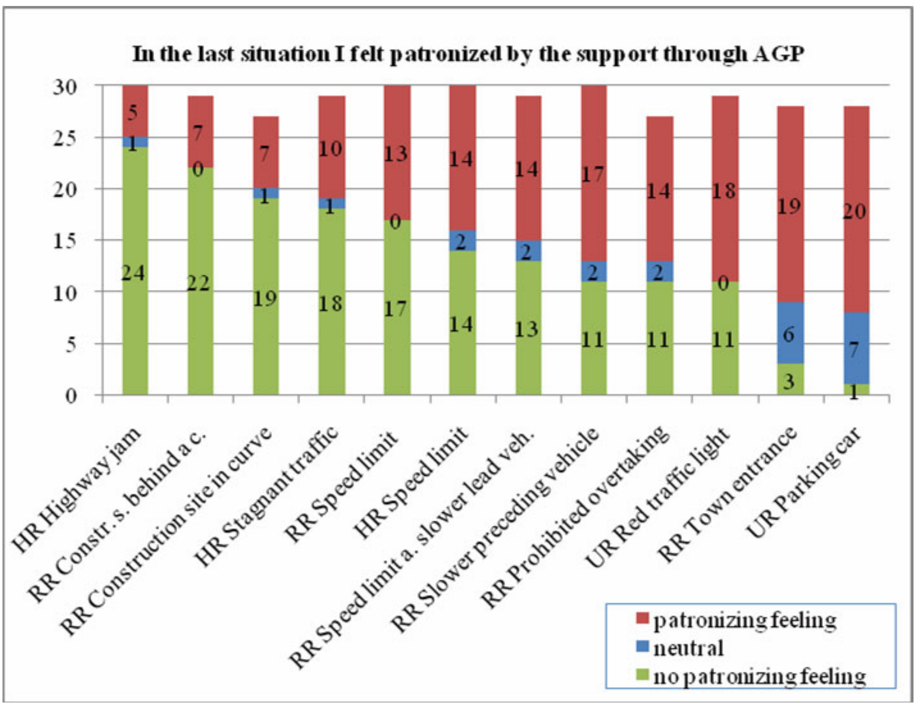

Fig. 4. Results regarding patronizing feeling experienced by the user with AGP activation in different situations

The acceptance of the AGP advice without feeling patronized is comparatively high in the highway and rural road situations, which cannot be perceived by the driver early and possess unexpected character ("HR Highway jam", "RR Construction site behind a curve on a straight segment", "RR Construction site behind a right curve"). Also the situation "HR Stagnant traffic" is considered by the test subjects as potentially critical, and therefore AGP advice is perceived as applicable.

23 out of the 30 test subjects see the potential benefits of the proposed concept and would be ready to activate it on the highway roads, and 21 on rural roads.

Detailed explanation of the driver's acceptance can be found in [7].

4 Summary

The study presents an investigation of a multimodal human-machine interface (HMI) of an anticipatory driver assistance system. The HMI of the system consists of visual indicators displayed in the digital instrument cluster and a discrete impulse of the active gas pedal (AGP). The assistance recognizes the upcoming driving situation, informs the driver, and suggests the driving action, which execution assures significant reduction in fuel consumption.

The experiment was performed at the fixed-base driving simulator located at the Lehrstuhl für Ergonomie, Technische Universität München. 30 test subjects took part in the experiment; their average age was 37 years. The twelve included deceleration situations systematically differ in their criticality and the duration of the suggested coasting phases. In the fixed-base simulator experiments, the quantitative values for some of the driving measures may differ from those of real drives. However, a clear tendency can be derived.

In 50% of all cases the participants step of the gas pedal for the first time within 1.2 seconds after the first information. In 80% of all cases the reaction takes place within 2 seconds. Throughout the entire drive, the test subjects are able to reduce fuel consumption on average by 7.5% with activated assistance. This occurs due to the fast reaction and longer coasting phases which are being proposed by the assistance system, and, as a general rule, are reflected in driver's actions.

The results regarding AGP appeal to the test subjects in deceleration situations are following: eight test subjects do not show any interest in the currently proposed concept of AGP assistance (two of whom clearly state their dissatisfaction), 21 of the 30 participants assess the concept as "good" or "very good", and one test subject cannot decide. Overall, it can be stated that test subjects perceive haptic assistance in form of discrete impulses of the accelerator in deceleration situations rather as a warning, than as information indications for a fuel saving strategy.

Up to 80% of the test subjects prefer activation of an AGP on rural and highway roads, especially in the situations which cannot be perceived at larger distances, which are considered to be of rare occurrence, and which can demand extreme decelerations if the driver is not informed in advance. Such situations include construction sites on rural roads, stagnant traffic and jams on highways. Situations with slower moving vehicles are excluded from the list where AGP assistance would be welcomed. It can be concluded, that the haptic impulse of the gas pedal is subjectively felt as a warning regarding approaching deceleration situations, rather than an advice to coast a vehicle for a gain in fuel consumption. Low interest for AGP is observed in the investigated urban situations.

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