Integrated HMI Concept for Driver Assistance and Automation

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Abstract

The present study describes the development of an integrated ADAS HMI concept within the European-funded research project *interactIVe*, its implementation and user-centred validation in a driving simulator. The HMI concept integrated visual, haptic and acoustic information-, warning- and intervention (IWI) strategies, and allowed the driver to select between three different assistance and automation levels. The concept was implemented in the fully interactive Ford HMI driving simulator and was validated in an empirical user study with N=24 participants. The vast majority of the sample was positive about the idea of integrated assistance functions integrated in three selectable modes. Good comprehensibility and learnability of the mode selection concept could be proven. The visual display concept with safety zone segments around the vehicle - representing the safety-shield metaphor - was positively recognized. User feedback and observation results also revealed some weaknesses in system usability. Detailed suggestions for improvement could be derived.

1 Introduction

The European research project interactIVe (Alessandretti et al. 2014) addressed the development and evaluation of next generation safety systems for intelligent vehicles. A wide range of safety applications was developed in order to integrate vehicle architecture, components and Human-Machine-Interaction concept.

From an HMI perspective the biggest challenge was: How to integrate all this different lateral and longitudinal safety intervention functions (e.g. Emergency Steer Assist and Rear-end Collision Avoidance) in combination with different levels of semi-automated continuous driving? (Figure 1)

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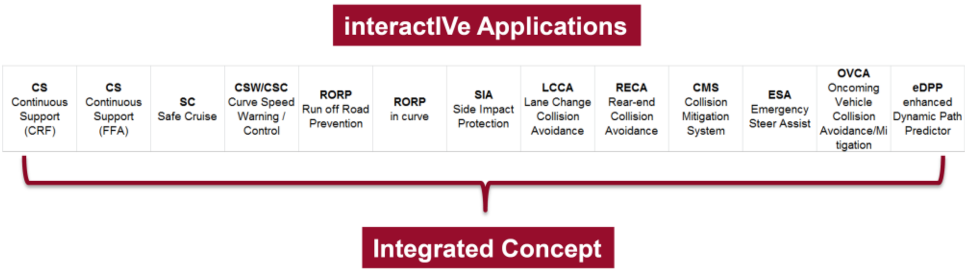

Figure 1: Range of safety applications and continuous, semi-automated driving support functions

On the basis of scientific literature and use case analysis the interactIVe information, warning and intervention (IWI) (Hesse et al. 2011) strategies have been developed as a set of guidelines and recommendations which is referring to how, when and where information, warnings, and interventions should be activated in hazardous situations or during semi-automated driving. Based on these IWI strategies, a comprehensive framework for a display and control concept was designed. As a result, both the IWI strategies and the HMI design concept were applied to the various interactIVe demonstrator vehicles (Brockmann 2013).

2 Integrated HMI Concept for Driver Assistance

The concept offers three levels of assistance and automation as selectable modes. The lowest level of assistance, called *Alert* mode, provides longitudinal and lateral warnings about possible collisions, running-off road, or too high speed in curves. The mid level, called *Active* mode, issues warnings and advices by applying haptic torque feedback at the steering wheel and the accelerator pedal together with visual and auditory warnings to actively inform about longitudinal and lateral collision threats. The Active mode must be enabled via steering wheel control. The third level, called *Assisted* mode, provides autonomous longitudinal and lateral support comparable to a full-range Adaptive Cruise Control in combination with a permanent lane keeping system, allowing hands-off steering wheel driving (SAE Level 3 Automation, see SAE 2014). The Assisted mode can be enabled or disabled at the steering wheel and additionally disabled via brake pedal activation.

In all three drive modes the system gives permanent visual feedback about the system's availability status. The display is located in the instrument cluster. The graphical representation makes use of the direction-criticality/distance-metaphor (Lindberg et al. 2009). Four segments spaced around the ego-vehicle shall give the impression of a 360° "protection shield". Shield segment elements are activated to indicate dangerous situations, and subsequently turn the colour into light-red or red (see Figure 2) to point to the hazard and the direction of the hazard.

Another design principle used in this approach was the grouping of the assistance levels on a one-dimensional automation scale (Flemisch et al. 2008) starting from the lowest automation mode ending with the highest automation level.

Figure 2: Safety shield metaphor in different use case examples (from left to right): blind spot warning, side impact warning, curve speed control, forward-collision alert

This was visually displayed by showing a mode selector box with Alert at the bottom, Active in the middle to Assisted at the top (see Figure 3). During selecting or changing a mode the mode selector box pops-up in full size.

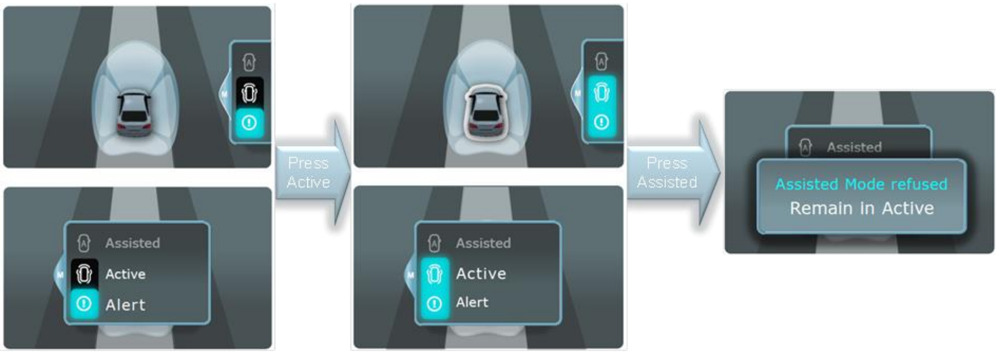

Figure 3: One-dimensional mode selector box with available and non-available modes (small and full size view)

The operation was realized by utilizing dedicated steering wheel buttons for each mode and a mode selector box switch. The strategy implied to select each mode in two-step activation in order to avoid unintended activations (see Figure 4).

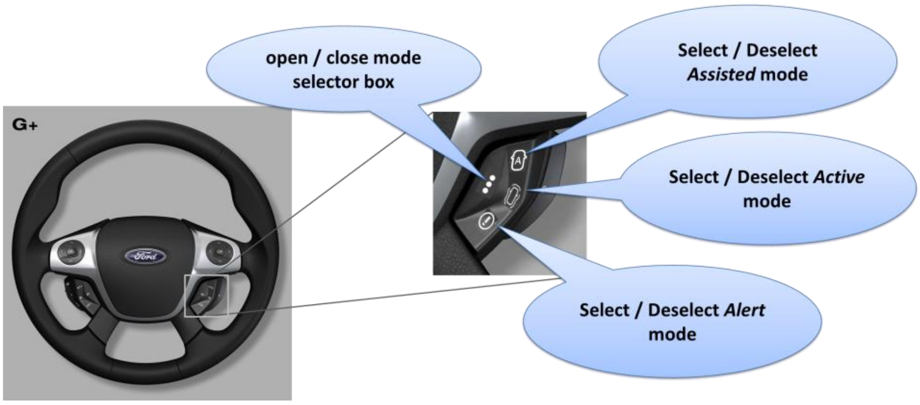

Figure 4: Operation via steering wheel controls

Spatial audio signals are used for longitudinal and lateral warnings coming from front and side speakers (longitudinal threat = front / lateral threat = left or right side). The warning sounds implemented in the simulator were Earcons: nonverbal audio messages in terms of synthesized tones (E.g. for longitudinal warnings a CAMP-style earcon was chosen utilizing a “looming” effect giving the sensation of something approaching). Furthermore, an acoustical signal occurred during mode transitions in order to confirm or reject a certain transition and also to inform about the direction of the transition: the Earcon for entering a higher automation mode was a short sequence of increasing tones; a sequence of decreasing tones confirmed the transition to a lower mode.

An Accelerator Force Feedback Pedal (AFFP©) from partner CONTIT has been implemented in the fixed-based driving simulator. The AFFP is an accelerator pedal with an integral electric motor (Leone et al. 2010) capable to apply counter-forces, vibrations or “ticks” to the driver’s foot. Steering wheel vibrations and forces up to 5Nm were used to simulate lane centring assist (as part of Assist mode) or lane keeping aid function (as part of Active mode). Forces were applied depending on lane width, lane position, time-to-line-crossing, vehicle speed and driver input.

3 Validation

3.1 Methodology

Main research questions addressed in this study were 1) Does the driver intuitively operate and use the system without causing mode confusion? And 2) Is the Integrated Driver Assistance system positively evaluated by the driver and fully accepted?

Twenty-four subjects participated in the study (12 females, 12 males). They were recruited from a Ford-internal employee panel from non-technical departments. The average age was 41.6 years (SD: 11.3 years, ranging from between 24 to 59 years). Participants held their driving license for a minimum of 5 years (M = 24.6 years) and drove for an average of 20130 km per year (SD: 10450 km). About 76% of the sample was familiar with Cruise Control Systems; with Adaptive Cruise Control at least 34%, Lane Departure Warning (31%), Forward Collision Warning (31%), Blind Spot Detection (31%) or Active Parking Systems (34%).

During a two hours’ simulator drive each participant experienced all three modes in different driving scenarios (on 3-lane motorway, different longitudinal and lateral warning scenarios at speeds of speed 80-120 kph, Stop-and-Go scenario in motorway traffic jam). For measuring how intuitive the mode change operation is, half of the sample was instructed about the system operation; the other half did not receive any information in preparation of the simulator study. Dependent measures were task success rate and time-on-task by observation (The time interval between receiving an operation task and performing it successfully) as well as system assessment with regards to usability, comprehensibility, and acceptance by means of a written questionnaire. Also qualitative data was gathered via Think-Aloud Protocol. The study was executed in a fixed-based driving simulator located at the HMI department of Ford Werke

GmbH in Cologne, Germany. The driving simulator environment consists of a seamless 180° horizontal forward panorama view with additional rear view mirror displays and back view LCD screen.

3.2 Results

To investigate the intuitiveness of the system operation, the participants were asked to control the system by switching from the actual mode to another mode, first in standstill, after that during driving on a motorway with 120kph. Providing operation instructions or not had only a limited effect on the task performance: Although not significant (*T-test:* $t = -1.189$, $p <= 0.2471$), the participants without information (*M=28.62s, SD=22.74s*) needed 10 seconds more time to accomplish the first task than the informed sample (*M=18.27s, SD=19.83s*). Analogue to that the previously instructed participants needed between one and seven attempts (*M=2.92, SD=1.92*) for the correct first-time mode activation. The participants that were not instructed before their first drive executed the task with a slightly higher number of attempts (*Between 1 and 8 attempts, M=3.25, SD=2.01*).

However, the difference between the two experimental groups disappeared almost completely after the first repetition (Figure 5).

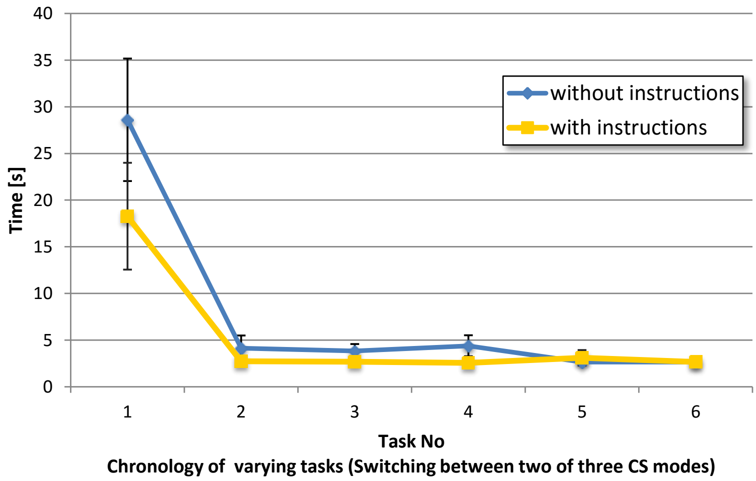

Figure 5: Time-on-Task performance for stationary mode change operation tasks as a function of task number (Error bars show +/- 1 Stan-dard Error)

In a second set of control operations the same series of tasks had to be performed during driving with the task to keep lane at a constant velocity of 120kph. The influence of previous instructions was comparable to the results from the stationary tasks: Only first task revealed a slightly shorter time demand (see Figure 6) of the informed sample (*M=3.6s, SD=3.13s*) versus the uninformed participants (*M=5.65s, SD=5,21s*) but without significance (*T-test:* $t = -1.067$, $p <= 0.2976$).

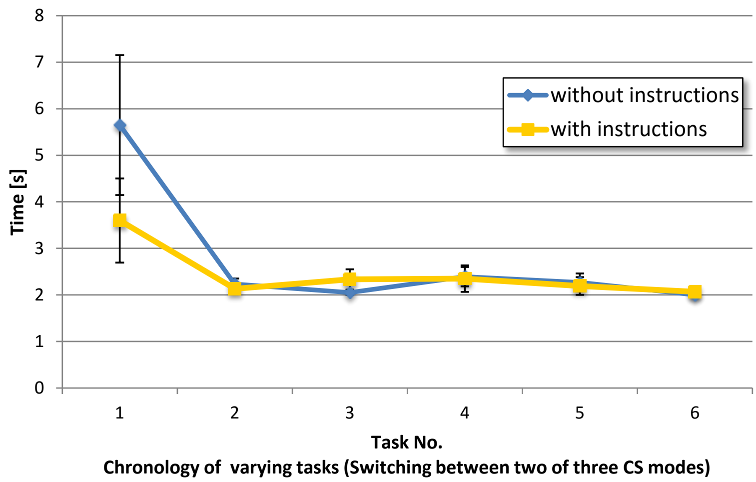

Figure 6: Time-on-Task performance for mode change operation tasks during driving as a function of task number (Error bars show +/- 1 Standard Error)

After completing the test drive, the participants were asked to assess the operability of the system in general: Overall, the system was not directly self-explanatory but quite easy to operate from the drivers' viewpoint. No significant differences between the two experimental groups could be found. A central topic of system comprehensibility was the understanding of the visual and acoustic mode indication. The mode indication was rated positively but the influence of having been instructed or not was still obvious.

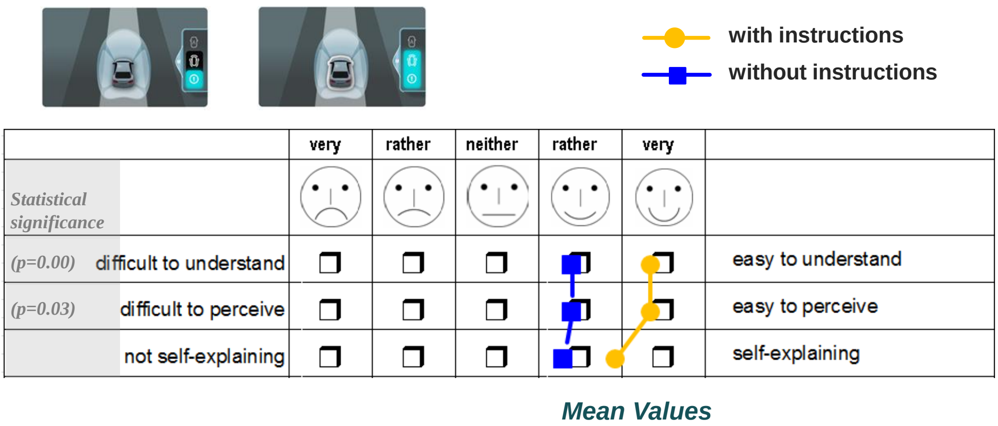

Figure 7: Comprehensibility assessment of visual mode indication for active mode ("How difficult or easy is it to understand which mode is currently active?")

For the pre-informed participants, it was very easy to perceive and to understand which mode was currently active when looking at the display indication (see Figure 7). The without-instruction group assessed the comprehensibility (*T-test: t=2.554, p<=0.00193*) and perceptibility (*T-test:* $t=2.999$, $p<=0.03454$) also positively but significantly less positive. Some criticism was given in the direction of insufficient discriminability. Discriminability between grey and black icons, which were hard to discern, was regarded as insufficient.

Regarding the visual safety shield indication (including the visual indication of other obstacles in the warning case) the majority of the sample rated it as being comprehensible and self-explanatory but they also saw room for improvement concerning number of shields and their proportions.

Feedback about the quality of acoustic and haptic warnings was given: both warning modalities were experienced as easy to perceive, beneficial for safety, helpful, effective, and acceptable. Some criticism pointed into the direction of the steering wheel haptic feedback especially the stronger and more permanent torque applied from the Lane Centering Assist in the Assist mode condition. In this context the steering was described as being “strong” and rather “annoying”. Compared to the trustworthiness of the Alert and Active mode the Assisted mode was seen as less trustworthy (ANOVA: $F=4.271$, $p=0.018$).

From the analysis of the Think-Aloud protocols improvement potential could be found on one hand in a stronger visual discrimination of the mode indication to make the distinction of active and non-active modes clearer. Also a clearer naming of the modes could support the intuitive understanding. But another important enabler for a successful implementation would be that the modes have to be chosen in a way that they reflect real steps on the automation scale rather than being alternative modes with different levels of feedback. The application of a one dimensional automation scale with three sequential modes was accepted but participants also felt it was not adequate in every detail. Currently the visual concept implies that the higher mode covers all functions of the lower mode(s). While the display of these increasing modes was well understood, they also caused some criticism: The automation did not logically increase from mode to mode. There was almost no automation step from Alert to Active but a big step from Active to the Assist function. The modes were rather alternatives than steps on a hierarchical one-dimensional scale. One appropriate option could be to select three single modes disjunctively. In this case the graphical representation would not indicate the lower modes as being active too. The acceptance of systems offering these kinds of automation modes is further highly depending on the availability of customization possibilities for each single mode as well as the possibility to switch the system fully off. Especially acoustic and haptic feedback is sometimes not wanted in a special domain (e.g. at the steering wheel) whereas in another domain (e.g. the force feedback pedal) it is highly desired.

4 Discussion

The pre-information notice had only one clear effect: participants without any instruction perceived the system to be less self-explanatory. But although the system was not seen as self-explanatory it was regarded as easy to operate. Being exposed to the mode switches for the first time was rather problematic in the first attempt. Yet, when exposed for a second time, participants got used to it quite quickly independent from the pre-instruction. This reflects an overall good learnability and usability of system operation. However, instruction seemed beneficial especially with regard to understanding the mode statuses, i.e. whether a certain mode is currently active, available or not-available.

Overall it could be shown that - although the combination of various assistance and automation features is extremely complex – an integrated user interface concept can facilitate easy operation and quick learning. Nevertheless, the increasing number of driver assistance features in the future cannot only be answered by an integrated HMI concept. A more holistic simplification approach towards feature bundling and less complex automation concepts will be essential.

Acknowledgements

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