Ambient light based interaction concept for an integrative driver assistance system – a driving simulator study

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For today’s vehicles several advanced driver assistance systems are on the market supporting the driver in critical driving situations or automating parts of the driving tasks. In the future there will be even more. Currently, those assistance systems do not use a common and consistent interaction strategy to communicate with the driver. The goal of the present study is to present and to evaluate a concept using ambient light for presenting information of different assistance systems in an integrated way. Research on visual peripheral warnings showed positive effects on driver reaction times in demanding situations. This paper presents results of a driving simulator experiment, in which an ambient light concept using peripheral visual perception were tested. A 360° LED stripe was installed around the driver in a fixed-based driving simulator providing interaction signals via peripheral vision. The developed ambient light display should support the driver in different driving situations by a consistent colour-coded interaction design. In a between-group design 41 participants (21 with and 20 without ambient light) drove eight different highway scenarios to test the display. Results of the ambient light interaction design regarding driver reactions and subjective evaluation regarding comprehensibility of the ambient light concept are reported and discussed.

Introduction

More and more of today’s car manufactures develop assistance functions with one main goal: automated driving. Numerous driver assistance systems are already on the market. While some driver assistance systems support drivers in critical driving situations only (Scott & Gray, 2008, Lee et al., 2004), others are able to take over whole driving tasks, such as longitudinal or lateral control (Adaptive cruise control (ACC), lane keeping assist (LKAS)). In specific situations both lateral and longitudinal control can be delegated to the automation (traffic jam assistant). Ironically, the integration of the driver becomes a crucial point on the way to automated driving (Bainbridge, 1983) as the vehicle automation might not be able to handle all driving situations under all conditions when introduced into the market. Thus, different automation levels (SAE international, 2014) will be available in one and the same car requiring transitions of control between the driver and the...
automation. Essential for achieving a good integration of the driver is a good driver-automation interaction design to allow the driver to build up a correct mental model of the overall system and to choose and perform the correct actions if necessary.

For a longer period of time some automated driving functions, e.g. for highway driving, might exist in parallel to various other driving assistance systems that support the driver only in specific driving tasks and situations until automation is available for most of the driving environments. Often, these assistance systems are not designed as an integrative driving assistance system which results in different and inconsistent ways to communicate with the driver. The usage of different modalities, symbols or positions for information could lead to a confusion of the driver (Tretten & Gärling, 2011) which results in difficulties to interpret the information and warnings correctly (Cummings et al., 2007).

The goal of this study is to present and to evaluate an interaction concept for an integrative driver assistance system, which combines information from different assistance systems and presents them consistently and understandably to the driver (Utesch, 2014; Maier, 2014, Zarife, 2014). To ensure that presented information are perceived and understood by the driver the right communication modality is crucial. In the present study an interaction concept is used which is based on peripheral vision. While driving, the visual modality is one of the most important but also most demanded modality (Sivak, 1996). This may be true for foveal vision, but peripheral vision could offer a new way to communicate information without overloading drivers. Existing literature on peripheral vision for driver assistance systems show positive effects regarding reaction time in demanding situations (Henning et al., 2008; Utesch, 2014; Maier, 2014; Laquai et al. 2011; Kienast et al., 2008). That is why some researchers develop and evaluate applications of peripheral information systems using different kinds of light, colours, animations and locations in the vehicle (Löcken et al., 2015; Pfromm et al., 2013, Kienast et al., 2008, Laquai et al., 2011, continental, 2013). If peripheral vision is used to communicate information, some physiological characteristics need to be considered. Humans are not able to see sharp in the periphery. This means that text messages or symbols would not be suitable for this for peripheral vision. On the other hand, humans are very sensitive for light, movements and stimuli changes in their peripheral field of view (Remington et al., 1992). Following this, the presented integrative interaction design uses colour-coded lights and animations to deliver peripheral information.

While existing concepts use the ambient light only to communicate specific information like warnings in critical situations (Utesch, 2014, Maier, 2014; Pfromm et al. 2013, Laquai et al 2011) or lane change information (Löcken, 2015) the approach used in the present study has the goal to present different kinds of information from different assistance systems in an integrated way. Following this approach our colour-coded interaction design is based on the theory of ecological information by Gibson (1966). Regarding Gibson’s theory the perception of the environment and its affordances are a critical factor for the behaviour. Kelsch and Dziennus (2015) described how to create affordances by the colour-coded design of the ambient light. Following this approach the present study investigates whether
peripheral ambient light signals could stimulate desired driver behaviour compared to a baseline without any assistance.

**Method**

**Experimental setup and participants**

**The ambient light**

An ambient light concept using a 360° LED stripe to communicate interaction signals via peripheral vision was installed and tested in a fixed-based driving simulator (see Figure 1a). The ambient light surrounded the driver. Following this, the ambient display was divided into four different segments: front, rear, left and right (see Figure 1b).

![Figure 6. a) Ambient display surrounding the driver, b) Segments of the ambient display](image)

Signals of the ambient light were displayed in the particular segment to create affordances for the drivers to initiate (recommendations) or to stop (warnings) driving manoeuvres. To achieve this goal, a colour-coded interaction design was used. According to that the colour white was used to illustrate that the ambient display was active (Figure 2a). To indicate that a driver should stop a driving manoeuvre the particular segment of the ambient light turned red and gave a directional warning (e.g. in case of a longitudinal warning the front segment turned red, Figure 2b). With rising criticality of the situation the ambient light changed from only red (Time headway < 2s) into a blinking red (THW < 1s). Furthermore it was possible to communicate recommendations for driving manoeuvre to the driver. In this case the ambient light changed the colour of the segment into green (Figure 2c). Making recommendations more salient to the driver the ambient light started blinking (for 4s) if the driver did not react to a recommendation within four seconds. Affordances created by the ambient light should support drivers to perform the correct reaction (e.g. brake reaction or lane change). The ambient light design used for this study was a reduced design which included no head-down display or auditory feedback.
Simulator

The experiment was conducted in a fixed-based simulator in the Interaction Design and Ergonomics lab (IDeELab) at the DLR Braunschweig. The simulator was a single fixed simulator equipped with an active steering wheel and pedals.

Scenarios

To test the impact of the ambient light on driver behaviour created eight different scenarios were created. Even though the warning or recommendation scenarios were different, the interaction design for warnings and recommendations was identical. The ambient display should provide generic information to guide the attention to a specific direction. The scenarios were divided into four warnings and four recommendation scenarios (see Table 1). Every participant drove on the same curved three-lane highway and experienced identical scenarios in the same order. The scenarios took between 30 and 80 seconds and the vehicle was stopped automatically to allow the investigator to switch between the scenarios via software control. While participants in the experimental group were supported by the ambient light, participants of the baseline experienced no support at all.

Table 6. Number of used scenarios

<table>
<thead>
<tr>
<th></th>
<th>Warning</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lateral</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Longitudinal warnings

In the first longitudinal recommendation scenario participants drove with 100 km/h on the right lane. Participants approached a traffic sign which restricted the velocity to 80km/h. To warn the driver that he was too fast the ambient display changed the colour of the front segment into red. In the second scenario participants drove with 100km/h on the right lane. Suddenly the front vehicle started braking at a time-headway of 1.5s. In the ambient light condition the driver was supported by a red pulsing (until THW>1s) or a red blinking (THW<1s) LED segment in the front.

Lateral warnings

In the first lateral warning scenario participants started with 100km/h on the right lane. After ten seconds they received an auditory command to change the lane. In parallel two vehicles on the middle lane crashed into each other and made a lane change to the middle lane very dangerous. Again the left segment of the ambient display turned red to signalize that a lane change was not safe anymore. If participants achieved a lateral deviation of more than 0.6m or used the indicator, the ambient light started blinking in red to underline that a lane change is not safe at all.
The second lateral warning scenario started on the right lane of motorway. Participants drove with 100km/h and experienced upcoming fog after ten seconds (see Figure 3). After 18s participants got an auditory command to change to the middle lane. At the same time the ambient light turned the left segment red to indicate that a lane change is not safe anymore. If participants achieved a lateral deviation of more than 0.6m or used the indicator, the ambient light started blinking in red to underline that a lane change is not safe. Six seconds after the auditory command or four seconds after the lateral deviation a truck appeared on the middle lane and took over with a velocity of more than 180km/h. If participants changed the lane, they would collide with the truck.

Figure 8. Lateral warning scenario

Longitudinal recommendations
In the first longitudinal recommendation scenario participants drove in a traffic jam with a speed of 20km/h. When participants reached the end of the traffic jam, surrounding traffic started to accelerate and the front segment of the ambient light changed into green to signalize that participant should speed up. In the second scenario participants started with 80km/h on the right lane. After ten seconds they saw a traffic sign which indicated a speed limit of 120km/h. Again the frontal element of the ambient light changed its colour into green.

Lateral recommendations
In the first lateral recommendation scenario participants drove with 100km/h on the right lane of the motorway and approached a slower vehicle on their lane. The left segment of the ambient display turned into green to recommend a lane change. In the second lateral recommendation scenario, participants drove with 100km/h on the middle lane of the three lane highway with surrounding traffic on the middle and left lane. After ten seconds the ambient light changed the colour of the right segment into green to give a lane change recommendation.

Participants
A total of 41 (20 male, 21 female) participants with an age between 19 and 64 (M=36.8; SD=14.13) took part in the present study. Participants were randomly distributed to an experimental group with ten males and eleven females and a baseline group with ten males and ten females. Regarding driving experience 56% of the participants reported to drive more than 10000km per year. Most of the participants (88%) also indicated to have no or little experience with driver assistance systems such as Adaptive Cruise Control (ACC). All participants were
recruited from the participant pool from the German Aerospace Centre (DLR). For the participation in the experiment participants were paid 10€ per hour.

**Experimental design**

In the present study a one factor design, with the factor *system support*, was used. All participants drove eight driving scenarios in manual mode. The presence of the assistance system “ambient light” defined the factor *system support*. This between factor had two conditions: “ambient light” and “baseline” (see Table 2).

**Table 7. Experimental design of the study**

<table>
<thead>
<tr>
<th>System support</th>
<th>Ambient light warning</th>
<th>Ambient light Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lateral &amp; Longitudinal</td>
<td>Lateral &amp; Longitudinal</td>
</tr>
<tr>
<td>Baseline</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Ambient Light</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**Procedure**

Each participant completed the experiment in approximately 1.5h on a single day. At first, all participants filled out a consent form and a demographic survey. Participants of the ambient light group were instructed that the purpose of the study was to test a new assistance system for motorways. After that, all participants experienced a test drive of 15min to familiarize themselves with the simulator. Afterwards participants of the ambient light condition were instructed that they will be supported by a new, light based assistance system while driving. The exact functioning of the system was not instructed. Participants of the baseline were not supported by any assistance system. After each scenario participants of the ambient light condition had to fill out a questionnaire regarding their understanding of the signals presented by the ambient light and its usability. At the end of the presented study a questionnaire regarding the general attitude towards the ambient light was handed out. For participants of the baseline the experiment ended at this point. Participants of the ambient light condition were now instructed about the method of operation of the ambient light and drove all scenarios again in the same order to experience the ambient light one more time (Only results of the first drive are reported). After this participants had to fill out a sort questionnaire regarding acceptance of the system. After a short debriefing participants received their payment.

**Dependent Variables**

In the present study the number of correct reactions was used as dependent variable. A correct reaction was defined as a specific reaction that should be triggered by the ambient light. In longitudinal warning scenarios the correct reaction was to decelerate or brake. In lateral warning scenarios participants performed a correct reaction when they didn’t execute a lane change. In longitudinal recommendation
scenarios participants who accelerated performed a correct reaction. Regarding lateral recommendations participants should change the lane.

Additionally, the participants rated the comprehensibility, meaning, and usability of the ambient display after each scenario on a seven-point scale (-3 to 3) with ten semantic differentials (comfortable vs. uncomfortable, safe vs. unsafe, distracting vs. not distracting, useful vs. not useful, nice vs. disruptive, permissive vs. prohibitive, forcing vs. relenting, inhibiting vs. supporting, avoiding vs. affording, limiting vs. expanding).

**Results**

The number of correct reactions and subjective data on the two lateral and longitudinal warning scenarios and the two lateral and longitudinal recommendation scenarios are clustered and reported in the following section.

*Lateral warnings*

For the lateral warning scenarios seven participants of the baseline and three of the ambient light condition were not considered in the data analyse due to technical problems. Figure 4 show that that the ambient display led to significantly less critical lane changes (six lane changes) ($\chi^2=11.86; p=.001$) compared to the baseline condition (18 lane changes). Participants evaluated lateral warnings as not limiting or expanding ($M=0$, $SD=1.96$) and not avoiding or affording ($M=0$, $SD=2.15$). Further they rated the lateral warnings as supporting ($M=1.2$, $SD=1.8$), forcing ($M=1.3$, $SD=1.25$), prohibitive ($M=-2.2$, $SD=0.9$), nice ($M=0.85$, $SD=1.52$), useful ($M=1.38$, $SD=1.89$), not distracting ($M=0.74$, $SD=1.9$), safe ($M=1.76$, $SD=1.48$) and comfortable ($M=0.88$, $SD=1.41$).

![Figure 9. Number of lane changes in lateral warning scenarios](image_url)
Longitudinal warnings

Regarding the question if the ambient light could trigger a braking manoeuvre the brake reaction of the drivers were compared between the conditions (Figure 5). Results showed no significant differences between the groups regarding the number of brake reactions (baseline=33, ambient display=38) ($x^2=1.122; p=.289$). Nevertheless, participants rated longitudinal warnings as limiting ($M=-0.24, SD=1.76$), affording ($M=1.56, SD=1.57$), supporting ($M=0.9, SD=1.64$), forcing ($M=-1.22, SD=1.13$), prohibitive ($M=-0.98, SD=1.33$), nice ($M=0.2, SD=1.66$), useful ($M=1.46, SD=1.63$), not distracting ($M=0.8, SD=1.52$), safe ($M=1.2, SD=1.54$) and comfortable ($M=0.73, SD=1.43$).

![Figure 10. Number of braking/deceleration in longitudinal warning scenarios](image)

Lateral recommendations

One participant of the ambient light condition was sorted out (only in one of the two reported scenarios) because he changed the lane before receiving a recommendation of the ambient light. In addition to warnings the ambient light communicated recommendations for driving manoeuvres. A Chi-square test showed no significance ($x^2=3.59; p=.058$) between the groups (see Figure 6). A further look into the scenarios showed that in the scenario with the recommendation for a lane change to the right twelve out of 20 participants driving with ambient light reacted to this recommendation and changed the lane. In the baseline condition no driver changed to the right. This led to a significant difference ($x^2=17.14; p<.001$) between the conditions. Participants rated the lateral recommendations by the ambient light as expanding ($M=0.83, SD=1.43$), affording ($M=1.22, SD=1.27$), supporting ($M=1.2, SD=1.33$), forcing ($M=-0.15, SD=1.2$), permissive ($M=1.32, SD=1.35$), nice ($M=0.39, SD=1.56$), useful ($M=0.56, SD=2.01$), not distracting ($M=0.41, SD=1.77$), safe ($M=0.7, SD=1.36$) and comfortable ($M=0.61, SD=1.43$).
ambient light based interaction concept

No significant difference between the groups regarding longitudinal recommendations was found in the present study ($\chi^2=.02; p=.886$) (see Figure 7). The ambient light had no effects on the acceleration behaviour of the participants. Nevertheless, participants rated the ambient light as expanding ($M=0.6, SD=1.54$), affording ($M=1.7, SD=1.12$), supporting ($M=1.13, SD=1.48$), forcing ($M=-0.63, SD=1.22$), permissive ($M=1.5, SD=1.61$), nice ($M=0.4, SD=1.83$), useful ($M=1.0, SD=1.86$), not distracting ($M=0.83, SD=1.91$), safe ($M=0.33, SD=1.42$) and comfortable ($M=0.80, SD=1.61$).

Subjective Data

The results for the rating of warnings and recommendation regarding the semantic differentials are displayed in Figure 8. Participants rated warnings as significantly
more limiting ($t_{144} = -3.074, p = .003$), more avoiding ($t_{144} = -2.102, p = .037$), more forcing ($t_{144} = -4.67, p < .001$), more prohibitive ($t_{144} = -12.708, p < .001$), useful ($t_{144} = 2.227, p = .027$) and safety relevant ($t_{144} = 3.732, p < .001$) than recommendations. The results showed that participants could easily distinguish between a warning and a recommendation.

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![Figure 13. Subjective rating for semantic differentials](image)

**Discussion**

The presented study shows the potential of a colour-coded ambient light based interaction concept for an integrative driver assistance system. Using the ambient light for warnings and recommendations reveal an ambiguous picture regarding the direction of support (lateral/longitudinal):

For lateral warnings and recommendations the ambient light had an effect on driver behaviour. More than 84% of the participants who experienced the lateral warning cancelled the lane change and avoided a collision with an approaching vehicle from behind. While the hazard was not visible for the drivers, the ambient light was able to communicate information helping the driver to anticipate future events. For lateral recommendations a significant influence on driver behaviour was found for one of the two driving scenarios in which the ambient light helped driver to change to the right lane. Compared to that, using the ambient light for longitudinal warnings and recommendations had no positive effect in this study.

From our point of view, these effects could be explained by the scenarios chosen for this study. The selected scenarios for longitudinal assistance were not sensitive enough to show any advantage of the ambient light. The needed actions were very clear and easy to understand for the drivers resulting in a high percentage of correct reactions in both the ambient light and the baseline condition (ambient light=90.5%, Baseline=82.5%). Differences between the groups could not be found because drivers did not need further support to handle these situations. Concluding, the ambient light stimuli seem to have a positive effect in all scenarios where no salient
stimuli from the environment exist. Here, the ambient light helps the driver to anticipate what the correct action could be. If this positive effect is additionally dependent from the direction of the support (longitudinal/lateral) or if it is a pure effect of the scenario selection as described above could not be fully understood by the results of the study and needs further investigation.

The study also showed that participants were able to understand and distinguish between warnings and recommendations and act accordingly to it even though a generic colour coding was used for the different scenarios. The subjective rating showed that participants experienced warnings presented by the ambient light as very prohibitive, limiting and enforcing while recommendations were rated as permissive, expanding and relenting. Against our expectation, participants did not distinguish between the semantic differentials activating-preventing. It seems like participants perceive signals from the ambient light always as a recommendation to do something and not as a signal to stop an action. In depended from this interpretation, this led to the correct actions of the driver.

Outlook

The ambient light showed its potential to integrate the information of different driver assistance systems in one generic interaction design using colour codes for various recommendations and warnings. The ambient light helped to trigger appropriate actions by the driver. In further studies, the combination of the ambient light with other information channels (multimodal interaction) seems to be very promising to further enhance the effectiveness in critical situations. Furthermore, the potential of the ambient light concept for higher levels of automation should be under research to understand if the ambient light provides a generic approach to support the driver not only during manual driving but also during the automated drive. The ambient light could be used to support the driver to build up correct mode awareness by changing the colour of the light in different automation levels, to react appropriately during transitions of control or help him building up a correct situation awareness by highlighting relevant cues in the environment.

References

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