Reflecting the automated vehicle’s perception and intention

Light-based interaction approaches for on-board HMI in highly automated vehicles

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ABSTRACT

The number of automated driving functionalities in conventional vehicles is rising year by year. Intensive research regarding highly automated vehicles (AV) is performed by all big OEMs. AVs need advanced sensors and intelligence to detect relevant objects in driving situations and to perform driving tasks safely. Due to the shift of control, the role of the driver changes to an on-board user without any driving related tasks. However, the interaction between the AV and its on-board user stays vital in terms of creating a common understanding of the current situation and establishing a shared representation of the upcoming manoeuvre to ensure user acceptance and trust in automation. The current paper investigates two different light-based HMI approaches for AV / on-board user interaction. In a VR-Study 33 participants experienced an automated left turn in an urban scenario in highly automated driving. While turning, the AV had to consider other road users (pedestrian or another vehicle). The two HMI approaches (intention- vs. perception-based) were compared to a baseline using a within-subject design. Results reveal that using perception- or intention-based interaction design lead to higher user trust and usability in both scenarios.

KEYWORDS

HMI for automated vehicles, on-board HMI, intelligent HMI

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1 Theory

Encouraged by the vision of environmental friendly, efficient and safer mobility, vehicle manufactures research towards automated driving. Following the SAE standards [1], a highly automated vehicle (AV) in SAE level 4 is able to perform the full driving task without any driver input. Even if the vehicle reaches a system limit, the driver does not need to intervene. While the vehicle intelligence performs the driving task, it has to collect information regarding the current driving situation and it needs to plan its next driving manoeuvre. Although, the role of the driver changes significantly from driver to on-board user, the interaction with the vehicle automation conveyed via a human-machine interface (HMI) stays important for user acceptance and trust in automation. Due to the changing role of the driver the amount and type of information changes as well. For a driver-centred interaction strategy it is crucial to highlight the information exchange between vehicle intelligence and on-board user. Novel interaction strategies need to focus on creating a common understanding of the current driving situation and a foreseeable future behaviour of the AV for the on-board user to avoid automation surprises. Inadequate knowledge regarding situation and AV intention could lead to unnecessary or even dangerous driver intervention. LED-bands installed in the interior of the vehicle have been shown to create an intuitive and well-accepted HMI [2], using human peripheral vision to display important information about environment and automation status. However, these interaction concepts are developed for motorways and lower SAE levels, and they need to be adjusted for urban scenarios. While driving in automated mode, left turn scenarios are expected to induce high user uncertainty and would benefit from an understandable interaction between automated vehicle and on-board user. Therefore, the current paper investigates in a first step towards an intelligent HMI for highly automated vehicles two different light-based HMI approaches for AV / on-board user interaction for an automated left-turn manoeuvre.

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2 Method

A VR-Headset (HTC Vive pro) and Unreal Engine (4.18.3) was used to create the virtual environment for this current experimental simulation study with 3x2 within-subject design. All participants experienced the three different HMI interaction designs (factor 1: baseline vs. perception-based vs. intention-based) using a virtual LED-band in the interior of the AV while driving in highly automated mode (SAE level 4). Two different scenarios were chosen (factor 2). 33 (14 female) participants with a mean age of 34.1 ($SD = 11.4$) years took part. Participants experienced the two left-turn scenarios as an AV’s on-board user not naïve to the HMI. During the scenarios, participants had to indicate their level of uncertainty as a continuous measure by pressing a trigger button on the Vive Controller. The more uncertain they felt, the more they had to press the trigger button. Additionally, after each trial they had to rate their perceived safety, usability and user trust. In total two constructs were measured: 1) user trust was measured using an adapted version of the Self-Assessment Manikin [3] (with the subscales: pleasure, arousal, dominance) and data from the button press intensity of the Vive controller. 2) Usability was measured by a self-devised questionnaire assessing the three dependent variables simplicity, information richness and predictive value on a 7-point Likert scale. Two left-turn scenarios were used: in the 1) pedestrian scenario, the AV approaches a four-way intersection and reduces its speed stepwise. While turning, the AV needs to take the trajectory of a crossing pedestrian into account and adjust its velocity. In the 2) vehicle scenario, the AV had to adjust its left-turn manoeuvre to an upcoming vehicle on the oncoming lane. Aiming at a common understanding of the current driving situation to establish a shared representation of the upcoming manoeuvre, three different HMI interaction strategies using the LED-band for a light-based interaction were tested. The intention-based design was used to explicitly communicate the current driving manoeuvre and intention of the AV to the on-board user (Figure 1), i.e., when the AV was about to perform a stopping manoeuvre, the entire LED-band starts to pulse slowly (in cyan) with a frequency of 0.5Hz. If the vehicle was about to start moving after standstill, the LED-band was pulsing (in cyan) fast with 2Hz. The perception-based HMI design communicates the perception of relevant objects by the AV. Therefore, a 15cm long segment of the LED-Band was illuminated in a bright blue colour directly underneath the position of the detected object in the driving environment. The illuminated segment kept following the position of the tracked object to indicate a constant perception by the AV. Both HMI versions were compared to a baseline condition which was characterised by a cyan illuminated light band, only displaying the current automated driving mode.

Figure 1: Intention-based (l.) and perception-based design (r.)

3 Results

User trust and usability were measured on a metric level using a repeated measures design and thus data was evaluated using a Repeated Measures ANOVA. With regard to the first construct of user trust, in the left turn scenario when the AV had to interact with a pedestrian (by trend) significant differences between the different interaction designs on the LED-band were found (pleasure $p < .01$, $\eta^2 = .19$, arousal $p < .05$, $\eta^2 = .09$, dominance $p < 0.01$, $\eta^2 = .19$). Pairwise comparisons showed that participants rated the intention- and perception-based HMI as significantly more pleasurable (intention $p < .01$, perception $p = .02$), felt less arousal (intention $p = .04$) and more dominance (intention $p < .01$, perception $p = .01$) compared to the baseline. No significant differences were found for intention vs. perception. In the car use case significant differences were found only in pleasure ($p = .02$, $\eta^2 = .22$). Pairwise comparisons showed a difference between baseline and perception-based ($p = .03$). There were no differences between the HMI variants regarding the button press intensity in any of the scenarios. Significant differences for the subjective ratings for the second construct usability (Figure 2) were found between the different HMI designs in regards to simplicity ($p = < .01$, $\eta^2 = .28$), information richness ($p = < .01$, $\eta^2 = .64$) and predictive value ($p < .01$, $\eta^2 = .62$) in the pedestrian scenario. For all three categories the pairwise comparisons showed significant differences between the experimental conditions and the baseline. No significant differences were found for intention vs. perception. The same results were found in the car scenario. There was always a significant difference between the baseline and intention or perception but not between intention and perception in all three categories.

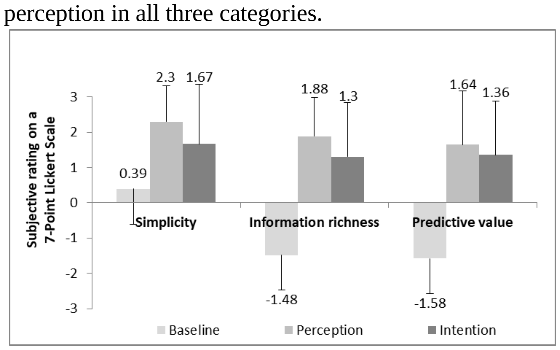

Figure 2: Usability ratings for the pedestrian scenario

4 Discussion and Outlook

In terms of user trust, the both interaction strategies were mostly rated as significantly better than the baseline, especially in the pedestrian scenario. The present study shows that the developed interaction designs support the information exchange between vehicle intelligence and on-board user. Participants reported a significant higher predictive value of automation behaviour by using the intention-based or perception-based interaction strategies. Further, the signals were easy to understand and contained a good level of information richness. For the present study a simple scenario with only one interaction partner at a time was chosen. We will evaluate in a next step more complex scenarios with multiple interaction partners. Also, different interaction strategies for different road user (e.g., cyclists, bikes, and children) will be investigated. The gain in complexity will lead to more intelligence on the vehicle automation side which also needs to be reflected on the HMI. Additionally, the driver state should be taken into account to develop a more intelligent and adaptive interaction strategy which delivers additional information when needed via the intelligent user interface.

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