Don't You See Them? Towards Gaze-Based Interaction Adaptation for Driver-Vehicle Cooperation

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Abstract
Highly automated driving evolves steadily and even gradually enters public roads. Nevertheless, there remain driving-related tasks that can be handled more efficiently by humans. Cooperation with the human user on a higher abstraction level of the dynamic driving task has been suggested to overcome operational boundaries. This cooperation includes for example deciding whether pedestrians want to cross the road ahead. We suggest that systems should monitor their users when they have to make such decisions. Moreover, these systems can adapt the interaction to support their users. In particular, they can match gaze direction and objects in their environmental model like vulnerable road users to guide the focus of users towards overlooked objects. We conducted a pilot study to investigate the need and feasibility of this concept. Our preliminary analysis showed that some participants overlooked pedestrians that intended to cross the road which could be prevented with such systems.

Author Keywords
Automated driving; cooperation; eye tracking; study.

CCS Concepts
•Human-centered computing $\rightarrow$ Empirical studies in HCI;

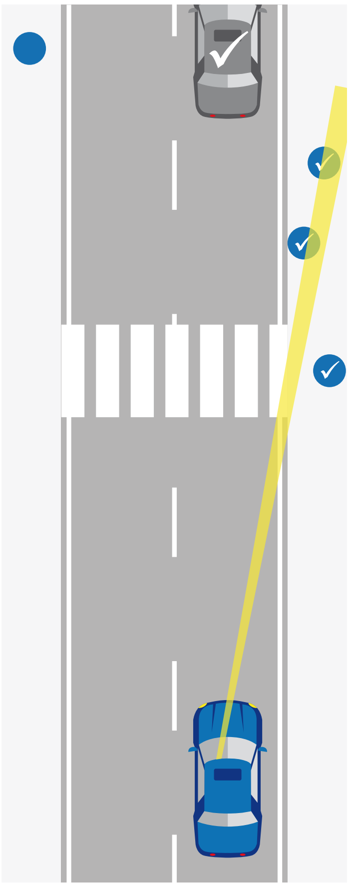

Figure 1: Every object, e.g. cars or pedestrians (blue circles), at which the user looks (yellow ray) is marked accompanied with a timestamp in the vehicles environmental model (checkmarks).

Introduction

Today's prototypes of highly automated vehicles made their way on public roads [18]. Nevertheless, there remain challenges that have to be resolved before fully automated driving is possible under all circumstances [11]. Instead of falling back to manual driving when system boundaries are reached, cooperative driver-vehicle interaction has been suggested [14] to avoid handover issues [6]. For instance, vehicles can ask their users to make decisions [16], approve maneuvers [17], and to classify unrecognized objects [12]. Users of automated vehicles are likely engaged in non-driving related tasks [7] which may affect situation awareness [5] and can cause them to be out-of-the-loop [2].

Eye tracking is used in the automotive domain as a tool for drowsiness, distraction, and visual attention detection [8, 9, 10]. Eye-gaze and road events can be correlated as an indicator for inattentiveness of drivers and can be used to inform or warn drivers if necessary [4]. While Fletcher and Zelinsky [4] focus on avoiding inattentiveness in manual driving, we focus on users of automated vehicles that are likely out-of-the-loop and are only asked to cooperate every once in a while. We propose that automated vehicles should monitor their users as well to get an indicator whether they are able to cooperate. In particular, merging the user's direction of gaze with the environmental model of the system generates an indicator for the level 1 situation awareness (perception) [3]. While systems cannot rely on users having perceived everything they looked at (*"looking but not seeing"* [4, p. 800]), they know where users did not look at and can, if necessary, guide the focus of users towards relevant areas or objects. Such relevant areas can for instance be the sidewalks next to a crosswalk or the oncoming lane prior and during an overtaking maneuver. Relevant objects could be for instance vulnerable road users, traffic lights whose status is unknown or objects that are perceived by the vehicle's sensory but that could not be classified.

We conducted a pilot study to investigate whether this approach is feasible. In particular, we asked participants engaged in non-driving-related tasks to cooperate in three scenarios (pedestrian intention prediction at crosswalks, traffic light state recognition and overtaking maneuver approval) and analyzed their gazes. Our preliminary study highlights the need for adaptive interfaces that take the user's gazes into account.

Fusion of Environmental Model and User's Gaze

Integrating the perceptional processes of both cooperation partners (system & user) facilitates the creation of a shared situation representation [15]. Consequently, we suggest to integrate the vehicle's environmental model with the gaze direction of the user to get an indicator for overlooked objects. As a result, the system can adapt the interaction accordingly and can guide the attention of the user to relevant areas or objects in the surrounding. In conclusion, the system checks which objects or areas of the surrounding have been looked at and which have been overlooked.

This could be implemented as follows: First, a ray originating from the head of the user is cast in the direction of the user's gaze into the environmental model as shown in Figure 1. Secondly, by knowing which objects are and were in the direction of gaze, several indicators for the user's awareness regarding each object can be derived:

- total duration being in focus
- frequency of being in focus
- longest duration being in focus
- first time being in focus
- last time being in focus

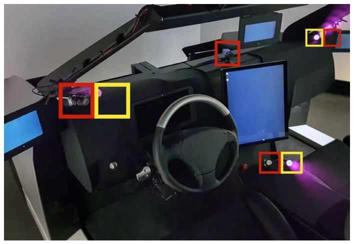

Figure 2: Cockpit equipped with eye tracking cameras (red) and IR lights (yellow).

ray angle	pedes-trian	car
2.0°	83%	93%
	SD=8	SD=5
1.5°	82%	87%
	SD=13	SD=9
1.0°	72%	79%
	SD=9	SD=14
0.5°	65%	69%
	SD=13	SD=14

Table 1: Tracking rate while fixating dynamic objects.

Finally, these metrics can be used by the system to predict whether the user is (still) aware of the presence of relevant objects in the environmental model. The system can use the derived assumptions to guide the user's attention to missed objects or areas in the surrounding.

Preliminary Evaluation

We implemented the described concept in a driving simulator running *SILAB* simulation software. The cockpit was equipped with a *smart eye* eye tracker consisting of four cameras and three IR lights (see Figure 2). In front of the cockpit there were three projections with a field of view of 190°. Moreover, the cockpit was equipped with displays mimicking the side and rear-view mirrors, as well as the instrument cluster and a touch display in the center stack. Two experiments were conducted: first, we investigated how large the opening angle of the gaze-ray should be to produce robust results, and second, we investigated the general feasibility and need of the concept with observing gaze behavior in cooperation situations.

Experiment I: Determining the Gaze-Ray Opening Angle

The first experiment was conducted with nine participants, four identified themselves as female and five as male. They were on average 22.7 years old ($SD = 2.2$) and had normal or corrected to normal vision. In this experiment it was investigated how big the opening angle of the gaze-ray, in whose boundaries the environmental model was queried, should be to produce stable results. Participants had to focus on static objects (traffic signs and traffic lights) at a distance of 60, 40, 25, and 10 m and dynamic objects (crossing pedestrians at 10 m and oncoming cars from 60 m - 0 m). The opening angle of the gaze-ray was reduced stepwise, starting at 2°. We found that some participants did not achieve a tracking rate of 95% with the starting angle of 2°, especially when the target was further away and located more towards the periphery of the scene. This was also prevalent in case of dynamic targets. As the results in Table 1 show, the tracking rate for the crossing pedestrian was worse compared to the oncoming car, likely because the target moved further towards the periphery and was smaller than the approaching vehicle. The search ray should be as narrow as possible to allow to detect which objects the user really looked at but has to be wide enough to allow to get any results. Consequently, we used a 2° angle for the follow up study as a trade-off.

Experiment II: Gaze Behavior During Cooperation

In the second experiment 25 volunteers participated, six identified themselves as female and 19 as male. These participants were on average 24.52 years old ($SD = 6.48$) and owned a driving license for cars for on average 7.26 years ($SD = 6.79$). Four subjects needed to correct their visual impairment with glasses or contact lenses since (corrected to) normal vision was required to participate in the study.

Participants drove in total 49 km ($\approx$ 75 min) within this experiment. 12.6 km at the beginning of the study were driven manually as acclimation to the driving simulator. The simulated vehicle drove automated in the remaining time; beginning with an introduction to each of the three cooperative tasks, followed by two experimental drives that consisted each of five different crosswalk situations, four traffic light situations, and two overtaking situations. The order of the different situations was intermixed within one experimental drive; however, the order was the same in both experimental drives. During the experimental drives, participants had to engage in a cognitive-visual-motor variation of the surrogate reference task [1] (see Figure 3) to simulate engagement in a non-driving-related task (NDRT).

When the vehicle reached one of the cooperation situations, it decelerated and asked the participants with a di-

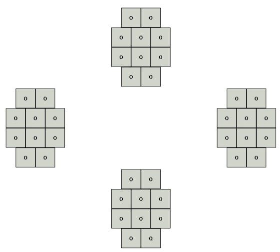

Figure 3: NDRT: participants had to click the cluster that contains a *Q* instead of an *O*.

Figure 4: Interface for cooperation.

Figure 5: Crossing pedestrian.

alog on the touchscreen in the center stack whether the crosswalk is clear and the vehicle can drive on (Figure 4), whether a traffic light is green or whether they want to overtake a slower vehicle. To tell the vehicle to drive on or to overtake, participants had to hold the button in the dialog down (Figure 4). When they lifted their finger off before the cooperative situation was finished, the vehicle canceled the overtaking maneuver or stopped in the other situations similarly to [13]. In case participants approved overtaking even though there was oncoming traffic present, the system was able to cancel and sway back behind the slower vehicle.

Critical Crosswalk Situations In each experimental drive participants were asked to cooperate in two situations in which a pedestrian wanted to cross. In one of these two situations a group of three pedestrians was standing at the right roadside (right-hand traffic) and another pedestrian wanted to cross the road from the left (see Figure 5). 16 out of 50 trials were critical, which means that the participants let the vehicle drive on even though a pedestrian is walking to the crosswalk (two participants succeeded in cancelling at the last second). Figure 6 shows the timeline of the interactions. Nine of the 16 critical trials in this situation provided good eye tracking quality (at least 85% of time successful tracking) and could be analyzed: no participant glanced to the left roadside prior hitting the button to drive on, only two directed their gaze straight ahead for a short time. In the remaining trials participants' gazes were only directed towards the right and the touchscreen prior input.

Discussion & Future Work

We propose to incorporate eye tracking in cooperative interactions between a highly automated vehicle and its user. In particular, when merging this information with the environmental model of the system the focus of users could be guided towards overlooked areas and objects relevant

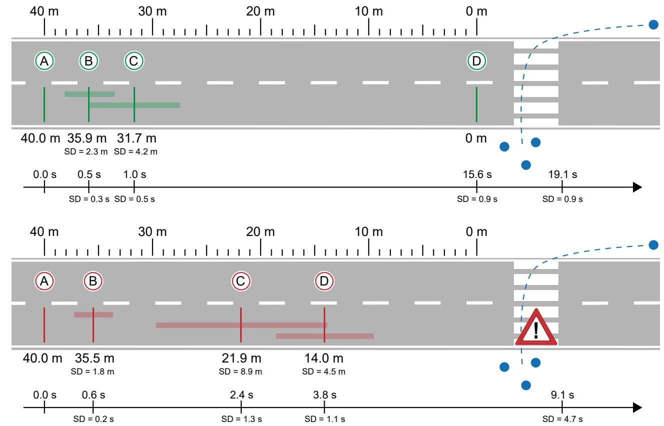

Figure 6: Timeline of interactions in uncritical (top, $n_{\geq 85\%} = 31$) and critical (bottom, $n_{\geq 85\%} = 9$) trials. (A) dialog appearance, (B) gaze away from touchscreen, (C) first glance at a pedestrian, (D) button press. Calculations are based on trials with an eye tracking rate of at least 85% of time ($n_{\geq 85\%}$).

to the driving situation. Our preliminary analysis of critical crosswalk situations highlights the need for such adaptive interfaces since all participants in our experiment who made a wrong decision (telling the vehicle to drive on even though a pedestrian was about to cross the road) did not look at the left roadside where the pedestrian was walking towards the crosswalk. In future work we will analyze the remaining scenarios participants were challenged with.

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