Using Eye-Tracking to Help Design HUD-Based Safety Indicators for Lane Changes

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Abstract
Lane changing can slow down traffic flow and play an important role in traffic accidents, especially because the drivers' eyes-off road time and awareness of the rearward road scene are critical. Our work focuses on visual aids to reduce risks in such situations. During a real-world driving test of performing lane changes, we collected eye-tracking data and analysed the drivers' eye movement in lane changing scenarios, considering fixation areas and fixation moving paths frequency. The idea of this methodology is to inform a potential ideal design of a HUD-based warning indicator that supports lane changes. Our future research will validate the effectiveness of using the eye tracking method to inform the positioning of indicators, and use it for supporting safety of other driving tasks and trust in higher levels of automation.

Author Keywords
Car driving assistance; Fixation area; Fixation moving path; Head-up display (HUD) design; Lane changing scenario.

CCS Concepts
HCI design and evaluation methods
Interaction design process and methods

Introduction and Related Work
Sen [10, p. ix] analysed the maximum injury severity of crashes in different driving scenarios "which revealed that 14% of lane change crashes resulted in some forms of injury". Accident statistics confirm the need for systems that support car drivers when changing the lane [11]. Lane changes increase the

Fixation points

Figure 1.Fixation points (examples); Top: target lane; Bottom: left mirror, Red dots mark fixation points.

The five Fixation areas: Two for dividing the road ahead: lane where to change (target lane TL), lane before lane change (current lane CL), and three for the mirrors: outside of the passenger side (right mirror RM), left rear-view mirror, outside of the driver side (left mirror LM) and inner rear-view mirror on the windshield between driver and passenger (rear-view mirror RVM).

overall workload [16]. The driver has to deal with multiple tasks gathering detailed information from the road scenario ahead, from mirrors, the blind spot and dashboard within the vehicle, to obtain information about current road signs, distances to surrounding cars, current speed, etc. This can easily take the driver's eyes off the road at critical times (e.g. lead car braking).

Lane Change Decision Aid Systems (LCDAS) integrate lights into the outside mirror or A pillars to warn about vehicles in the blind spot. These warning signals are basic and do not provide different levels [17] or other additional information that may help drivers. Richer interfaces such as Head Up Displays (HUDs) provide new opportunities for this.

HUDs are well researched in the automotive domain [9] and available in commercially available cars today. Lamble et. al report that information should be positioned as closely as possible to the driver's normal line of sight, i.e. typically on top of the dashboard [8, p.809; 13]. Tretten et. al [12] note that HUDs allow "for the display of safety systems information in an easily noticeable location" and propose just below the line of sight at 5° as the most preferred. As HUDs become more advanced offering full windscreen aspects, the questions of where to best position *driving task specific* HUD-based warning indicators or decision aids needs to be addressed. For this we leverage eye-tracking.

Eye-tracking studies "visual and attentional processes" [7] and can be used in research to detect visual demand [2] or drivers distraction processes [5]. Visual attention attraction is considered a fixation [1]. Drivers use fixation for scene interpretation and decision making. In this context, fixations, saccades, and smooth pursuits are the most studied. In our study we only consider fixation and saccades [6]. We refer to saccades between fixations as moving paths when investigating the driver's normal lines of sight during lane changes.

As such, the overall aim of this project is to enable a good view management concept for HUDs that provides rules for the location of information specific to different driving scenarios, avoiding clutter and overlap which could distract the driver and impact driving performance [4]. Our pilot study presented here aims to identify where to display what information to the driver during lane changes. It tests our methods and obtains preliminary verification of our hypothesis that eye-tracking can become a general method for informing HUD design, which we aim to explore further in future, more elaborated studies. (see future work section).

Methods

Our pilot study took place in standard cars on regular streets. Rather than assuming existing typical HUD placements, our research takes a step back, employing a user-centred "in the wild" approach by investigating the drivers' natural eye-movements during lane changes on semi-open roads.

Experimental setup

The experiment took place within our comparatively large (and road rich) Tongji university campus. The roads are standard two-lane China motorway roads with a stable (low) level of traffic. The lane changing experiment was part of a longer drive, totally lasting 30 minutes on average and including several typical driving tasks (reversing, parking, crossing intersections, etc.) with 17 test drivers (9 male, 8 female; aged 25 to 50 years with driving experience one to thirteen years (mean: 6.8 years, standard deviation: 17.29). The test vehicle was a SAIC Tiguan SUV.

For the lane changes under study, an accompanying test supervisor asked participants to move into an adjacent lane. The number of lane changes was limited to two per driver. All drivers performed the lane changes along the same stretch of road. Being a quiet university campus, the traffic conditions were similar during all drives, but being an open road, they

Fixation moving paths –
Right to left lane change

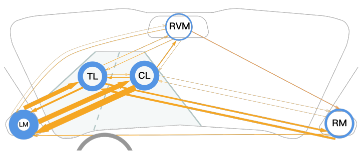

Figure 2. Fixation moving paths and fixation areas on right-to-left lane changing

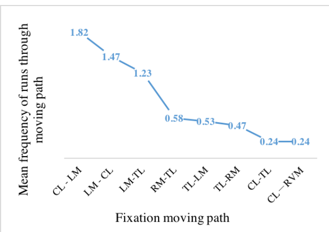

Figure 3. Fixation moving paths on right-to-left lane change

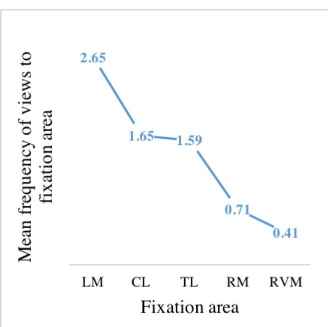

Figure 4. Visits of fixation areas on right-to-left lane changing

could not be controlled for. It represented a compromise between a fully controlled but unnatural test track, and an uncontrolled public road.

Data collection
We used the wearable eye tracker Tobii Glasses (Analyser_ 1.41.2285) in binocular tracking mode. An accompanying test supervisor used theTobii Pro Glasses Controller Software on Pro tablet to manage participants, control the eye tracker and view both real-time and recorded eye tracking data. Parallax compensation was set to automatic. We used tinted lenses in case of strong sunshine to decrease noise in the data. The algorithm was based on angular velocity to make eye recog-nition more reliable. Calibration was done once at the beginn-ing and live viewing was used during the experiment to ensure the system performed well.

Data analysis
After data collection, we used Tobii Pro Glasses Analyzer Soft-ware to export and interpret the data with a sampling rate of 50 Hz, the duration of a fixation is more than 200 msec in our experiment. The Tobii software automatically creates an "eye-movement video", which contains the fixation points (Figure 1). To reduce their number and complexity, we manually grouped fixation points located close to each other to five *fixation areas*. Through further analysis of the eye movement video, we obtained the *fixation moving paths,* i.e. the eye's way from one fixation area to another. We then analysed the different cha-racteristics of the fixation moving paths quantitatively during a) left to right and b) right to left lane changing. We also analyzed the eye-movement video qualitatively through detailed obser-vations to obtain what information the driver appears to search for and need.

Results
Our participants rely on fixation to obtain traffic information. In this report, the visual characteristics of the driver are mainly identified by two aspects, fixation moving path and fixation area.

Fixation moving path is the direction of the drivers' gaze moving from one fixation area to another. In Figure 2, we use arrow thickness to illustrate the number of runs through fixation moving paths and circle thickness to show the number of visits to a fixation area. Figure 2 shows fixation moving paths and fixation areas superimposed of all participants in right- to-left lane changing.

Figure 3 shows the mean values of the eight most frequent eye movements between fixations areas (fixation moving paths) per participant for right-to-left-lane changing. We obtained 14 moving paths. The highest number of movements stems from Current Lane to Left Mirror (CL→LM: 1.82), second highest is from Left Mirror to Current Lane (LM→CL: 1.47), third highest is from Left Mirror to Target Lane (LM→ TL: 1.24). The *visual weight*, i.e. the sum of these three values (Σ=4.52), is much higher than the visual weight of all other (11) values together (Σ=3.02). The analysis means that movements between Left Mirror and Lanes occur most frequently, and that this region attracts most attention. This result is confirmed by the number of visits of respective fixation areas (Figure 4). For left-to-right lane changing, results are correspondingly.

Observing the eye-movement video in detail, we found that the driver checked mirrors several times or with long glances until an objects intention seemed to be resolved.

Discussion
Information organisation in our case is the task to visually structure and define interface information, workflow, and inter-action of the driver, so that they can quickly and accurately find the information they need. In turn, we discuss how our findings from the experiment influenced design choices in supporting drivers in lane changes.

Indicator location on the HUD

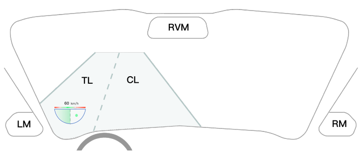

Figure 5. Indicator location on right to left lane changing

Green here means that in this situation the driver can change line.

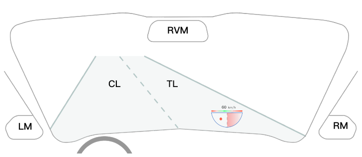

Figure 6. Indicator location on left to right lane changing

Red here means that in this situation the driver must not change line.

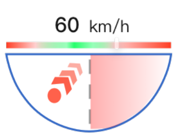

Figure 7. Potential information of indicator on left to right lane changing

As shown in Figure 2 attention attraction in lane changing from right to left is maximized in the LM/CL/TL region. Considering the relevant fixation areas, LM is more often visited than CL and TL. We therefore recommend putting the HUD indicator in this region, leaning slightly in the direction towards LM, as illustrated in Figure 5. For left-to right lane changing we suggest to put the HUD indicator leaning slightly in the direction towards TL (Figure 6). In either case the indicators are displayed in such a way that they virtually appear on the respective target lanes. This position avoids visual distraction, because the driver will look towards the target lane anyway. The preliminary HUD design (Figure 7) shows how to potentially help drivers to get more information about the most likely projections/intentions of the rear car.

Lessons Learnt and Future Work

We found some very interesting results about positioning safety indicators for lane changing on a HUD. The results were achieved in a semi-open traffic environment and therefore may be more valid than those from closed traffic tracks. Nevertheless, our results have a preliminary character only, because we did not control our (pilot) experiment, and we did not yet accompany our eye-tracking method by a systematic collection and interpretation of user experience data. Therefore, it is worth thinking about conclusions we can draw from the pilot for a larger main study. What worked well, what did not? What will we do differently when continuing our research?

In our future work, we will evaluate the indicator positions under real driving conditions (considering traffic density, weather conditions, driving course etc.), including research about drivers' safety information needs, information (over)load, trust in the system etc., to determine the overall potential safety benefits. Drivers will do the experiment on open road with eye tracking glasses. To validate the results, we consider using the following conditions: a) no safety indicators, using traditional mirrors only; b) commercially available safety instruments like BSW systems in mirrors; c) our through eye-tracking informed warning indicators positioned in the HUD with additional safety information like speed, distance, projected path and kind of approaching objects in rear target lane. Future experiments may also benefit from using a Woz Way [14] approach to ask drivers immediately after the lane change to gain insights about drivers' experiences, thoughts, information needs, rational for visual search processes, stress impact, attention distraction, trust etc.

We also consider using a second car in addition to the test car to create special situations, like overtaking the test car. This could create a more complex and realistic situation in a controlled way. In general, we want to find out if eye-tracking is an appropriate method for overall design of HUD safety support.

Positioning indicators was just the start of a more complex consideration of HUD based visual aids to improve safety. Good warnings require advanced sensors and software. Besides speed and acceleration information, indicator systems will need data about distances between cars, image recognition of camera data, driver reaction time etc. Based on these, the content of HUD design should have dynamic levels of detail. In our design (Figure 5) we use simple colour coded warnings, but if the traffic environment changes suddenly and frequently, the flickering warning may confuse drivers, so we need to consider what other details should be offered to the driver like the potential direction and prediction time of other cars. This functionality is already available in highly automated cars. In this context, information-driven indicators used as HUD safety elements could aid situational awareness and trust [15].

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