Gaze-steering coordination with supervised automation: A test track experiment on AstaZero

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1. Executive summary

A pilot assist system can keep the vehicle on the road, but the driver is still needed to monitor its performance and take over the control when necessary. In order to make takeovers as smooth and safe as possible, it is valuable to understand the perceptual and cognitive processing occurring when the driver detects that the vehicle is no longer steering along the intended path and that s/he has to step in to correct this. Previous research has established what is typical for gaze-steer coordination in manual driving, but that coordination is less understood for supervised automation conditions.

In this pilot study, 14 volunteers drove on the AstaZero proving ground with an instrumented vehicle from Revere lab and wore an eye-tracker during the experiment. Participants drove both in manual mode and in simulated supervised automation mode. We aimed at analysing and modelling differences in eye movements patterns between the two modes, as well as in silent transition situations (i.e. where the supervised automation is functioning normally but fails to maintain the expected lane position).

The project provided valuable experience on using the Revere lab instrumented vehicles on AstaZero proving ground. There were some technical difficulties with the eye tracker, which made the analysis of eye movements patterns challenging. However, other data clearly suggest that there are two different strategies: either drivers trust automation and let the vehicle deviate from their own lane, or they do not trust it, and respond immediately. The results will be used to further develop driver models for automated driving within the VINNOVA-funded project QUADRAE (Quantitative Driver Behaviour Modelling for Active Safety Assessment Expansion).

2. Background

Pilot assist (PA) is a SAE level 2 automation function intended to support the driver in keeping the vehicle within the lane. Despite the possible benefits introduced by PA, , even state-of-the-art PA functions have sensor system limitations. Due to these limitations, the function may at any time stop to maintain its lane keeping. The driver therefore needs to continuously monitor the function's performance and be ready to take over whenever the function no longer is keeping the vehicle in the lane.

In this project, we aimed to investigate the eye movement patterns in detail when the steering automation no longer keeps the vehicle in the lane and the human driver has to take over. Our aim was to better understand what visual information is used to detect that the function no longer is keeping the vehicle in the lane and what visual information is needed to successfully re-engage the driver in the steering control loop. The results were intended to help creating advanced driver models for design and evaluation of supervised automation functions.

While research in this area is limited and only conducted during manual mode, some studies have been performed. For example, in curve driving, drivers look most of the time to their direction of travel in a rather systematic fashion (Lappi, Lehtonen, Pekkanen, & Itkonen, 2013). Drivers' gaze is making zig-zag (back and forth) pattern on the path the driver intends to follow. Most of this zig-zag movement happens in small scale, within a couple of degrees within the visual field, but sometimes drivers make more anticipatory look-ahead fixations over the curve (Lehtonen, Lappi, Kotkanen, & Summala, 2013). Simulator studies have shown that steering automation increases the proportion of these anticipatory look-ahead fixations (Mars & Navarro, 2012). A possible explanation is that drivers do not need their gaze for visual control of steering, and therefore have more time to spent on visual monitoring of the environment.

Although work in the area has begun, there exists a need for more fine-grained analysis of eye movements during automated steering, and especially during transitions to manual driving, since we do not yet know exactly what visual cues drivers use to detect when the steering automation no longer is keeping the vehicle in the lane (and hence that the driver needs to steer). There is also a clear need for studies performed in test-track environments rather that in driving simulators, because the driving simulator does not provide all the visual and kinesthetic cues that drivers are using while driving.

The analysis and modeling was planned to be performed within the predictive processing framework (Engström et al., 2017). In this framework, steering control can be conceptualized as actions which will cancel the mismatch between the predicted outcome (expected position on the lane) and the observed outcome (perceived position on the lane). It is also known that when looking away from the road ahead, e.g. toward an in-vehicle display, drivers can use peripheral vision for lane-keeping (Summala, Nieminen, & Punto, 1996). In line with general gaze leads action principle (e.g. Flanagan, Bowman, & Johansson, 2006), the previous research has found that drivers prefer to look back the road ahead just before correcting their steering. Interestingly, when the road ahead is still visible in low eccentricity, drivers also start to steer before they look. In this case, looking back can be interpreted more like monitoring the outcome of the action, or resolving the uncertainty of the lane position generated by the steering action itself, rather than by visual guidance of steering.

3. Purpose, research questions and method

The following research questions were to be addressed:

1. Where do drivers look when they drive with pilot assist compared to manual driving? The goal was to see if steering automation produces quantitative or qualitative changes to the gaze patterns compared to manual driving in the current test situation.

2. Where do drivers look when the pilot assist function does not keep the lane? Based on the analysis of the existing research literature and previous data, we have identified two possible strategies on how drivers may react with their gaze when steering assistance does not perform as expected. First, the drivers may directly re-engage to steering by directing their gaze on the path and steer. Second, the drivers may first direct their gaze to other sources of relevant visual information, like lane edges, to assess if they really are leaving the lane, before re-engaging in steering.

3. How can the gaze patterns be modelled using a predictive processing framework? The predictive processing framework assumes that drivers take actions to cancel the error between the prediction and the perception of external visual or kinesthetic cues. The plan was to model the sequential structure of gaze patterns in relationship to the steering actions, in order to understand which visual features in the environment are used as visual cues triggering drivers' action – in this case a movement of the steering wheel – when a steering automation failure occurs.

Track and equipment

The experiment was performed on the AstaZero test ground on the rural road. The data was collected on 18th, 19th, 23rd and 24th October 2018. The test track time was funded through AstaZero open research initiative funding. In the experiment, we used an instrumented vehicle provided by Revere labs at Chalmers. The vehicle was equipped with a joystick control system, which allowed the passenger on the front seat to control steering and simulate supervised automated driving. Such a system was used because the GPS based steering system did not function as reliably as needed. Drivers' gaze was tracked with an eye tracker installed to the car, and data from the car was collected and synced with the eye tracker data.

Participants

14 volunteer participants were recruited for the experiment.

Experimental design

Participants drove on the AstaZero rural road loop track four times, both in manual mode and with the pilot assist function engaged while their eye movements were tracked. This experimental design was chosen to establish what are the overall differences between manual and automated driving. Normally occurring and/or induced pilot assist lane keeping errors were used to see how drivers react to with their gaze and steering.

Implementation

The pilot study was implemented as an Automotive Engineering Project course at the Chalmers University of Technology. The student participated in the design and execution of the experiment and made the preliminary analysis of the results. The project report written by the students is attached as an additional document.

4. Results

The pilot study provided insight to the strategies which drivers use when driving with supervised automation. The behavioral results suggest that drivers either trust or do not trust the automation. If drivers trust, they let the vehicle deviate from its own lane much more than if they do not trust. This strategy difference could be also seen in the eye tracking data. Drivers who did not trust, and intervened quicker, kept their gaze more on the road ahead. Unfortunately, due to the technical difficulties with the eye tracker (it got distracted by the infrared radiation from the sun), we could not analyze eye tracking data properly in quantitative terms.

The experiences with the project can be utilized when developing quantitatively driver models for steering with supervised automation.

5. Conclusion and outlook

The project was a valuable learning experience on performing research with Revere lab vehicles on AstaZero proving ground. The experience was seminal for kick-starting future projects utilizing the same infrastructure.

6. Lessons learned, experience from testing at AstaZero

The infrastructure on AstaZero worked very well. On the other hand, our requirements were rather modest (track time).

The rural road was very applicable for this type of research, because it provided multiple sections where planned steering deviations could be performed safely.

The main challenge with using AstaZero is that it is hard to get participants to AstaZero and back, and it took also considerable time from us. Therefore, the test-track can be more feasible to studies where there is no need to have many different drivers.

7. Publication and dissemination (incl. planned)

The work resulted in the publication of a report written by the students involved in the Automotive Engineering Project course at the Chalmers University of Technology..

8. Participating partners and contact persons

The project was run by Chalmers University of Technology in collaboration with Volvo Car Company (VCC). From Chalmers, the key persons were Postdoctoral researcher, PhD Esko Lehtonen (esko.lehtonen@chalmers.ser) and Assistant Professor, PhD Giulio Bianchi Piccinini (giulio.piccinini@chalmers.se). Arpit Karsolia (arpit.karsolia@chalmers.se) was the main contact person at REVERE lab. On VCC, the main collaborator is Technical Specialist, PhD Mikael Ljung Aust (mikael.ljung.aust@volvocars.com).

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