Driver interaction with a semi-autonomous vehicle on the road

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ABSTRACT

The current Society of Automotive Engineers (SAE) Level 2 (automated acceleration and steering capabilities) autonomous vehicles on the market require constant monitoring and intermittent interventions by the driver whenever the system reaches its limitations. Although drivers' workload could be increased in the processes, interactions associated with them have rarely been explored in a naturalistic environment. Therefore, our understanding about drivers' interaction with the current generation of autonomous vehicles seems limited. In order to extend the relevant knowledge, this paper investigates drivers' interaction with a semi-autonomous vehicle in a complex naturalistic urban environment. Five drivers with varying levels of experience in autonomous cars participated in the experiment. Findings show that active monitoring was required in automated driving for safety to gain sufficient situation awareness that preceded manual interventions in certain conditions. The process seemed to be smoother for the experienced drivers as they had a better understanding about capabilities and limitations of the autonomy. Insights to automotive manufacturers on how driver-vehicle interaction could be enhanced are discussed.

KEYWORDS

Driver-autonomous vehicle interaction, interface, workload, situation awareness

Introduction

Level 2 semi-autonomous vehicles require constant monitoring and timely intervention from the driver as the vehicle could issue takeover requests whenever the system reaches its limitations (SAE International, 2018). In automated systems, a great deal of problems result from deficiencies in coordination and communication between the operator and the system. They are acute in cases that authority over the operation of the system is shared between the two parties (Degani and Heymann, 2002). However, driver interaction with semi-autonomous vehicles has scarcely been observed on public roads. Simulations have been used to investigate it although they do not sufficiently represent the real-world conditions (Endsley, 2017). Understandably, in-depth understanding about it in naturalistic conditions has not been achieved thoroughly. Hence, this study aims to explore driver-autonomous vehicle interaction in naturalistic settings to improve the relevant knowledge. An urban environment was chosen because it requires active monitoring of traffic situation and vehicle status due to varying road conditions that include pedestrians, traffic lights, and road infrastructure (Franke et al., 1999).

Method

The study was designed to identify driver-vehicle interaction focusing on drivers' supervisory tasks for monitoring, and their interventions. Jaguar I-PACE, an SAE Level 2 autonomous vehicle equipped with Adaptive Cruise Control (ACC), Lane Centring (LC), and Stop & Go features was used. ACC was activated by pressing the silver button fitted on the steering wheel (see Fig. 1. A). It was cancelled when the button, or the brake pedal was pressed. Once cancelled, the driver needed to press the button to resume ACC. It was overridden by acceleration, but once the pedal was released, it was resumed autonomously. LC was activated by pressing the steering assist button (see the orange icon at the bottom left corner in Fig. 1. C). LC went active when lane markings for both sides were detected. Whenever active, the hands-on wheel icon was illuminated in green (See Fig. 1. E).

A B C D E

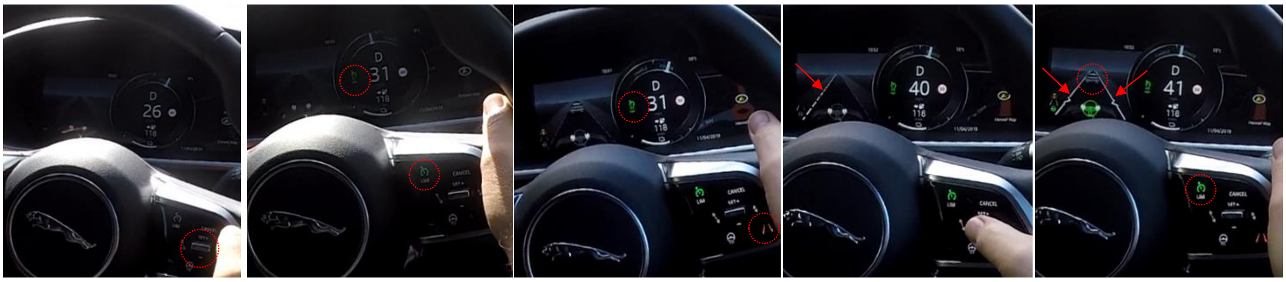

Figure 1: Images of mode status presentations on the cluster display and steering wheel
A. Manual mode
B. ACC active with no lead car in front detected (LIM icon is illuminated in green on the wheel and the display on the left hand side of the vehicle speed)
C. ACC active with a lead car in front detected (A car is shown on the display above the hands-on wheel icon)
D. ACC active, LC not active with only left line detected (Left lane marking is highlighted in dashed line on the display)
E. ACC active with a lead car detected, and LC active with both lines detected

The route was on public roads in Coventry, UK that included junctions, roundabouts, curves, pedestrian crossings, traffic lights, roads with complicated lane markings, and divided lanes. Prior to the experiment, participants received training about the autonomous features at a test track. In the experiment, they were requested to drive on the planned route, and engage autonomous features as much as they could when safe to do so. A safety driver was ready to intervene whenever needed to ensure safety. Video and audio were recorded to capture their verbal protocols, actions, vehicle's interface and the road conditions. Drivers' interactions with the vehicle for longitudinal and lateral control were carefully observed as they are the main features of Level 2 autonomous vehicles. Five adult drivers (one female, and four males) holding a full UK driving licence aged between 35 and 59 participated. Two were experienced and three were novice in driving the selected vehicle. They were recruited within the members affiliated in the University of Southampton, Cambridge and Jaguar Land Rover in accordance with the company' insurance policy.

Results and discussion

This section will describe driver-vehicle interaction focusing on drivers' supervisory roles including monitoring of the external environment and the vehicle status, and decision making regarding longitudinal and lateral control followed by manual interventions. Descriptions of several instances will be provided along with interpretations.

With regard to longitudinal control, activation of ACC seemed to be successful in most cases. Once engaged, the vehicle controlled the speed steadily in relation to the speed of the vehicle in front with few unexpected disengagements. When a lead vehicle in front detected by the system came to a halt, the host vehicle decelerated whilst keeping a safe distance and stopped accordingly. Gradual decrease in speed seemed to elicit a positive reaction from participants one and four. Therefore, drivers were able to focus on monitoring the road ahead to assure a safe distance to the car in front rather than checking the status when ACC was active. However, drivers' manual interventions were needed when the ACC system reached its limitations. The cases occurred when the host vehicle could not detect a stationary vehicle in front or a vehicle quickly cutting in, when the car in front was not tracked by related sensors due to a bend on the road, or when there was no vehicle in front that could lead the host vehicle to stop at traffic lights and pedestrian crossings. These generic limitations of current semi-autonomous vehicles, that are not specific to the vehicle used in the present study, require the driver's timely manual brake input and have to be remembered by drivers. Relevant instances were found in all the participants' cases, with novice drivers waiting for the vehicle to slow down as a response to these situations, delaying their brake intervention.

Regarding lateral control, there were instances that LC could not provide stable assistant. The reason was the route had complex road conditions - lines were complicated or absent or bends were sharp at certain parts. In these areas, relevant lane markings for the intended route were not easily identified by the vehicle, whose features were primarily designed for a highway use (offering clearer and more consistent line markings and fewer sharp bends in the road). SAE International (2018) states drivers of Level 2 autonomous vehicles must constantly supervise the autonomous feature and steer whenever needed to maintain safety, considering the general limitations of lane-sensing system in current Level 2 vehicles. Therefore, drivers' active monitoring was required to check LC status by looking down the cluster display as the vehicle only offered visual signal through the hands-on wheel icon toggling between green (active) and grey (inactive) without auditory warning for change in statuses. In a few instances, the drivers were not aware that LC went temporarily inactive when the both lane markings were not picked up, especially in the novice drivers' cases. Participant four took her hands off the wheel without knowing that LC was not supported when fixing her sights on the road ahead. Although auditory warning for alerting the statuses would be helpful, most of autonomous vehicles of major manufactures do not seem to provide auditory cues. Manual steering interventions were made when the drivers were going through junctions, driving roundabouts to take the correct lane or exit as these environments are outside the operational domain. These were observed in all the participants' cases, but the time to take manual control varied across the drivers' characteristics and expectations. For instance, drivers who had a higher expectation about the autonomous feature waited longer to see if the vehicle approached the intended lane. Intermittent steering inputs were also applied to adjust the steering angle when driving on a bend sharper than the vehicle could handle. In addition, the participants steered manually when they felt that the vehicle deviated from the centre of the lane. Participant two, an experienced driver, was able to apply a subtle adjustment to the steering wheel angle without overriding the LC on a gentle curve.

The experienced drivers could predict better at which point the vehicle would not be able to detect relevant lane markings. Thus, they seemed to know better when to look down to check the LC status whether it was still active or not and when to intervene, rather than delaying their manual intervention. This was dissimilar to the novice drivers who were uncertain about whether the LC system could handle certain situations or not, thus they had to look down more frequently to check the status, for example, when driving on a curve or positioning on a multilane road.

In summary, monitoring and intervention in autonomous driving described above could be interpreted as actions to gain situation awareness required to drive safely in the situations. The actions were acquiring information from surrounding traffic, such as the headway distance, lane markings, road shapes and the vehicle status including mode and limitations of automation, to decide whether to let the vehicle drive or to take control back. In order to drive safely, these types of information needed to be acquired concurrently to be judged correctly to make a timely and appropriate decision. The information seeking and retrieval processes in relation to monitoring tasks may increase perceived mental workload that are not required in manual driving (Warm et al., 2008). Additionally, some differences between novice and experienced drivers were found. The experienced drivers had a better understanding about the limitations of the vehicle and conditions for activations of ACC and LC. Therefore, more accurate projections about the vehicle's behaviours and the intentions determined on the basis of information acquired from external conditions. Hence, the more experienced drivers were likely to be able to better utilise the autonomous features to facilitate their driving by knowing when to, or when not to, engage them (Young and Stanton, 2007). This may be explained by the driver's situation awareness being affected by how accurate and complete the driver's mental model of the system is, as developed through experience and training (Endsley, 2017).

Conclusion

This study investigates driver's interaction with a SAE Level 2 autonomous vehicle in a complex urban environment focusing on the interaction in relation to lateral and longitudinal control, and transition of the control between them. The findings showed that active monitoring of the traffic conditions, the system and the vehicle's behaviour was required for safe autonomous driving. It was conducted during the transitions as well as while supervising the autonomy to define when manual interventions were needed. The tasks were construed to be acquisition of situation awareness to a sufficient level to be able to understand the internal and external conditions, make an appropriate decision, and take action (Stanton, 2016; Endsley, 1995). Regarding the difference between the novice and experienced drivers, the latter were able to identify better in which conditions the vehicle would reach the limitations that required manual control. Further, they were able to make better use of the capability of the autonomous features. However, we cannot always expect the driver to be experienced, in good physical and emotional condition, and to be able to solely focus on driving tasks without any distractions. Therefore, it is suggested to enable clear communication between autonomous vehicle and the driver about mode of automation and its limitations. The interface needs to be designed to better shape the driver's mental model to narrow the gap between the driver's expectation and the vehicle's behaviour (Norman and Draper, 1986; Revell et al., 2018). For instance, the interface should be designed to be understood intuitively, and used easily with inducing less cognitive load. Consideration by manufacturers of the findings of this study could help promote driver-vehicle interaction.

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