“That was scary…” exploring driver-autonomous vehicle interaction using the Perceptual Cycle Model

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ABSTRACT

Semi-autonomous cars are already on the road and highly autonomous cars will soon be with us. Little is understood about how drivers will adapt to the changing relationship with their vehicle, but to ensure safety and consumer acceptance, it is vital to gain this insight. This paper highlights evidence of poor synergy between driver and vehicle in semi-autonomous mode when preparing for a manoeuvre on a UK motorway. As part of an on going study, six UK drivers were observed using a semi-autonomous vehicle whilst employing the ‘think aloud’ technique. Video and audio footage of their interaction with the vehicle was captured and analysed using Neisser’s (1976) Perceptual Cycle Model (PCM). A case study of a single driver is presented in this paper to provide a practical demonstration of the utility of PCM to gain a system’s view of driver-vehicle interaction. The need to consider the drivers schemata of automation capability in the context of use is demonstrated, and implications for interaction design are discussed.

KEYWORDS

Perceptual Cycle Model, autonomous vehicles, interaction design, adaptive cruise control

Introduction

Self-driving cars have been predicted for some time, and are nearly with us. Semi-automated cars (BASt Level 2) are already on public roads and within 10 years, highly automated (BASt Level 3+) cars will be a reality. The largest gap in our understanding of vehicle automation is how drivers will react to this new technology and how best to design the driver-automation interaction. This paper describes early results from a study in progress designed to examine, in a naturalistic setting, how users interact with current semi-autonomous interaction designs from leading manufacturers (e.g. Tesla, Mercedes, and BMW). The findings from the full study will inform best practice for the design of future (BASt Level 3) highly automated cars (Gasser, 2012). This paper will briefly introduce the reader to Neisser’s PCM before describing the method adopted for data collection and analysis.

The Perceptual Cycle Model

Neisser (1976) presented the view that human thought is closely coupled with a person’s interaction in the world, both informing each other in a reciprocal, cyclical relationship (Plant and Stanton, 2012). By considering the operator and environment together, the interaction ‘in context’ can be better understood. The PCM has been used to account for accidents in safety critical domains, including rail (Salmon et al., 2013), road (Salmon et al., 2014) and aviation (Plant and Stanton, 2012). It reinforces the ‘systems view’ of human error that strongly emphasizes context and an evolving situation to understand behaviour.

The PCM is depicted in figure 1 as a simplified relationship between World, Schema, and Actions. Schemata, as a concept, were first popularized in Psychology by Bartlett (1932). They can be thought of as mental ‘templates’ in long-term memory based on common features of similar experiences. These templates are used to interpret information in the world, predict events and focus attention and behaviour. The relationship between World, Schema and Actions are interrelated through a serious of top down and bottom up processing. Top down processing occurs when a schema is triggered, and particular types of information are then anticipated. Bottom-up processing often follows, whereby actions are directed to seek particular information, and are interpreted within the framework of the existing schema. When what is perceived in the world, contradicts expectations driven by an existing schema, modifications to schemata or selection of an alternative can occur. The actions undertaken, and the type of information sought out from the world, are then directed by the new, or amended, schema.

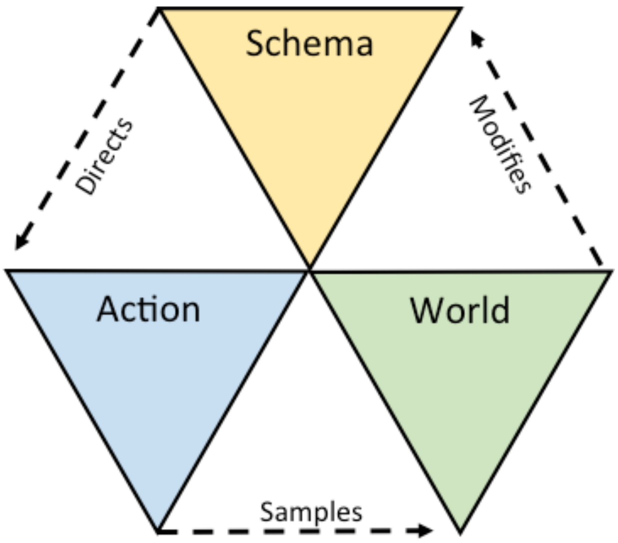

Figure 1: Simplified representation of the Perceptual Cycle Model based on Neisser 1976

The aim of this paper is to demonstrate, through a case study of a single non-optimal incident, the benefit of a context-based systems approach to the design of interactions between driver and autonomous vehicle.

Method

Participants

Six participants (five male and one female), aged between 26 and 56 research participated in part one of this study. The participants formed two equal groups who took part in the study on separate days following the same route and protocol.

Equipment

The study was undertaken in a Mercedes S Class with pilot assist features comprising of ‘Distronic Plus’ and ‘Steering Assist’. Distronic Plus consists of 2 short range sensors and a long range radar used to provide Adaptive Cruise Control (ACC) to automatically maintain a safe headway from the vehicle in front by braking when necessary and accelerating again when the traffic conditions permit (Daimler AG, 2016), Steering Assist uses stereo cameras to identify lane markings and passes the signal to the electric steering which maintains the position between lane markings. It keeps the vehicle in the centre of the lane on straight roads and around bends (Mercedes Benz, 2012) The combination of two BASt level 2 features such as Distronic Plus and Steering Assist result in a driver experience that is conceptually ‘hands and feet free’ from control as there is no need to make inputs to control lateral (steering) or longitudinal (accelerator and brake) locomotion. This feature does not allow ‘eyes free’ control of the vehicle (BASt level three) however, as the driver is still required to monitor the road and automation status and capability, and be ready to take manual control of the vehicle at short notice.

The drivers’ actions and verbalisations were recorded using 2 hand held digital video cameras operated by passengers. One camera focussed on the view through the windscreen and recorded the voice of the driver. The second camera was focussed over the right shoulder of the driver allowing a view of the steering wheel, the hands of the driver and the Distronic display. A head mounted GoPro video camera was used to identify the broad direction of gaze. For redundancy, a head mounted microphone connected to a digital Dictaphone was used to capture driver verbalisations.

Procedure

Prior to the experiment all participants were asked to read a participant information sheet and read and complete a consent form. A safety driver conducted a training session on the test track to familiarise each participant with the Mercedes S Class and the Distronic Plus and Steering Assist features. The safety driver was present throughout the study to provide continued advice on the route and verify the conditions were suitable for activation of the automation features.

Following directional instruction from the safety driver the participant then drove two pre-determined routes of approximately 20 minutes duration. One route comprised predominantly of motorway, with the second route featuring urban roads through a small town. Each route was driven manually first then in automated mode by each participant. During the scenarios the drivers were required to use the ‘Think Aloud’ method on which they had previously received training.

Data analysis

Think Aloud audio data was transcribed and entered into NVivo software for qualitative data analysis. The content of verbalisations were coded according to Neisser’s (1976) PCM, relating to:

1. World
    - References to information observed inside the vehicle such as the dashboard icons relating to the automation, primary controls or standard dashboard outputs (e.g. speed).
    - References to information observed outside the vehicle such as traffic, other road users, road conditions, and weather.
2. Action
    - Actions undertaken by the driver.
    - Actions the driver verbalises that they intend to take.
3. Schema
    - Where the driver makes reference to their individual ‘cognitive template’ of the situation.
    - Interpretations of events, or rules that dictate analysis of a situation etc.

During coding, key incidents were identified from each driver where a lack of synergy between driver and automation was evident (based primarily on verbalisations by the driver of frustration, confusion or panic). The video data for each incident was then examined in detail to more comprehensively populate the PCM with observation and context data in a similar way that Plant and Stanton (2012) used accident reports to populate a PCM for an aviation accident. Any assumptions made, particularly regarding schema content, were verified with the participant in question in a follow up session in person or by phone.

Results and discussion: a case study of driver confusion when using Distronic Plus (ACC)

This section examines one incident from a single driver relating to the use of the Distronic Plus in the Mercedes S Class on a UK highway. It occurred when the driver was in the middle lane of a highway with two cars (one red, one white) and a lorry ahead in the same lane. The red car directly ahead of the Mercedes S Class car indicated and moved to the right hand lane to overtake the lorry (see Figure 2). The driver decided he also wanted to manually overtake the lorry so also indicated to overtake. During this time the white car directly behind the lorry also indicated and moved to the right hand lane proceeding to overtake the lorry. Whilst waiting for a clear gap in the right hand lane to pull out, the driver noticed his car accelerating. In confusion and panic, the driver braked suddenly to counter the acceleration that he attributed to an error in the automation. He then continued with the overtake procedure and verbalised his fear that the automated car had been on course to drive into the back of the lorry in the central lane. Table 1 shows the incident broken down according to PCM categories of World, Action and Schema.

Table 1: Breakdown of observations during below optimal driver - vehicle interaction, categorised by 'Schema', 'Action' or 'World' according to Neissers (1976) PCM. Content in '[]' has been derived from video content or verified with the participant.

PCM Category	Video / Audio transcription
World	1) "…there's vehicles all around me. It feels quite heavy traffic."
World	2) "So, we've dropped down to…"
World	3) ['Hands on Wheel' Icon observed]
Action	4) "…another bit of input, it wants – okay, just given it."
Schema	5) "I'm thinking about doing an overtake now."
World	6) [Lorry observed]
Schema	7) "So, I get past this lorry…"
Action	8) "…and I'll try indicating."
Action	9) "…check behind me"
World	10) "ooh... we're speeding up"
Schema	11) "Oh, no. Blimey!" [we're going to crash]
Action	12) "Brake."
Schema	13) "…and I didn't trust it"
Action	14) "I'm pulling out now."
Schema	15) "…that was scary" [safe headway breached]
Action	16) "So, I think I'm going to have put that back on again."
Action	17) "Distronics on 70."
World	18) "We're doing 60."
Action	19) "Hands off the wheel."
Schema	20) "If I hadn't grabbed it back then it would have ploughed into that lorry."

From Table 1, it can be seen that the lead up to the incident (sentence 1-9) is relatively calm with attention being focused mainly on the 'World' in terms of outside traffic conditions, the speed status, and the alert (dashboard icon) to remind the driver to keep his hands on the wheel. Figure 2 below shows the scene just after the red car has moved into the right lane, and before the white car starts to indicate. The Distronic Plus dashboard clearly shows the white car has been sensed (car ahead icon is present) but the headway has not yet been reduced to the prescribed setting (gap evident between yellow headway line and the car ahead icon).

Figure 2: Showing Distronic Plus is correctly representing the outside world but is yet to reduce the headway (see within red circle) as it had increased after the red car in front had moved to the right hand lane.

Before the distance between the Mercedes S Class and the white car can be reduced to maintain the set headway, the white car also moves into the right hand lane extending the headway between the Mercedes S Class and the vehicle ahead (now the Lorry). There is no evidence from the video or audio data that the driver has paid attention to 'World' data relating to the status of headway maintenance shown on the dashboard. The Distronic Plus accelerates to bridge the gap between the Mercedes S Class and the lorry ahead. This acceleration, however, was noticed by the driver who senses the change in the 'World' in sentence 10 in Table 1 "ooh... we're speeding up". Without checking the headway status to help interpret the situation, the driver assesses the situation and his interpretation results in sudden braking as a means of preventative action to avoid an accident (see sentences 11, 12, 13 in table 1. These, and the verbalisation "that was scary" in sentence 15, highlight the fear and lack of trust experienced during the incident. Figure 3 below shows the point of braking.

Sentences 15 and 20 in table 1 make it clear that the driver's existing schema could not reconcile the acceleration of the vehicle at that point in the manoeuvre with correct functioning of the Distronic Plus automation, reducing trust in the system. There was clearly a 'mismatch' between the 'expected' and 'observed' behaviour of the vehicle experienced by the driver. To understand the reason for this it is necessary to consider the context of the incident in terms of a manual overtake of a large vehicle, and how this differs from that of a small vehicle. When overtaking a small vehicle, if the lane to the right is clear and there is visibility ahead of the vehicle for re-entry into the lane, it is appropriate to accelerate towards the vehicle to adopt 'overtake position', allowing the overtake to occur immediately (Roadcraft 2013). In the scenario described, traffic was present in the right hand lane preventing an immediate start to the manoeuvre, and the large vehicle obscured the view of the road ahead. In this situation it is prudent to drop back to a following positioning until a gap in the right hand lane is imminent. This also allows greater visibility of the road ahead of the vehicle, and avoids positioning your own vehicle in its blind spot for any extended period of time (Roadcraft 2013).

Figure 3: Showing the instant of manual braking when the driver lost confidence in the operation of the Distronic Plus. Within the red circle it can be seen that the Lorry has been sensed and the headway has not been breached, indicating correct functioning.

If the driver had been in manual control of the longitudinal locomotion, he would not have accelerated at the point chosen by the Distronic Plus. As he was about to engage in a manual manoeuvre, it is not surprising that a schema for manual control was in place that interfered with appropriate interpretation of events. It should also be noted that the automation system was not aware of the driver's intention to initiate a manual takeover. Although the driver did activate an indicator, this input is not integrated with the performance of the Distronic Plus. In the same way, the driver was unaware of the intention of the Distronic Plus to reduce the headway between the Mercedes S Class and the Lorry in front in order to keep to the prescribed setting. A key factor for the incident clearly arose out of a conflict of goals between the vehicle and the driver, and obstacles to communicating each other's intentions. We are not suggesting that there was a serious safety breach with Mercedes Distronic Plus, rather there was a mismatch between the expectations of the driver and the behaviour of the vehicle. Ideally, this apparent mismatch could be addressed in the design of vehicle automation. There may also have be a 'gap' between the driver's 'device model' of the function of ACC as a feature that maintains headway, rather than speed, (which is more applicable to the functioning of standard cruise control) (Norman 1986).

Implications for interaction design

Semi-automated cars (e.g. anything below BASt level 5) require input from drivers where the road or environment conditions prevent full automation. High levels of synergy between driver and automation is required for performance and safety, but this synergy relies on trust and understanding on both sides. Hancock et al. (2009) argue that individual case representations are increasingly relevant for the design of human-machine systems, and generalisations can be derived. From the single case study described in this paper, the goals to be achieved through interaction design can be summarised as follows:

- **Design for conflicting intentions between driver and automation**. For example, when the driver begins or ends a manual manoeuvre, there needs to be a means for this to be communicated to the existing assistive technologies so where necessary, they are disabled until the manual manoeuvre is complete.

- **Design for reassurance.** Such as when an atypical change in longitudinal or lateral locomotion is initiated by the automation, the action and its reason needs to be successfully communicated to the driver to avoid unnecessary or potentially risky manual intervention by the driver. Visual dashboard displays may be insufficient if the driver is focused 'eyes out' of the windscreen, observing potential hazards, so Head Up Displays (HUDs) or alerts may be more appropriate.
- **Design for appropriate mental models.** By ensuring the function of any assistive automation is effectively understood by the driver.
- **Design for context.** For example, recognise the expected behaviour by a car when following a large vehicle will differ from that when following a standard vehicle. Interaction design should either appropriately set the drivers' expectations in a range of contexts, or the automation should be programmed to adjust to differing expectations based on context.

Conclusions

This paper set out to highlight the benefit of applying Neisser's (1976) PCM to explain non-optimal interaction between drivers and semi-autonomous vehicles in context. A single case study was presented highlighting confusion over vehicle behaviour when ACC was engaged prior to initiation of a manual manoeuvre to overtake a lorry on a UK highway. The ability to interrogate the evidence through the lens' of 'World', 'Schema' and 'Action' proved advantageous in deriving generalisable recommendations for interaction design to ensure the experience when a driver interacts with a semi-autonomous car is no longer 'scary'.

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