Investigating Kinematic Parameters of a Turning Seat as a Haptic and Kinesthetic HMI to Support the Take-Over Request in Automated Driving

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Abstract. When driving a conditionally automated vehicle, a haptic signal might be an option in order to facilitate the TOR, since the driver's visual and acoustic modalities may be occupied by non-driving related tasks. Therefore, the driver's seat rotation is examined here as haptic cue in the TOR since, so far, it has not been considered in detail, yet. The turning seat actively turns the driver away from the driving task in AD mode. The modified seating position during AD is intended to support the driver's Mode Awareness. In the case of a TOR, the driver receives a kinesthetic cue by applying a torque around the vertical axis of his seat, turning him back to the driving task. To investigate the turning seat, a preliminary expert study was conducted. Results show that drivers prefer an eccentric vertical turning axis which leads to a rotation away from the steering wheel.

Keywords: Automated Driving · Take-Over Request · Mode Awareness · Turning Seat

1 Introduction

Numerous manufacturers already offer automated vehicles at SAE Level 2. It is highly likely that in 2021 conditionally automated vehicles (Level 3) will drive on public roads. At this level of automation, the vehicle can execute the driving task. Before a system limit is reached, however, the driving task must be handed over from the vehicle to the driver within a limited time span of several seconds. The take-over process shown in Figure 1 is initiated by a take-over request (TOR) from the vehicle. [1]

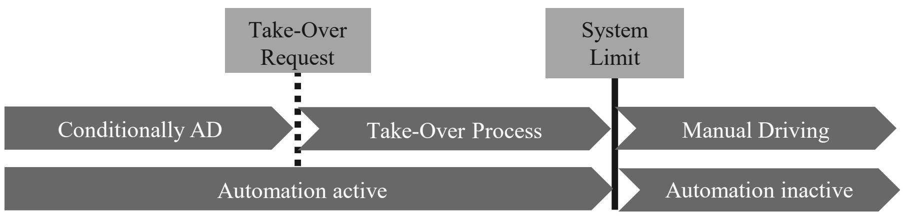

Fig. 1. Take-over process in a SAE Level 3 vehicle.

During automated driving (AD), drivers can engage in non-driving-related tasks (NDRTs). These NDRTs often occupy the driver's visual and auditory sensory channels, e.g., in the case of watching TV or reading. WICKENS shows in his multiple resource model that the occupation of visual and acoustic attention channels has a strong negative effect on the perception of other visual and acoustic signals. Therefore, the driver may perceive a TOR signal that uses attention channels already occupied by the NDRT with a significant delay or, in the worst case, not at all. [7], [8], [9]

In recent years, numerous studies with regard to TOR design have been conducted. The majority of the studies consider a combination of visual and acoustic signals. Only some studies investigate TOR concepts involving haptic signals [2–6]. These studies show that integrating a haptic cue in a TOR may have a positive effect on take-over time. Several previous studies focus on vibrotactile cues; for instance, PETERMANN-STOCK used a vibrating seat [4]. With regard to kinesthetic and vestibular cues, to our knowledge, only a brake jerk has been considered so far [10]. Although this cue seems to be very promising, it has a significant disadvantage since a brake jerk can be perceived as rather uncomfortable. Furthermore the brake jerk addresses all passengers, not only the driver. Yet, kinesthetic and vestibular sensory channels are usually not occupied by a NDRT and may be utilized in a comfortable way. Therefore, this type of cue could lead to both high acceptance and improved TOR performance.

One promising option to realize such a kinesthetic and vestibular cue within the vehicle is by turning the driver's seat [11]. Currently, there are no data on the effect of a turning seat as a haptic and kinesthetic HMI to support the take-over request in automated driving. This paper investigates kinematic parameters of a turning seat. The seat is thereby turned slightly inwards in AD mode, allowing the driver to focus better on the vehicle interior and entertainment options. During TOR, an increasing torque around the vertical axis of the seat is applied, turning the seat back and hence also the driver to the driving task. The resulting stimulus is intended to complement visual and auditory cues. Moreover, the turned seating position shall provide a continuous notification of the current driving mode to the driver. With such a system, multiple trade-offs have to be taken into account, on the one hand, for example, the turning angle should be large enough so that the driver is aware of the rotation. On the other hand, the smaller the angle, the easier it is to integrate the concept into a vehicle package. Furthermore, the positioning of the vertical turning axes has to be considered, since it has a major influence on the trajectory of the driver's seat.

Topics that become relevant in a dynamic driving situation, e.g. the combination of a turning seat with visual and auditory signals or the topic of kinethosis, etc., are not considered in this investigation.

2 Method

As a preparatory measure step for a larger user study, an exploratory expert study has been conducted to investigate the turning seat and to find a way to balance the aforementioned trade-off. This chapter describes the research method in more detail.

2.1 Experimental Equipment

A simple seating buck has been used as shown in Figure 2 (left). The seating buck comprises a steering wheel, pedals, and a center console. The driver seat provides a turning motion around different vertical turning axes (P1, P2, P3) (see Fig. 2 right). The acceleration, speed and angle of rotation can be adjusted.

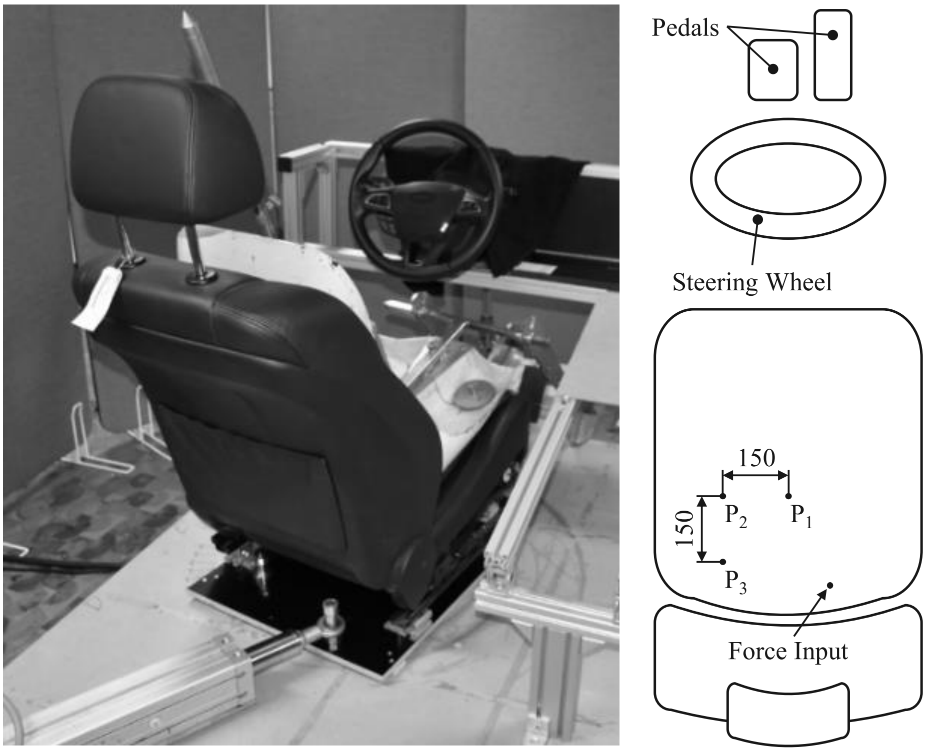

Fig. 2. (left) seating buck with turning seat; (right) turning seat (top view)

This expert study examined especially the kinematic characteristics of the turning seat in more detail. First of all, different axes of rotation were tested. The rotation around the vertical axis exactly through the Seating Reference Point (position P1) conveys the most familiar movement, known for example from office chairs. The rotation around the vertical axis through (position P2) is shifted 150 mm to the left from the rotation axis through P1, causing the driver to move slightly away from the steering wheel during rotation. This increased distance to steering wheel and pedals may positively affect the perception of space. When rotating around in position P3, which is shifted 150 mm to the rear relative to P2, the driver is additionally moved towards the center of the vehicle. This results in a slightly greater distance from the steering wheel, and in addition, the feet may be easily moved away from the pedals, providing more space in the footwell. Choosing a transversal offset for P2 and P3 compared to P1 seems promising with regard to implementation success and perceptibility.

2.2 Procedure

The expert study has been conducted as an exploratory study to answer the following research questions:

- What is the required minimal turning angle at which the driver can clearly distinguish between the manual and the automated driving position?
- Is the kinesthetic cue provided by the rotation of the driver seat perceived as a take-over cue?
- Which position of the vertical rotation axis (P1, P2 and P3) appears comfortable to the driver?

All experts experienced the rotations around the vertical axes in position P1, P2 and P3 during the experiment. The different positions of the vertical rotation axis were presented in randomized order to eliminate habituation effects. Different rotation angles (5°-20°) with an equal step size were chosen to enable a standardized evaluation. The equal step size of 5° was large enough to be perceptible, but not too large to enable a useful resolution for the data. During the expert study, the different angles of rotation were named only variant 1-5. The information provided by the experts during the execution of the experiment was documented and subsequently evaluated to answer the research questions stated in 2.2. A questionnaire that was used for documentation was filled in by the instructor. The rating was based on a Likert scale from 1 (bad) to 5 (good). For each turning variant, questions were asked about the perceptibility of the turning motion as TOR cue and the separation between manual and automated driving (Mode Awareness). For each vertical turning axis, a fast-turning cue from 15° turning angle to driving position was alternatively provided to check whether a critical TOR can be displayed in that way. At the end of the study, the experts still had the opportunity to provide further comments regarding their impression.

2.3 Sample Description

The sample consists of 13 experts who have already been involved in the development of various TOR concepts. The group consists of three females (23%) and ten males (77%), with ages ranging from 28 to 41 years and body heights from 1.66 m to 1.92 m. To enable a holistic view, experts from both Engineering and Psychology departments participated.

3 Results

Table 1 shows the results of the experts rating regarding the comprehensibility and the conveyed Mode Awareness of the turning of the seat as TOR cue. The rating was based on two Likert scales, each from 1 (bad) to 5 (good). A mean rating of 4 (on both Likert scales) was taken as a threshold as this is the lowest scale value above which a positive rating can be assumed for the Mode Awareness and the TOR cue. This threshold is reached for the rotation axes P2 and P3 from a rotation angle of 15°. For all rotation axes from a 5° turning angle onwards, the take-over cue was rated on average equal as 3 or more on the Likert scale. The target value (threshold) of at least four points is achieved for all three variants at a rotation angle from 15° onwards. Turning the seat from a turning angle of 15° back to the driving position quickly (normal 1.8s; quick 1.3s) was perceived as a signal for a critical TOR by 84% of the experts.

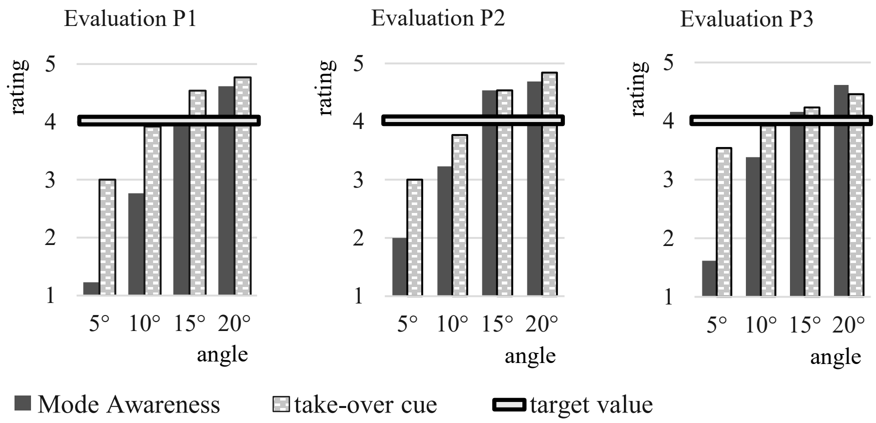

Fig. 3. Rating of the rotation center points (P1, P2, P3) and angles (1=bad to 5=good)

In total 92% of the experts rated the position P2 of the vertical rotation axis best in comparison with P1 and P3. Both the Mode Awareness and the perception of the TOR were rated with a mean value ($\bar{x}$) of 4.5 points (V=0.4; SD=0.6) for a rotation angle of 15° at the P2 rotation axis. For the same rotation angle (15°), the experts rated P3 ($\bar{x}$=4.2; V=0.3; SD=0.5) and P1 ($\bar{x}$=3.9; V=1; SD=1).

3.1 Further Comments

In addition to their rating on the scale, four experts stated that they could perceive the backward rotation as kinesthetic cue very well. In particular, the angular acceleration was said to be much more crucial than the magnitude of the angle of rotation. Two experts stated that the rotation in position P3 was most suitable for TOR cues. The main reason given for this was the greater distance between the feet and the pedals. One expert stated that the angle of 20° is a bit too large. Although an angle of 15° was considered as sufficient, two experts stated that they would like to see a larger angle of rotation. Two experts considered a slower rotation speed to be useful. One expert considered a higher rotation speed to be useful. No information was provided as to why the rotation speed should be increased or reduced.

4 Discussion and Conclusion

Following the evaluation of the expert study, new insights were gained to answer the research questions provided in section 2.3. Basically, the turning seat is rated as a useful human machine interface (HMI) by all experts. The kinesthetic TOR cue was perceived very clearly in the expert study, even at small turning angles. For a perceptible TOR cue, the angular acceleration seems to be more important than the turning angle itself.

To achieve a reliable Mode Awareness, larger rotation angles of about 15° are preferred. However, rotation around the vertical rotation axis in position P1 is rated lower than those in positions P2 and P3. Rotation in position P3 was rated as rather good. Further comments by the participants suggest that this is related to the larger distance between pedals and feet and that the space gained in the footwell contributed to this positive rating. Rotation around the rotation axis in position P2 is rated even as slightly better than P3. This is presumably due to the fact that the distance to the steering wheel is increased and thus more space is available for the driver. The communication of a critical TOR by increasing the angular acceleration is perceptible.

The results of our research show that further investigation of the turning seat as a kinesthetic HMI is reasonable. The work presented in this paper is a firm basis to further develop the turning seat concept. To ensure this, a high-fidelity prototype should be developed and integrated in a simulator mockup to be able to learn more about the turning seat's potential by conducting a user study with normal drivers.

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