Active Vehicle Pitch Motions as Feedback-Channel for the Driver during Partially Automated Driving

Stephanie Cramer*, Karl-Heinz Siedersberger† and Klaus Bengler‡

Abstract: During partially automated driving, the driver must have a good awareness of the automation system's state to fulfill his supervising task sufficiently. In this contribution, a concept for feeding back state transitions and intentions of the automation is presented. The feedback is not communicated visually, as usual, but instead via vehicle movements, strictly speaking active pitch motions. Feedback through active pitch motions is shown to test persons in four selected test scenarios in a driving study. Thereby, the design of these pitch motions as feedback for state transitions and intentions of the automation is evaluated.

Keywords: Active pitch motions, feedback, mode awareness, partially automated driving

1 Introduction

At the present time, the development and research of driver assistance systems tends strongly towards automated driving. The technical feasibility of conditionally automated driving (SAE-Level 3 [14]) comes within reach. In that matter, the automation takes over the longitudinal and lateral vehicle guidance for specific situations for a certain period of time and the driver does not have to supervise the automation system permanently [14]. However, the driver has to take over the vehicle guidance within a certain amount of time [5]. As long as the technical challenges regarding sensors, functional safety, situation interpretation etc. are not entirely solved, partially automated driving (SAE-Level 2 [14]) represents an intermediate step on the way to conditional automation and will prospectively be available simultaneously to conditionally and highly automated driving. During partially automated driving, the driver must be able to take over the driving task anytime as a fallback level at system boundaries [5].

One risk that comes along with automation of the vehicle guidance is that the driver mentally withdraws himself from the vehicle guidance. This is especially a challenge at system boundaries because it can take some seconds until the driver takes over the vehicle guidance again [6]. "Out of the loop" effects occur because of excessively high trust and misuse [15], [13] as well as driver's inaccurate mental models of the automation system [1],

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[7] and thereby accompanied by a lacking situation [12] and mode awareness [16]. To avoid these negative impacts, feedback on system behavior and system state is indispensable [17]. Consequently, state transitions and intentions of the automation should be fed back to the driver that he can fulfill his supervising task sufficiently. This feedback is so far mainly visual, as for example via the contact analogue head-up display [3]. Each human sensory channel is limited according to its performance. Therefore, the human mode awareness can be improved by feeding back the system state via several sensory channels [2]. The feedback via vehicle movements (vestibular sensory channel) illustrates a further possibility and is considered in the following. An approach using communicative trajectories in the vehicle's longitudinal and lateral direction can be found in [9] and [8]. [11] developed a feedback concept which does not patronize the driver on the steering wheel because the relevant intervention information is transferred to the driver via roll motions. Moreover, [10] had the idea to design the announcement of maneuvers during automated driving via body movements of the vehicle. Until now, this idea has not been realized and there is no prior research on the potential of designing the feedback via the vehicle's movements around its axes of rotation. This includes pitch and roll motions of the vehicle.

In this article, a concept for feeding back state transitions of the automation system via rotational motions is described initially. Subsequently, a driving study in a real test vehicle as well as its results are presented.

2 Feedback Concept

The just mentioned rotational motions, in the form of active pitch and roll motions of the chassis, are realized with an active body control vehicle. Two possible pitch and roll motions of the test vehicle are shown in figure 1a and 1b.

(a) Pitch motion of the vehicle with a positive pitch angle

(b) Roll motion of the vehicle with a positive roll angle

Figure 1: Possible body motions of the test vehicle

Thereby, a pitch motion with a positive pitch angle corresponds to a forward rotational motion of the vehicle (see figure 1a) and a pitch motion with negative pitch angle to a backward rotational motion of the vehicle. With regard to roll motions of the vehicle, a positive roll angle expresses a rotational motion of the vehicle to the right (see figure 1b) and a negative roll angle expresses a rotational motion of the vehicle to the left.

In the first instance, the domain highway is considered for this feedback concept via the vestibular sensory channel. It is illustrated with its relevant maneuvers, states as well as their possible transitions in figure 2. The maneuver *follow lane (FL)* includes the two states *distance control* and *velocity control*. The maneuver *lane change (LC)* can be divided in the two states *regular lane change* and *lane change abort*.

[1] points out on the basis of a study that information for monitoring the automation system (e. g. system state, prospective maneuver) plays an important role for the driver during partially automated driving to accordingly obtain respectively increase his mode awareness [16].

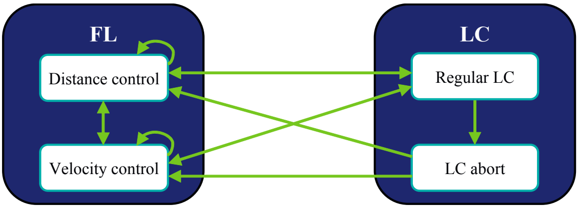


Figure 2: Relevant maneuvers and states of the domain highway

The objective of the presented concept is to feed back the state transitions of the automation system, displayed in figure 2, via body movements of the vehicle (see figure 1).

According to [8] feedback should be designed timely, clearly perceptible, comfortable and associable. [1] combines feedback with the terms transparent, predictable and comprehensible. Referring to [4] and [2] system responses should occur in time and be clearly perceptible (exceeding the driver's perception threshold).

Consequently, it should be examined how changes of the automation's system state can be represented via active body movements of the vehicle (pitch and roll motions) according to the particular driving situation. The feedback has to be designed perceptible and should not generate discomfort.

3 Method

The goal of the displayed driving study is to identify the desired design of pitch motions as feedback for the driver in selected driving situations. In the first instance, roll motions are not considered in this driving study. Thereby, essential exploratory questions are:

- Should the direction of the pitch motion represent the vehicle's natural pitch motion for each particular driving situation? Using the example of the transition from *velocity control* to *distance control*, the natural pitch motion would be with a positive pitch angle due to the required deceleration.
- Should the amplitude of the pitch motion be greater for more critical driving situations?
- Should the return of the vehicle into the horizontal position rather be perceived by the driver or not?
- Differentiation of certain items between the selected driving situations: How *useful*, *misleading* and *comprehensible* does the driver rate the feedback via pitch motions? In addition, does the driver *perceive the state transition* and is the *mode awareness increased* via pitch motions? The evaluation of these items is described in detail in chapter 4.

3.1 Test Scenarios

Chapter 2 describes for which state and maneuver transitions the feedback via the vestibular sensory channel by pitch and roll motions can be realized. Four specific state transitions are chosen for the underlying driving study and are implemented in the test vehicle (green arrows in figure 3).

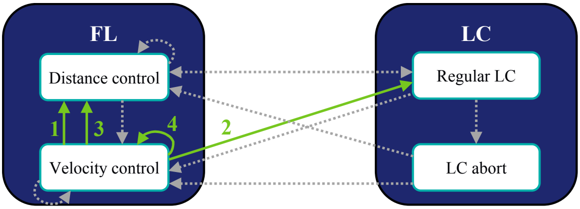
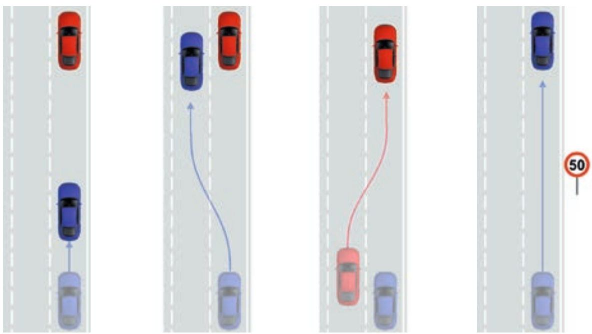


Figure 3: Realized feedback of state transitions in the driving study

For evaluating these state transitions, a driving study was conducted on an approx. 1,4 km three-lane oval test track on which was driven multiple times for each driving situation without stopping the automation system. The maximum velocity was 60 km/h on the straight part of the track and the minimum velocity approx. 22 km/h in the curve. The automation system completely takes over lateral and longitudinal vehicle guidance and lane changes are triggered by the experimenter. Though, the driver had to show his availability by touching the steering wheel once each round. A second vehicle was driven manually. A test scenario is performed on each straight. The four test scenarios are shown in figure 4 and are based on the green marked state transitions in figure 3.



(a) Scenario 1 "PV to follow" (b) Scenario 2 "PV to overtake" (c) Scenario 3 "Cutting-in vehicle" (d) Scenario 4 "Speed limit"

Figure 4: Scenarios of the driving study

The state transition from *velocity control* to *distance control* (detection of a preceding vehicle (PV)) is experienced twice by the test person: in the scenario "cutting-in vehicle" (see figure 4c) as well as in the scenario "PV to follow" (see figure 4a). The two scenarios differ in their criticality. For the scenario "cutting-in vehicle", the velocity of the PV is approx. 63-69 km/h and the distance approx. 10-15 m when crossing the lane marking. The scenario "PV to overtake" (see figure 4b) is identical to the scenario "PV to follow" until the detection of the PV. However, on the one hand a PV to overtake and on the other hand a PV to follow is detected. For these two scenarios, the velocity of the PV is approx. 40-45 km/h. Concluding, a test scenario is realized which receives a new external condition (a speed limit) and the velocity is accordingly reduced.

The trigger time for the feedback differs between the test scenarios. For scenario 1 and 2 the detection of the PV (mean distance 79,7 m) and for scenario 4 an approx. 70 m distance to the limit sign automatically initiates a pitch motion. On the contrary, the feedback motion for scenario 3 is manually initiated by the experimenter when the front right wheel of the second vehicle completely passed the lane marking.

3.2 Study Design

The sequence of the driving study is presented in figure 5. Following an oral introduction and a setting-in phase, the test person runs through four driving situations in a randomized order. Concluding, an overall investigation of the gained impressions during the driving study takes place via a questionnaire.

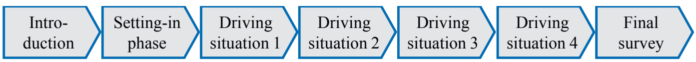


Figure 5: Sequence of the driving study

In each test scenario, the driver experiences feedback with the following randomized variations: pitch motion with positive and negative pitch angle as well as 1 ° and 2 ° maximum pitch angle. During these four alternative pitch motions, the return of the test vehicle into the horizontal position is constant. However, there are also two variations for the return: symmetric and slow linear return. After the test person observed the four alternatives and chose his favorite, it experienced its preferred pitch motion with the two possible returns and selected an overall favorite pitch motion for each test scenario and evaluated it afterwards. The variations of the pitch motion are displayed in figure 6 (absolute pitch angles). The detailed design of the pitch motions is not part of this paper.

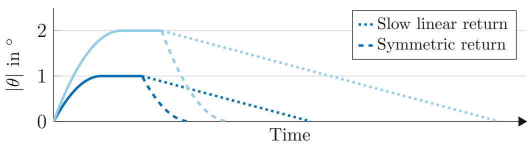


Figure 6: Schematic representation of the pitch motion's variations

3.3 Sample

A sample of N = 35 test persons is available for this test series which composes of 12 female and 23 male test persons. At the time of the driving study, the mean age of the test persons is 29.74 (SD = 4.49, MIN = 19, MAX = 41) and the mean mileage per year is 21286 km (SD = 10158 km, MIN = 5000 km, MAX = 50000 km). Moreover, all test persons have experienced cruise control, 94.3% adaptive cruise control, 91.4% active lane keeping assistance and 57.1% partially automated driving systems (e. g. traffic jam assistance).

4 Results

Design of pitch motions

After each driving situation, the favorite pitch motion is evaluated. Figure 7 shows the distribution for the preferred direction of pitch motions. It is assert with further analysis of the data that 71.4% of the test persons choose a motion compliant feedback. That means that "acceleration" (scenario 2) is assigned to one and "deceleration" (scenario 1, 3 and 4) to the other pitch direction. Out of these 71.4%, 16.0% favor pitch motions equivalent to a helicopter behavior. These test person assign a forward pitch motion to a acceleration and a backward pitch motion to an deceleration. Whereas, 60.0% in absolute terms of the test persons choose a pitch motion direction in accordance with the estimated vehicle behavior.

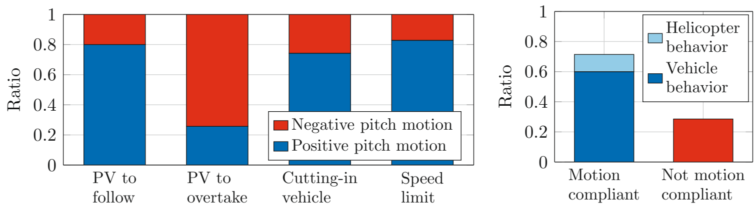


Figure 7: Distribution of the favored direction of the pitch motion

The distribution of favored amplitudes is presented in figure 8. It becomes apparent that a |1°| pitch motion is preferred. 40.0% of the test person choose a feedback with |2°| for the test scenario "cutting-in vehicle". Allover, 45.7% keep a constant amplitude of the pitch motion for all four test scenarios which is always |1°|. 34.3% decide on a |2°| feedback for the scenario "cutting-in vehicle" and a |1°| feedback for the remaining three test scenarios. 20.0% of the test persons have no explicit schema of their favored amplitude depending on the test scenario.

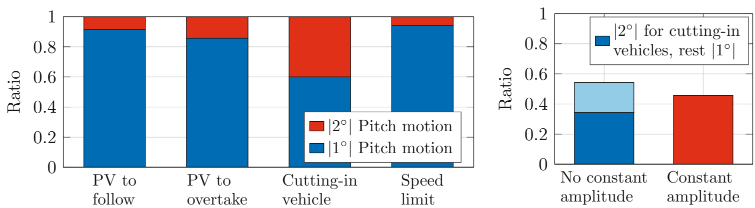


Figure 8: Distribution of the favored amplitude of the pitch angle

As seen in figure 9, there is a minor tendency towards the slow linear return. Moreover, 74.3% of the test persons have no structured behavior for a preferred return of the vehicle into the horizontal position according to the test scenarios. Whereas, 14.3% prefer constantly a slow linear return and 11.4% a symmetric return. Further analysis of the data shows that for |1°| pitch motions the slow linear return is favored and for |2°| pitch motions there is a minor tendency towards the symmetric return except for the scenario "PV to overtake".

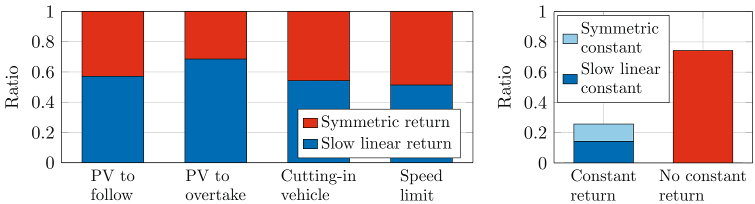


Figure 9: Distribution of the favored return of the pitch angle

Evaluation of pitch motions

After designing the favored pitch motion for each scenario, the agreement to the following statements is surveyed on a six point Likert scale (1 ≙ does absolutely not apply - 6 ≙ does absolutely apply) via a questionnaire after each test scenario (items written in italics):

- I find the pitch motion *useful*.
- The pitch motions are *misleading*.
- I perceived the *state transition* via the pitch motions.
- The pitch motions increased the system transparency and my *mode awareness* for the automation.
- The pitch motions were *comprehensible* and clearly assigned to the driving situation.

A graphic representation of the evaluated items can be seen in figure 10. Generally, all items get positive mean ratings for each scenario. The scenario "cutting in vehicle" gets the best evaluation out of the four test scenarios.

An analysis of variance with following post-hoc analysis using Bonferroni correction is conducted. If Mauchly's test for sphericity showed significance, the data is corrected (Greenhouse-Geisser). The results show significant main effects on the items *useful*, *state transition perceived*, *mode awareness increased* and *comprehensible*. Contrary, the item *misleading* shows no significant main effect. The related data is presented in table 1.

Table 1: Results of the ANOVA considering the items within the driving situations

Useful	$F(3, 102) = 4.084$	$p < .01$	$\eta_p^2 = .107$
Misleading	$F(2.165, 73.620) = 1.914$	$p = .144$	$\eta_p^2 = .055$
State transition perceived	$F(3, 102) = 6.617$	$p < .001$	$\eta_p^2 = .163$
Mode awareness increased	$F(3, 102) = 3.494$	$p = .018$	$\eta_p^2 = .093$
Comprehensible	$F(3, 102) = 3.986$	$p = .010$	$\eta_p^2 = .105$

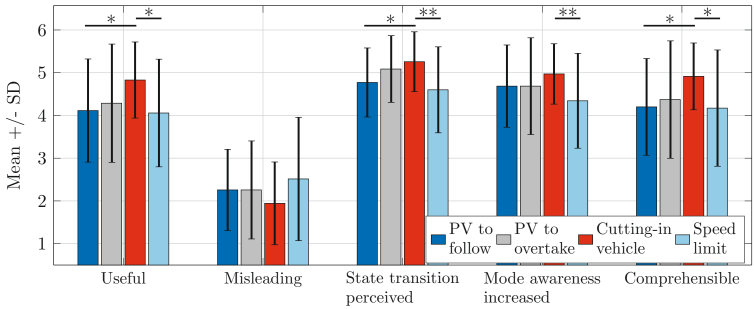


Figure 10: Evaluation of the items *useful*, *misleading*, *state transition perceived*, *mode awareness increased* and *comprehensible*

Considering the item *useful*, post-hoc analysis reveals significant differences between the scenario 1 ("PV to follow") and 3 ("cutting-in vehicle") ($M_{1-3} = -.686, p < .05$) and scenario 3 and 4 ("speed limit") ($M_{3-4} = .771, p < .05$). *State transition perceived* shows significant results between scenario 1 and 3 ($M_{1-3} = -.486, p < .05$) and scenario 3 and 4 ($M_{3-4} = .657, p < .01$). Moreover, the analysis between scenario 2 ("PV to overtake") and 3 demonstrates a tendency towards significance ($M_{2-4} = .486, p = .090$). The post-hoc analysis for the topic *mode awareness increased* indicates significant results between scenario 3 and 4 ($M_{3-4} = .629, p < .01$). Concluding, the item *comprehensible* reveals significant differences between scenario 1 and 3 ($M_{1-3} = -.714, p < .05$) and 3 and 4 ($M_{3-4} = .743, p < .05$).

5 Discussion and Conclusion

The results of the design of pitch motions show that these should be motion compliant and represent a vehicle-like behavior. The return of the vehicle from |1°| in a horizontal position reveals a tendency towards the slow linear return and from |2°| a tendency towards the symmetric return. Though, for the scenario "PV to overtake" overall a slow linear return is preferred. The comments of the test persons point out that a slow linear return from |2°| takes too long and they could not identify in what tilt position the vehicle is. Because of this, the gradient of the slow linear return for |2°| pitch motions should be increased.

Moreover, |1°| pitch motions are preferred. Nevertheless, the increased number of favored |2°| motions for the scenario "cutting-in vehicle" shows evidence that the feedback depends on the criticality of the situation. The comments of the test persons support this assumption.

With the regard of the evaluation of the pitch motions for the selected driving situations, a generally positive attitude towards the new feedback concept is revealed. The scenario "PV to overtake" shows a wider range of rating scores. This is due to the fact that the study revealed two different rating tendencies: the test persons who liked the feedback as it was and the ones who found the feedback important but don't like the pitch motion itself for this feedback. 10 of the test persons mentioned that a roll motion would be preferred for the feedback of the upcoming lane change. These statements enhance the thesis that feedback for state transitions resulting in a longitudinal maneuver or state should be realized with a pitch motion and state transitions resulting in a lateral maneuver or state should be performed with a roll motion. Accordingly, the design of feedback for an upcoming lane change or an abort of a lane change should be investigated in detail.

The study contains three scenarios with feedback in combination with a dynamic object and one with a static object (scenario 4). The last mentioned scenario has a tendency to a positive rating and showed feasibility for such a feedback. However, the ratings are very varied and there was just the test vehicle on the test track during the study. There is a chance of misunderstanding if other vehicles and speed signs are simultaneously to be fed back. Consequently, the scenario "speed limit" and generally static objects are not further considered for the feedback via pitch motions to avoid misunderstanding.

The lower ratings for the scenario "PV to follow" should be critically questioned. The main point is that the preceding vehicle was always driving in front of the test vehicle throughout the whole time of this scenario. So the test person saw the PV nonstop, just the radar sensor lost the PV when it drove away. Because of this and the fact that the scenario was very uncritical, the ratings might have been negatively influenced. This was also reflected by the comments of the test persons. Additionally, further comments show that the intensity and trigger time of the feedback for a "PV to follow" or a "cutting-in" vehicle should be reliant on relative velocity and distance to the preceding vehicle. Therefore, a driving study on the highway will be conducted to investigate on the last mentioned fact.

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