Manual Adaption of Steering Support in a Take-Over Scenario – A Technical Evaluation

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Abstract: This paper presents the technical development and evaluation of three systems to manually adapt steering support in a take-over scenario during conditional automated driving. Speech command, pressure sensors and clutch paddles were individually examined in a prototype state. Results indicate that speech commands exceed time limits during processing and pressure sensors are too sensitive for human fingers. Clutch paddles are most promising, both in signal processing and mounting in a vehicle mockup.

Key words: automated driving, take-over scenario, steering support, adaption

1 Introduction

Transitions of driving control during conditional automated driving, as defined in [1], have been researched intensely in the last decade ([2, 3]). [4] more recently introduced a concept for a transition of control with added steering support for a human driver. An automated system actively steers the vehicle from the point of the Request to Intervene (RtI) until the system boundary is reached in cooperation with the human driver. The automation's applied torque at the steering wheel decreases over time because it won't be able to control the vehicle at the system boundary at the latest. Human drivers might want to speed up this process or disengage steering support altogether sooner to regain full manual control earlier.

In this paper we present our technical development and evaluation process for systems or devices that will enable the driver to adapt this steering support. First we define the requirements and the scenario in which the systems will be used. We exclude certain established use concepts based on these requirements and introduce ideas from similar applications. Three concepts are chosen for implementation as prototypes. We describe our testing procedures and conclude with the recommendation of one system.

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2 Requirements and Scenario

[4] described the scenario that is usually researched for transitions in conditional automated driving: The human driver is not paying attention to traffic or the environment and busy with a non-driving related task (NDRT). The feet are off the pedals and the hands are off the steering wheel.

The driver is now primed with the RtI for the upcoming steering support by a multimodal warning (see [5, 6]). The driver ideally already chose a preferred driving trajectory as he puts his hands on the steering wheel. At this moment the steering support sets in and the driver has to evaluate whether the performed assistance matches his chosen trajectory. If not, the driver can reevaluate the possible trajectories and give way to the steering support or explicitly adapt the influence of the system on the steering task to make way for his own steering choice.

If the driver chooses to adapt the steering assist, he or she now has an additional task, that a) is not yet represented with an interface in a standard car interior and b) has a major influence on the task of lateral vehicle control. One option would be to use this opportunity to rethink the steering interface altogether, for which [7] gives some examples. Another, more feasible approach, is to add another interface that is interlocked with the existing steering task and doesn't obstruct the conventional driving control.

Another factor was time efficiency. Available time for transitions in conditional automated driving ranges between five and seven seconds in the literature [2, 3]. Drivers already require between 1.45 seconds and 1.79 seconds ([2]) to place their hands on the steering wheel which is the point at which steering support would start ([4]). Drivers would lose more valuable steering time if they had to move their hands away from the steering wheel and towards a control element. Their situation awareness would also deteriorate if they had to move their gaze away from the road scene to localize a control element and coordinate their hand movements. Consequently, the planned concept should include control elements at the steering wheel or a control method through other modalities than the hands. Time efficiency is also required for any software processing following the usage of the concept control element.

Two more requirements are not yet specified but should be considered after an evaluation: A continuous or a discrete scale on which the driver can adapt the driving support and the possibility to correct given input by the driver.

3 Concept Development

3.1 State of Technology

We first took a look at existing control elements at the steering wheel and their suitability for the present use case. A standard multi-function steering wheel can offer (1) several buttons with dichotomous states on both wheel spokes (2) several levers behind and on both sides of the steering wheel with dichotomous states in two directions, possibly equipped with buttons with dichotomous states on the levers (3) two gear shift paddles with dichotomous states.

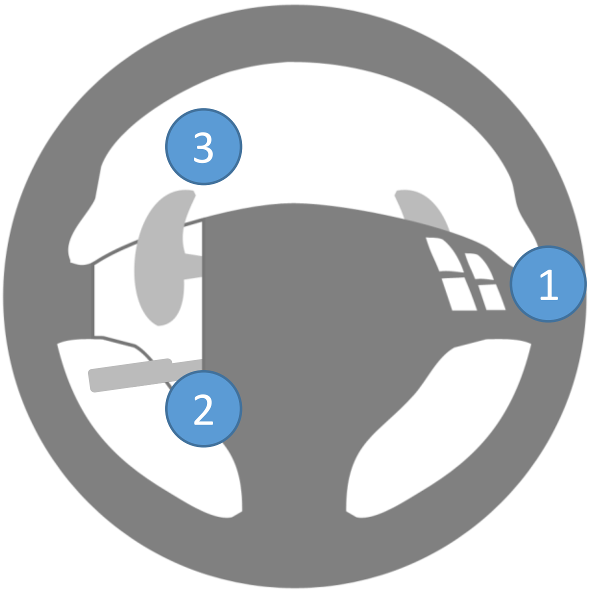

Figure 1: Example of a steering wheel with (1) buttons (2) levers (3) paddels.

(1) The existing buttons offer the possibility to control steering support in general. The buttons have to incorporate the factor time for a continuous scale, i.e. holding a button for a certain time decreases steering support by a certain amount. Buttons like +/- or up/down would allow changes on a discrete scale.
    Yet these buttons are usually already equipped with a specific task or function. This would require multi-labeling of a button for it's at least two functions which might confusion in a time critical scenario. More buttons could offer a solution, but aren't feasible if the mock-up shouldn't be reconstructed. It is highly unlikely, that a driver would count the seconds he pushed a button in a critical take-over scenario, so the use of buttons also requires an additional HMI to signal the driver what effect his input had.
(2) A minimum of two levers, turn signal and windshield wipers, is standard equipment in a current car. More advanced driver assisted systems may be controlled with an additional lever. The driver can shift this lever in at least two perpendicular directions and use several smaller buttons and other control elements on the lever.
    A possible fourth lever for the adaption of steering support might overcrowd the bottom space behind the wheel and induce extra workload for the driver in finding the correct lever in a time critical scenario.
(3) Gear shift paddles are found in vehicles with "half-automatic" transmissions. They can be pushed or pulled to fixed positions and spring back to a neutral state when

the hand is released. Each side represents a shift up or down, regardless whether the paddle is pushed or pulled.
Gear shift paddles share disadvantages of buttons, i.e. pre quipped with functions and required additional HMI.

3.2 Prototyping

We set out to develop three concepts based on the initial requirements as well as the constrains and advantages of an existing steering wheel.

(1) Pressure sensors activated by finger

The first approach was to implement pressure sensitive sensors that allow measurements on a continuous scale. Figure 2 shows the size of a sensor which required little to almost no space for implementation on the steering wheel. The sensors were mounted on the back of existing gear shift paddles which in turn were fixated. The idea was for the driver to push on the sensor with a finger of his choice. The harder or stronger the push, i.e. the more pressure measured, the less support would be provided.

Figure 2: Implemented pressure sensor on the back of a gear shift paddle [8].

The used pressure sensors weren't originally designed to be used as an interface for a human operator. Pretests showed that the sensor was too sensitive to be actuated on a continuous scale by a human finger. Measurements almost immediately jumped to full saturation with subjectively different amounts of pressures applied by a finger. This led to the early exclusion of this concept.

(2) Voice commands

The concept of voice control is established in many other fields in research as well as in daily life. Most contexts push for a good understanding of content and accurate, natural responses. In our scenario we focused on processing times first. We conducted a preliminary study with 15 participants in a desktop setup consisting of a laptop with a

USB plugged microphone. Speech recognition was based on Googles Cloud Speech API. The setup is described in detail by [9]. Results during a simulated take-over scenario reveal processing times around six seconds for several verbal expressions intended to adapt the steering assistance (s. Figure 3).

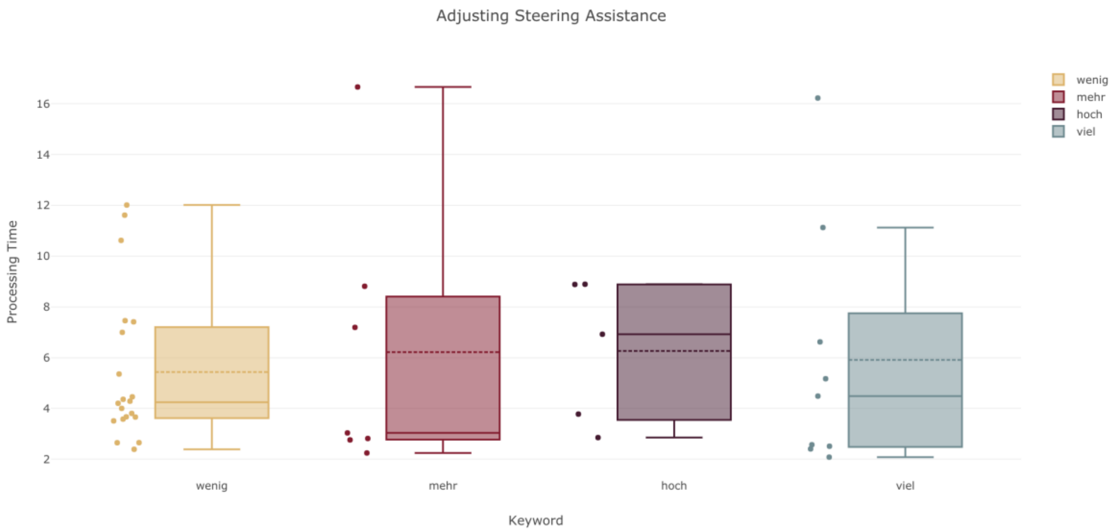

Figure 3: Distribution of processing times while adjusting the cooperation during the takeover using "less", "more", "high", and "much" [9]. The box plots show the quarter percentiles and the mean as dotted line.

We were not able to identify the cause of these comparatively long processing times although we used state-of-the-art software and hardware. Speech command was therefore not chosen for implementation in a vehicle mock-up

(3) <u>Clutch paddles</u>

The third concept consists of two clutch paddles that were originally developed for racing simulation by Ascher Racing ([10]) (s. Figure 4a). The paddles were designed to control analog inputs, such as the clutch, throttle and brake, based on the Hall effect. Since our simulation software is different than a commercial racing simulation a direct communication is not possible. Therefore, a micro controller (Arduino Mega 2560) was used to translate the voltage differences into values between 0 and 100, i.e. starting position and fully pulled position. The standard steering wheel does not provide an appropriate position for the clutch paddles and since the changes should be reversible an additional aluminum component was manufactured. This in turn is placed on the backside of the steering wheel and has two flaps for mounting the paddles (s. Figure 4b). It was assured that the additional plate does not cause too much friction and not influences the steering behavior. This concept meets all requirements: (1) easy to grasp because of direct attachment on the steering wheel and near to usual gripping position, (2) a continuous scale and (3) time efficiency due to a direct transmitted signal to the controller.

(a) (b)

Figure 4: Clutch paddles: (a) picture from Ascher Racing ([10]); (b) installed on the steering wheel of the static driving simulator ([8])

The presented concept refers to three levels of cooperation according to [4]:

1. Authority *or* Allocation of tasks & responsibilities: the clutch paddles directly influence the allocation of the lateral driving task between driver and assistance system. The more the driver pulls the paddles, the more authority he gains.
2. Interface: the presented concept allows an usage at any time during the transition process and unlimited interruptibility.
3. Contact: the concept is mounted on the control element that is crucial for the lateral action, i.e. the steering wheel, and at a position that does not interfere with the normal grip position.

After the implementation of the final concept we conducted another user study with 34 participants. The mean age was 25 years (SD = 7.2) among which 27 male participants took part. Drivers drove on a highway for approximately 10 km and then encountered a take-over scenario with a time budget of 6 seconds. The ego vehicle was on the middle lane at the time of the RtI with a blocked right lane. The cause for the RtI was a stranded vehicle on the middle lane. Therefore, the only possibility for an evasive maneuver was to the left lane which the automated system intended to support. All participants were instructed that they could, how they could and when they could use the paddles before starting the experimental drive. No participant reported any confusion or uncertainties about the use of the system.

We tested whether participants used the clutch paddles and if so, what effect it had on the steering support. The results indicate that only 6 out of 34 drivers used the paddles at all and only one driver pulled early enough to have an influence on the steering support. For the other five drivers the steering support was already reduced by the automated system below the threshold that they have set by the paddles. No participant indicated a reason why they didn't use the paddles in the final questionnaire.

4 Conclusion

The goal of is this research was to find a suitable interface to enable a driver to adapt steering support in a take-over scenario. Based on technical evaluations we were able to implement analog clutch paddles on the back of a steering wheel. The main reason of excluding the concept of the pressure sensors was that they were too sensitive for our use case. The second concept of voice commands was not further considered because of the long processing times of the system in relation to the time budget during transition phases.

The results of the user study show that only 6 out of 34 participants used the concept of clutch paddles during the transition phase in order to reduce the steering support by the system. We conclude that this was not due to the properties of our developed system but rather due to the general setting of a time critical take-over scenario. Drivers seem to have a very high workload in this situation and don't possess the necessary capabilities to deal with the possibility of reducing the steering support.

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