Human-centered challenges and contribution for the implementation of automated driving

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Abstract

Automated driving is expected to increase safety and efficiency of road transport. With regard to the implementation of automated driving, we observed that those aspects which need to be further developed especially relate to human capabilities. Based on this observation and the understanding that automation will most likely be applied in terms of partially automated driving, we distinguished 2 major challenges for the implementation of partially automated driving: (1) Defining appropriate levels of automation, and; (2) Developing appropriate transitions between manual control and automation. The Assisted Driver Model has provided a framework for the first challenge, because this model recommends levels of automation dependent on traffic situations. To conclude, this research also provided brief directions on the second challenge, i.e. solutions *how* to accommodate drivers with partially automation.

1 Introduction

Automated vehicles are, compared to human drivers, superior with respect to precision of operation and ability to operate under severe circumstances. Automated cars are therefore expected to cause less accidents and reduce congestion [1]. These advantages have the potential to help achieving goals for safer and more efficient road transport as set by the European Union [2]. However, autonomous driving involves more than automating the operational task alone. Generally, its realization can be divided in the areas: Navigation; Sensor technology (observing and understanding the vehicle's direct environment); Decision making (planning the vehicle's direct path of motion appropriate for the immediate traffic situation), and: Actuation (i.e. operating the vehicle). The areas Navigation and Actuation are very well developed. Most effort is currently addressed towards the sensor technology. The least developed area is: Decision making. Remarkably, this area is probably also the most difficult to solve. Due to the diversity in traffic situations and variety in traffic participants' behavior, it is very difficult to interpret and precisely predict oncoming changes in traffic situations. Interestingly, it is especially at these interpretation and decision making tasks that humans are generally good at in comparison to machine operation [3]. Recent demonstrations with automated vehicles on public roads – i.e.: The Stadtpilot project in Braunschweig, the Vislab Intercontinental Autonomous Challenge and Google's 'Robotic Cars' project– illustrate this state of art: Although the projects show far reached technical capabilities for automated driving, each of them also reports the necessity for human intervention in complex driving situations, like merging lanes or crossing an intersection.

The above explained state of art for automated vehicles illustrates that the development is most of the times based on what is technologically possible, not necessarily on what drivers are in need for [4]. Therefore, this research is intended to contribute to the development of autonomous driving by considering a human-centered approach. To do this, the next chapter will first explain our estimation upon the scale of implementation for autonomous driving, i.e.: the implementation of partially automated driving instead of completely automation. Based on this view, the chapter will also explain why two major challenges for the realization of automated driving relate to human aspects, i.e. (1) Defining the appropriate levels of automation, and (2) Developing appropriate transitions between manually and automated driving (vice versa). As an attempt to define appropriate levels of automation, chapter 3 introduces an Assisted Driver Model, which recommends driving support dependent on driving situations. The last chapter will comment on the aspects involved in designing the transitions between manually and automated driving.

2 Motivation for and challenges of partially automated driving

Current applications of (completely) autonomous driving are practiced within closed environments and with the support of dedicated infrastructure. Examples are driverless container terminals in harbours or driverless taxi's at airfields. For the future, people might envision autonomously driving vehicles which merely replace current passenger vehicles and make use of existing infrastructure. Following the autonomous vehicles' state of art from the introduction, the next section will explain why partially automation is a more realistic view for large scale implementation of automated driving than completely automation of the driving task. After that, the second section continues our considerations how human aspects relate to the implementation of autonomous driving and their subsequent challenges.

2.1 Motivation for development of partially automated driving

The first reason why the implementation of partially automated driving is regarded more realistic than complete automation relates to the fact that humans are more capable of dealing with the diversity in traffic situations, driving circumstances and road users. Secondly, due to technical constraints there will always exist system boundaries. Therefore, the system design needs to account for exceeding these boundaries, i.e. takeover by human operation. A third reason relates to liability: Drivers are personally liable for safe driving. In case something goes wrong, drivers need therefore be able to take over full control at any moment. On top, complete automation does not seem desirable, as it diminishes one of the automobile's remarkable attributes: i.e. the fun of driving and mastering a vehicle. A realistic view for applying autonomous driving is therefore: partially automated driving. Within this view, we acknowledge two general possibilities for partially automated driving: (1) The automation of a specific driving task, e.g. the automation of way finding with the aid of a navigation system, and (2) Applying automation to specific traffic situations, e.g. automated parallel parking. Both possibilities are visualized in figure 1. The main differences are the involved time span versus level of automation. For traffic situations the involved level of automation might be high, but for a limited period of time. For driving tasks, the level of automation might be low, but involve a longer time span. The machine does not acquire continuously full control and the human driver will need to be part of the control-loop on a frequently basis. This view on the realization of automated driving is in line with a previous assessment of the implementation of automated and semi-automated transport systems [5].

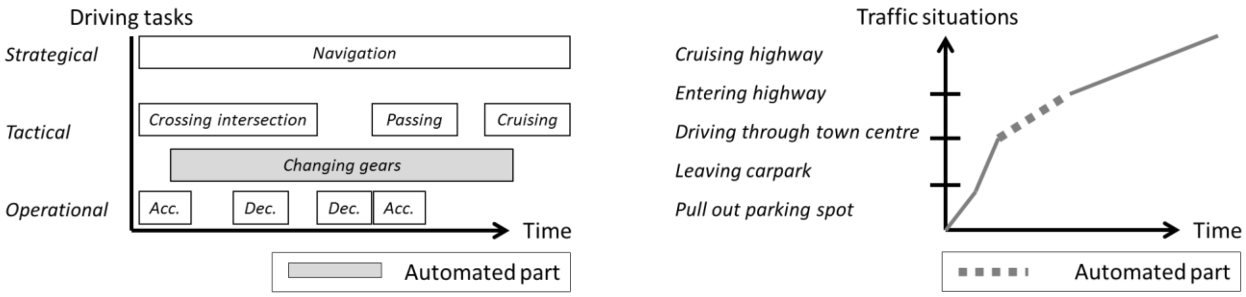


Fig. 1: Examples of partially automation applied to respectively driving tasks (left) and traffic situations (right).

2.2 Challenges for development of partially automated driving

The previously unveiled view of partially automated driving and the importance to consider human capabilities when developing solutions for the implementation of automation, lead us to assuming two major human-centered challenges: This is on the one hand defining the appropriate level of automation and on the other hand developing appropriate transitions to change between manually and automated driving (and vice versa).

A consequence of applying automated driving to specific driving situations or tasks is that transitions to and from these modes need to be accommodated. That means that appropriate solutions for giving and retrieving control need to be developed. Human Factors concerns, related to partially automation, underline the importance of appropriate transitions. The concerns are especially related to out-of-the-loop (OOTL) performance problems [6]. These problems basically mean that a user (the operator) is placed remote from the control loop during a situation of automated driving. As a consequence, the operator's awareness of the situation or system's status may be reduced. This causes problems for transitions to and from manually operation (especially when system errors, malfunction or break-downs occur), resulting in slower reaction times, misunderstanding what corrective actions need to be taken and manual skill decay [7]. This underlines the importance of the second challenge, i.e.: developing appropriate transitions between manually and automated driving (vice versa).

3 Defining appropriate levels of support for partially automated driving

As an attempt to help reducing the first challenge, i.e.: defining the appropriate level of automation, this chapter answers the following questions: What driving situations can be distinguished?; What levels of automation should be distinguished?, and: What automation level is recommended for which driving situation?

3.1 Driving situations

The driving task is often analysed in terms of three different performance levels provided by Rasmussen [8]: the knowledge-based, rule-based and skill-based level. Differences between the levels relate to the involved mental effort. At the highest, i.e. knowledge-based, level, considerable attention and effort is required. At this level human behaviour is goal-controlled and represents a more advanced level of reasoning. Rule-based behaviour is characterised by the use of rules and procedures to select a course of actions. The rules can be acquired through experience or can be based upon prior instructions (training). When driving, rule-based behaviour involves interpreting everyday situations and applying rules and regulations that fit that situation. At the lowest, skill-based level, highly practiced tasks are carried out, requiring very little attention.

Rasmussen considers the amount of mental effort needed to execute a task and therewith addresses a dependency on individual differences in task performance. Michon [9], on the other hand, proposed that the driving task could be structured at three generic levels (independently from individual differences): the strategic, tactical and operational level. At the strategic level drivers prepare their journey; this concerns general trip planning, choice of route, etc. At the tactical level drivers exercise manoeuvring control, allowing to negotiate the directly prevailing traffic circumstances, like crossing an intersection or avoiding obstacles. Here, drivers are mostly concerned with interacting with other traffic and the road system. The operational level involves the elementary tasks to manoeuvre the vehicle, mostly performed automatically and unconsciously (e.g. steering, using pedals or changing gears).

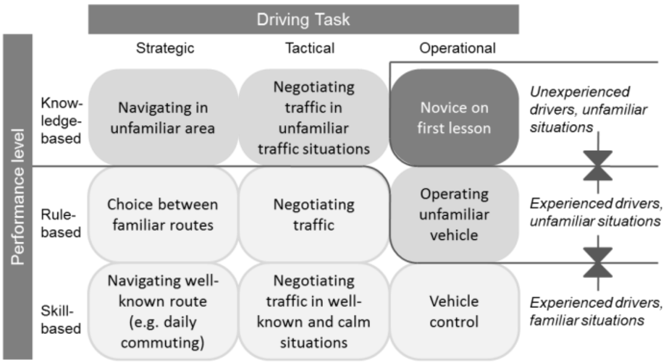


Fig. 2: Traffic situations.

Both models (the performance level taxonomy and driving task hierarchy) enable to classify driving tasks. Moreover, combining both models provides a good schemata to distinguish driving situations. The reason is that driving situations are characterized by environmental differences (e.g. road layout) in combination with individual differences of traffic participants (e.g. experience). This relation is very well recognizable in fig. 2. An experienced driver would for example execute an operational task with his own vehicle at skill-based level, but might need knowledge-based performance for finding his way in an unfamiliar city.

3.2 Levels of support for partially automated driving

Before introducing an Assisted Driver Model, which has been composed to recommend driving support dependent on driving situations, we first need to explain which levels of intermediate automation should be distinguished. These levels have been derived from an existing taxonomy of automation-levels [7], called Levels of Automation (LOA). The reason why this taxonomy has been adopted is that LOA considers a scale of 10 intermediate support levels offered by partial automation of a task. These levels also cover the levels of automation theoretically possible for driving. Besides, LOA’s aim is to facilitate appropriate system function allocations between human and computer controllers keeping both involved in the control loop –and this offers an important contribution to the avoidance of out-of-the-loop performance problems as indicated before. Levels of Automation (LOA) considers human and/or computer allocation to the following functions of the control loop: (a) Monitoring: Scanning displays or the system’s environment to perceive information regarding system status and/or the ability to perform tasks, (b) Generating: Formulating options or strategies to achieve tasks, (c) Selecting: Deciding on a particular option or strategy, and (d) Implementing: Carrying out the chosen option. Based on LOA, we acknowledge 6 levels of support relevant for automated driving, which are indicated and explained in table 1.

	SUPPORT TYPES	FUNCTIONS				DESCRIPTION	EXAMPLES
		MON.	GEN.	SEL.	IMPL.		
1.	Augmenting	H/C	H	H	H	• Both human and machine monitor the present situation. The machine especially supports acquiring sensory information.	Night Vision
2.	Advising	H/C	H/C	H	H	• The machine supports by generating options, the human selects. The selected option might be another option than generated by the machine.	Attention Assist, Lane Change Assist
3.	Warning	H/C	C	C	H	• The machine temporarily generates *and* selects an option which, according to the machine, is mandatory to perform.	Lane Departure Warning, Frontal Collision Warning
4.	Intervention	H/C	C	C	C	• The machine temporarily generates, selects *and* executes an option which, according to the machine, is mandatory to perform.	
5.	Action Support	H	H	H	H/C	• The implementation part is being supported.	Powered Steering, Automated Gear Box
6.	Decision Support	H/C	H/C	H	H/C	• By combining Advising and Action Support, the human is being supported in terms of allowing full dedication to the selection-role.	

MON.= Monitoring task, GEN.= Generating options, SEL.= Selecting options, IMPL.= Implementation task
H=Human task performance, C=Computer task performance, H/C= combined Human - Computer task performance

Table 1. Indicating 6 levels of support relevant for semi-automated driving

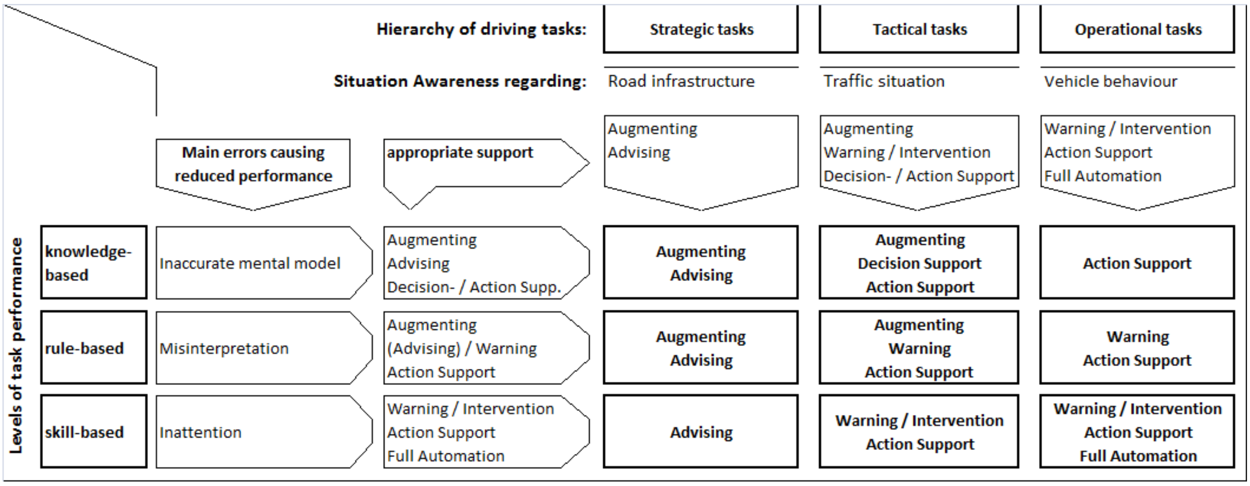
3.3 Assisted Driver Model

The Assisted Driver Model [10] has been composed to recommend driving support dependent on driving situations. The model is shown in figure 3. The previous section distinguished 6 intermediate levels of automation relevant for partially automated driving. To allocate these levels of automation to driving situations the Assisted Driver Model considered the prerequisites to provide good operation of the driving task. The considerations have been differentiated between the prerequisites for the involved performance level at one hand, and for the involved driving task type at the other hand. For the performance levels these prerequisites involve the avoidance of errors [8]. For the driving task types, the required level of perception and understanding (i.e. Situation Awareness) of the circumstances associated with the driving task, have been considered [3]. The selection of support types that fit both conditions resulted in the Assisted Driver Model.

3.4 Recommended levels of automation

The Assisted Driver Model shows for driving situations which are dominated by tactical and operational tasks executed at rule- or skill-based level, that automation is especially being recommended in terms of supporting the implementation task, i.e. Action Support. Within those conditions, Action Support enables the human to remain involved in task execution and preserves situation awareness, which allows better reaction times after failures and retrieval of control [11]. The model also advocates that driving situations which are dominated by option generating should not be supported in terms of joint human-machine task operation, i.e. Advising. Within those situations purely human generation of options performs far better than joint human-computer generation of options [7]. This superior human performance can be explained by distraction and doubts that humans encounter during joint human-computer selection of options.

Furthermore, the model shows that situations which require more intensive mental consideration (as is generally the case for strategic tasks) could be supported in terms of Advising. However, partially automation of decision making, like computer generation of options and human selecting, should be considered very carefully, for the same reason as mentioned before: Advising might cause worse performance due to doubts or confusion. However, because of the nature of these driving situations (i.e. strategic tasks which mainly involve way finding) alternatives are not available. With respect to performance after automation failure, tests show that recovery time is significantly lower with joint human-computer interaction during the implementation role, than with purely computer interaction [7]. This indicates that operator ability to recover from automation failures substantially improves with partially automation requiring some operator interaction in the implementation role.



		Hierarchy of driving tasks:	Strategic tasks	Tactical tasks	Operational tasks
		Situation Awareness regarding:	Road infrastructure	Traffic situation	Vehicle behaviour
Levels of task performance	Main errors causing reduced performance	appropriate support	Augmenting Advising	Augmenting Warning / Intervention Decision- / Action Support	Warning / Intervention Action Support Full Automation
knowledge-based	Inaccurate mental model	Augmenting Advising Decision- / Action Supp.	Augmenting Advising	Augmenting Decision Support Action Support	Action Support
rule-based	Misinterpretation	Augmenting (Advising) / Warning Action Support	Augmenting Advising	Augmenting Warning Action Support	Warning Action Support
skill-based	Inattention	Warning / Intervention Action Support Full Automation	Advising	Warning / Intervention Action Support	Warning / Intervention Action Support Full Automation

Fig. 3: Assisted driver model showing recommended support types (i.e. levels of automation) dependent on driving situations.

To summarize, the following levels of automation can be recommended in relation to different driving situations:

- Operational tasks benefit most from physical implementation assistance, requiring some human involvement. The human operator then remains involved in the control loop and this provides best recovery of control (after a transition from partially automation to full human control).
- Combinations of tactical and operational tasks performed at rule- or skill-based level benefit most from Action Support.
- Driving situations which are characterized by strategic tasks and/or dominated by option-generating are least appropriate for applying partially automation.

For some situations, it remains difficult to determine what level of automation is appropriate. We first notice a tactical task performed at knowledge-based level. This situation involves negotiating traffic in unfamiliar traffic situations and these circumstances typically involve decision-making, requiring considerable attention. Based on the model, either support in terms of Advising or in terms of Action Support would be recommended. Again, Advising could cause confusion. Action Support on the other hand could allow full dedication to the decision making part. Both types of support however, differentiate strongly upon the part within the control loop which is being supported. Therefore, further research is necessary to determine if and how partially automation would be beneficial for this situation. Also for an operational task performed at knowledge-based level it is difficult to determine what level of automation is beneficial. However, this situation involves novice drivers. Partially automation would therefore influence driving education and this is out of the scope for this research.

4 Final comments

This research explained why large scale implementation of partially automated driving is more likely to become reality than completely automated driving. Based on human-centered considerations we identified two major challenges for the realization of partially automated driving: (1) Defining appropriate levels of automation, and; (2) Developing appropriate transitions between manually and automated driving. The Assisted Driver Model helped us with the first challenge, because the model recommends support types dependent on driving situations.

Next to *when* to provide automated driving, the question “*How* to provide automated driving?” is also important. The second challenge relates to this question. To develop appropriate transitions, a good starting point seems to review the possible levels of automation. As we have seen in chapter 3 especially support in terms of joint human-computer interaction during the implementation task, requiring some operator involvement, is recommendable. The reason is that with such support the human remains involved in het control-loop and therewith preserves awareness of the system status and surrounding traffic situation. An example is the implementation of pedals with force feedback. During automated cruising on a motorway (e.g. with Adaptive Cruise Control), the brake and acceleration pedals would continue to move or offer resistance to indicate the system’s adaption in speed and distance in accordance with traffic situations. This would mean a more active involvement of the driver and allow better reactions when transitions to manual control are necessary.

Although support in terms of joint human-computer interaction during the implementation task allows better recovery, it will not necessarily make the driving task more comfortable. Examples from other area's (like aviation) often show that automation transforms human involvement from an operator-role to a supervision-role, without making the involved tasks easier, nor task performance safer. For the development of appropriate transitions in automation, it is therefore important to also acknowledge the relation with driver's acceptance. The fact that acceptance is more related to individual comfort, than advantages on a larger scale (like increasing traffic efficiency), leads us to a direction where we explicitly take performance of secondary tasks (e.g. listening to music or checking a dairy) into consideration. Interface solutions which combine performance levels for both the driving task and secondary tasks, could for example deliberately direct the driver's attention from a secondary task towards the driving task before automation terminates. However, future research, including experiments with simulated driving tasks, is required and foreseen to further develop appropriate interfaces for transitions between automation.

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