Driving-Task-Related Human-Machine Interaction in Automated Driving: Towards a Bigger Picture

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Abstract
The role and respective tasks of human drivers are changing due to the introduction of automation in driving. Full automation, where the driver is only a passenger, is still far-off. Consequently, both academia and industry investigate how the interaction between automated vehicles and their drivers could look like and how responsibilities could be allocated. Different approaches have been proposed to allow to deal with shortcomings of automated vehicles: control shifts (handovers and takeovers), shared control, and cooperation. While there are models and frameworks for individual areas, a big picture is still missing in literature. We propose a first overview that aims to bring the three areas in relation based on the particular differences (presence of mode changes, duration of interaction, and level of interaction).

Author Keywords
Automated driving; handover; takeover; shared control; driver-vehicle cooperation; framework; model; survey.

CCS Concepts
•**Human-centered computing** $\rightarrow$ **HCI theory, concepts and models;**

Introduction

Both academia and industry invest heavily in trying to reach autonomous vehicles. The ultimate goal is to enable an aviation-like kind of traveling as a customer, where only a destination has to be entered at the start of the journey. While there are already prototypes on public roads [31], there remain challenges before full automation under every possible circumstance is reached [30]. Consequently, it was investigated how system limitations can be overcome with interacting with the human driver or rather user.

Recent research investigated handing the control to the human driver if a boundary is reached [16]. The human driver has to take over control and perform all relevant parts of the driving task. Another approach to let system and vehicle work together is *shared control* [1, 23]: in contrast to the control shift approach, shared control allows to keep the driver involved in the control of the vehicle all the time, even when the vehicle is driving automatically, for instance through a haptic control interface. One implementation is the *H(-orse) Mode* [7, 10]: it allows for both the human driver as well as the system to simultaneously affect the vehicle during the driving task. However, the degree of human influence on the vehicle control can be varied. One effect of this is that the human driver is kept in the loop. A key characteristic is the bi-directional feedback given to both agents through their actions or through, for example, haptic feedback. Another concept that allows driving-task-related interaction is *Conduct-by-Wire* [7]: again, drivers are in the loop, since they have to conduct the vehicle by selecting maneuvers from a maneuver interface on a regular basis that are then executed by the automated vehicle.

The discussed shared-control approaches require the driver to stay in the loop (Conduct-by-Wire, some modes of H-Mode) and let the human driver directly influence the dynamic driving task, i.e. lateral and longitudinal control (H-Mode). The involvement of the human driver after a phase of automated driving can be problematic due to human factor issues as will be discussed in more detail in the next section. Consequently, cooperative strategies that implement driver-vehicle interaction only on a temporary basis on higher abstraction levels of the driving task have been suggested [25, 26, 27].

After discussing human factor issues in automated driving, we provide an overview regarding existing frameworks and models in the domain of driving-task-related interaction in automated driving and structure them according to the presence of mode changes, the interaction duration and the level of interaction.

Human Factor Issues in Automated Driving

Increased automation also leads to the possibility for the human driver to engage in non-driving-related tasks and therefore drivers divert attention away from the driving task [4]. This was shown, in part, through the investigation of off-road glances and secondary task engagement in an experiment by Llaneras et al. [11]. Distraction sources will be numerous in (semi-) automated driving [22]. Different types of distraction can occur during the journey: physical, auditory, visual, cognitive and technology-based as well as non-technology based [29]. This will probably lead to reduced situation awareness [5].

One common approach to overcome systems' limitations is the handover of control to the human operator [12]. As shown by Morgan et al. [17] there are several issues with this kind of implementation: Even with sufficient time budgets (which itself poses a challenge as sufficient times may vary due to differences in human operators) for take-over/ handover, impaired situation awareness can lead to late and incorrect responses to critical incidents. Post-automation effects such as unstable lateral control [14] or, after platooning, reduced distance to the vehicle in front can occur [3]. In the case of frequent fallbacks to the human driver, low operator trust in the automated system could be a consequence (mistrust) [28]. In the opposite case, driving skills could degrade and overreliance or complacency could follow [21]. This has been attributed to be a cause in the Tesla crash in May 2016 [2]. Banks et al. [2] argue that the scheme *Autopilot* is inaccurate and therefore leads to inappropriate trust in the system. Hence, they consider the crash not a driver but a designer error. Trösterer et al. [24] looked into what can be learned from pilots as they operate in a semi-autonomous system. The interviewed pilots stated that a calibrated (dis-)trust and a transparent system status is important. In aviation, frequent training is inevitable. The pilots advise future drivers to regularly think about the *What if's?*

Driving-Task-Related Interaction

One way of overcoming system limitations that has been widely investigated is to shift the control between the agents *automated system* and *human driver*. Mirnig et al. [16] surveyed academic publications and industry patents and categorized them according to their control transition interface framework. They categorized these based on *direction of the control transition* (takeover vs. handover), *initiator* (user vs. system), *user involvement* (active, semi-active, and passive), *completeness* (some vs. all driving functions), *system fallback strategies*, *existence of a mode awareness display*, and several other categories regarding the in- and output modalities of the control transition interfaces.

A taxonomy for handover situations has been suggested by McCall et al. [13]. It differentiates who initiated the handover (system or driver) and whether it was planned (scheduled, non-emergency, and emergency handovers). Moreover, they regard these situations in the light of situation awareness, SAE levels [9], responsibilities and which agent has to be aware of the operating limits.

In contrast to the binary approach of shifting control entirely between human and vehicle, shared control has been suggested as an input paradigm that allows to keep drivers in the control loop while supporting them continuously with the help of an automated system [18]. Hoc [8] differentiated *cooperation in action*, *cooperation in planning*, and *meta-cooperation* in human-machine cooperation. Flemisch et al. [6] give an overview over shared control and cooperative human-machine interaction. They suppose that both terms describe different perspectives or manifestations of a common concept on different levels of interaction (*strategic*, *tactical*, and *operational* [15]; in other words: *navigation*, (*maneuver* and *trajectory*) *guidance*, and *control* [7]), where shared control is considered as cooperation on the control level (see [20] for an overview of models considering cooperative and shared automation and assistance).

Considering shared control as cooperation on the control (operational) level, this cooperation could be considered as interaction based on results of problem-solving processes that were conducted by both agents individually [19]. Parasuraman et al. [21] suggested that automation can be applied to four functions, in particular to functions that reside not necessarily at the end of the decision-making process: *information acquisition*, *information analysis*, *decision and action selection*, and *action implementation*. Pacaux-Lemoine and Itoh [19] refer to cooperation within these functions as *horizontal extension of shared control*. Cooperative interaction between different levels (strategic, tactical, and operational), e.g. the driver decides when to perform a lane change (tactical level) and the vehicle performs the lane change (operational level), is considered as *vertical extension of shared control* [19]. This is in line with the previously described concept of cooperative human-machine interaction on the strategic, tactical and operational level.

Towards a Bigger Picture

Based on the survey of existing frameworks and models we see three disjoint domains of driving-task-related interaction with automated vehicles: control shifts, shared control, and cooperation. The main difference is whether there is a change of mode (i.e. automated driving ⇔ manual driving) or not. While there is one in the control shift approach, there is none in shared control and cooperation. The control can be shifted entirely (complete control shift) or partial (e.g. only lateral control). After a partial control shift is the control of the vehicle shared (→ shared control). Flemisch et al. [6] see shared control as a subset of cooperation. In contrast, we see both as disjoint concepts. We separate both based on the duration of interaction and consequently how long the driver has to be in the loop. A driver using a shared control interface has to stay in the loop continuously, whereas cooperative interaction happens within a short, self-contained time window. Moreover, in our view, the concept of shared control should be broadened: shared control can include interactions on all levels of the driving task, not only on the control level as defined by Flemisch et al. [6]. Consequently, in our view shared control contains the *horizontal and vertical extensions of shared control* [19] as long as the interaction takes place continuously. In contrast to the cooperation definition of Flemisch et al. [6], we exclude interaction on the control level from cooperation due to the continuous nature of actual vehicle control. Moreover, we see cooperation as a concept that should avoid human factor issues of automated driving by keeping the human out of the actual vehicle control. Figure 1 illustrates our proposed perspective on driver-vehicle interaction.

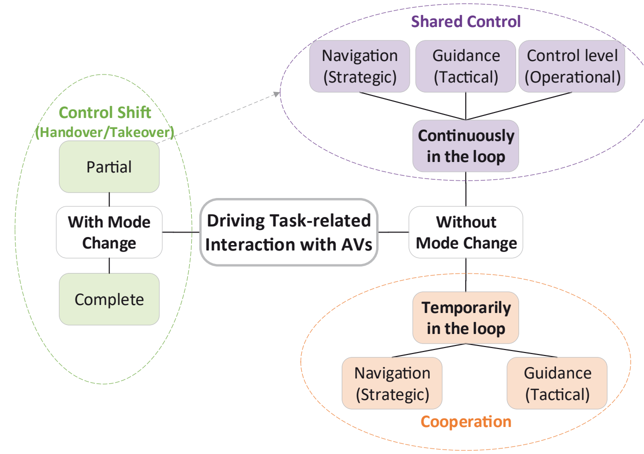

Figure 1: Driving-task-related interaction with automated vehicles.

Conclusion

We reviewed existing frameworks and models for driving task-related human-machine interaction in automated driving. To our knowledge, we made the first effort to structure the different concepts together in one big picture. First, we did this by separating the concepts on the basis of mode changes involved. Second, by the duration and level of the interaction. In future work we will survey implementations of the different concepts and evolve our structure if necessary.

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