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Ergonomic design of the vehicle motion in an automated driving car

Alexander Lange[a,]*, Martin Albert[a], Karl-Heinz Siedersberger[b], Klaus Bengler[a]

[a]*Institute of Ergonomics, Technische Universität München, Boltzmannstr. 15, 85747 Garching, Germany*
[b]*AUDI AG, 85045 Ingolstadt, Germany*

Abstract

This article presents a concept for the design of an automated driving system that uses the driver's motion perception to feed back the automation system's state and intention. The motivation for this approach is to keep the driver in the loop during an automated drive and increase the automation system's transparency. The concept aims for partially automated driving [1]where the driver is still responsible for the driving task and in charge of monitoring the automation system of his vehicle.

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1. Introduction

In the last years automakers, automotive suppliers and even computer technology firms worked intensively on the automation of the driving task. Even if there has been a lot of technological progress proven by showcases and scientific publications, there are still some major challenges to overcome before highly automated vehicles are ready for series production. Untiltechnological challenges in terms of sensor performance, situation interpretation and functional safety as well as legal questions are solved, the driver will still be necessary for monitoring and as backup for automated driving systems[2]. Previous research showed that humans perform quite poorly in monitoring complex automated systems[3]. Especially taking over the driving task from an automated car at a system boundary can take several seconds if the driver is out of the loop[4]. In consequence,one research goal is to find ways to keep the driver in the loop during an automated drive and support him in monitoring the automation system of his

* Corresponding author. Tel.: +49-89-289-15411; fax: +49-89-289-15400.
E-mail address: lange@lfe.mw.tum.de

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car.This article describes a concept that addresses those goals by creating a transparent system behavior and using the driver's perception of the vehicle motion to feedbackinformation about the system's state.

The article is organized as follows. Section 2 describes the fundamental theory behind the concept presented in this article. In section 3, a simple system model for automated highway driving is described. Based on that model, a concept to improve the transparency of the systemandto keep the driver in the loop is developed. Section 4 provides a short summary and an outlook on how the presented concept can be evaluated.

2. Theory

2.1. Being in the loop

In literature,"being in the loop" is often associated with having sufficient situational awareness[5]. When driving an automated vehicle, situation awareness does not only include being aware of the elements around the vehicle[6], but also being aware of the state of one'sown vehicle's automation system. A term that comes to mind in this context is "mode awareness"[7]. In the area of automated driving,"mode" is often used as a synonym for the level of automation. The kind of "mode"addressed in this articledoes not refer to the level of automationbut tothe state of the automation system inone constant level of automation.This is why the term "mode awareness" will not be used in the following; instead we will rather speak of state awareness. To be aware of the automation system's current state,two conditions have to be satisfied. First, the driver has to have a compatible mental model representing the automation system of his car[8]. Second, the driver needs to get suitablefeedback from the system to keep his mental model updated and know in which state the system is currently working[9,10].

2.2. Automation system design

This raises the question of how the state of the automation can be represented. To answer this question, one has to look into how vehicle automation systems work. Most approaches to automate the driving task start with trying to understand how a human driver operates a car and imitating his behavior. The development of models of the driving task is a central part here. There are pretty abstract representations like the three layer model of Donges[11]or adapted versions of it like the four layer modelof Löper et al.[12]. To implement an automated driving function for a vehicle in real traffic situations, those models have to be far more detailed. Creating comprehensive models for driving a car in a dynamic environment has been subject to research for decades. An aspect that most approaches have in common is the combination of discrete hierarchical state machines and continuous models, like planning components and reactive controllers[13–15]. The driving task is therefore divided into different subtasks represented by states. The states are organized in a hierarchical state machine with long term tasks on higher hierarchical levels and short term behavior at lower levels. At the lowest level,thediscrete statesresult in a continuous vehicle motion. This is achieved by associating dynamic models to the states. For example,adiscrete state representing the driving maneuver "Lane Following" is connected to a continuous dynamic modelthat uses the deviation from the lane center as input and produces a steering wheel angle as output. In the following the term "state" will always refer to a discrete state of a state machine while the term "dynamic model" describes a continuous function with in- and output signals.

Referring to the term "being in the loop", it can be concluded that a driver is in the loop if he has a very precise idea of the automation system's state. The degree of "being in the loop" can be quantified by how far down in the hierarchy of states the driver can specify the overall system state. As an example it is possible that the driver knows that his car is in astate "Highway Driving" but isn't aware of the current sub state "Lane Change Left" and not at all of the sub sub state "LaneChangePreparation". Previous research mostly concentrates on how to design the discrete part of the system i.e. the state machine and the HMI for a transparent system behavior. In this article, the focus lies on the ergonomic design of the continuous portion of an automated driving car. This includes the dynamic models in the form of controllers and trajectory planning modules. Those have great influence on the velocities, accelerations and jerks (change in acceleration over time)the driver perceives during an automated drive.