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User acceptance of cooperative maneuver-based driving – a summary of three studies

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Abstract. Modern cars offer drivers support with the help of a number of driver assistance systems. Those systems aim to relieve drivers through assumption of sub parts of the driving task (e.g. in case of an Adaptive Cruise Control by regulation of vehicle speed and time gap to preceding vehicle). Today, systems are controlled and monitored separately which leads to efforts to combine the functionality of all systems in an overlying assistance for drivers. The approach of the University of Technology Darmstadt is called Conduct-by-Wire and can be seen as a cooperative maneuver-based driving paradigm, where the driver gives maneuver command to the systems which are automatically executed. This paper summarizes the results of three studies which investigated the user acceptance of this driving paradigm. Overall, it can be said that the acceptance of the system depends on personal traits of the driver and on the driving situation. Almost all participants are willing to use Conduct-by-Wire for routine tasks such as commuting, which makes the systems interesting for company cars. Still, there remain a number of drivers who are not willing to use such a highly automated system at all.

Keywords: Conduct-by-Wire, maneuver based vehicle guidance, advanced driver assistance system, acceptance

1. Introduction

Driving a car is becoming more and more difficult. This is due to the denser traffic as well as to the longer travel times [20]. In current upper class cars a number of advanced driver assistant systems (ADAS) aim to support drivers in the fulfillment of their task. Due to the different displays and control elements for each system, which have to be monitored and controlled separately, it is questionable if the combination of multiple systems is perceived as a relief by drivers [14]. Instead of installing multiple systems Conduct-by-Wire aims to combine today's and future assistance functions into one overlying solution. Within the Conduct-by-Wire paradigm drivers maintain traditional control elements (driving wheel and pedals), but additionally have the opportunity to control the vehicle with the help of maneuver commands (e.g. "follow lane", "turn left"). The Conduct-by-Wire system executes the driver's commands which lead to a cooperative accomplishment of the driving mission between driver and vehicle.

Conduct-by-Wire is a research project funded by the German Research Foundation since 2008. During the last three years a number of studies were conducted to investigate general feasibility of maneuver based guidance (compare e.g. [12] and [16]). User tests revealed the relevant maneuvers and made statements on user behavior during the use of maneuver-based driving. Due to the early concept phase the question of user acceptance was not dealt with.

Since the beginning of the year 2010 Conduct-by-Wire is funded for a second project phase. This phase has two main goals: 1. improvement of the existing human-machine interaction including a redesign of the user interface and 2. evaluation of user acceptance of the Conduct-by-Wire system in different driving scenarios. This paper gives an overview to the first approaches to user acceptance of Conduct-by-Wire. Thereby it is important to mention that the focus lies on the general acceptance of cooperative

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maneuver-based driving and not particularly on the current implementation of Conduct-by-Wire.

The paper is structured as follows: 1. a theoretical introduction will be provided on the idea of Conduct-by-Wire and on the theoretical background for the user acceptance research. 2. First results of three studies on user acceptance of maneuver-based driving will be provided and 3. the restrictions of the current studies will be discussed and an outlook towards future work will be given.

2. Theoretical Background

To understand the purpose of this paper two theoretical foundations have to be given: 1. an explanation of the Conduct-by-Wire paradigm and 2. an introduction into technology acceptance research, which is the theoretical foundation for the herein presented studies.

2.1. Maneuver-based guidance on the example of Conduct-by-Wire

The principles of Conduct-by-Wire can be described with the Three-Level Hierarchy of driving task according to [6]. According to [6], the driving task is divided into driver, vehicle, and environment, as well as into navigation, vehicle guidance, and stabilization levels. Normal assistance systems support the driver on the stabilization level (drivers monitor the current trajectory and speed and compare it with their desired trajectory and speed) and until now, an exchange of information between driver and vehicle was limited to inputs on the stabilization level. For this communication, drivers have to break down their intentions to smaller parts, which can be communicated and supported by driver assistance systems. The more assistance systems are integrated into current vehicles, the more similar vehicles become to their real partners in driving. Within the Conduct-by-Wire paradigm, a new approach is used, which is closer to common communication between humans and is focused on exchanging intentions between driver and vehicle [11]. For this interchange of intentions, Conduct-by-Wire uses an assignment of small driving units, the so-called maneuvers (e.g. turn left/right, lane change left/right) which are similar to the tasks drivers perform on guidance level (choosing the desired trajectory (e.g. left or right lane)).

An essential element of the Conduct-by-Wire driving paradigm is the maneuver catalogue. Those maneuvers were identified in field and laboratory studies [16]. The results showed that maneuvers can be separated into two classes: The implicit and explicit maneuvers. Implicit maneuvers generally were not assigned by drivers. Those are basic states that will be activated automatically by the automation after an explicit maneuver, when a driver-input maneuver has finished. Explicit maneuvers are self-contained parts of the driving mission with a definite start and end point. Therefore, the cooperation in context of Conduct-by-Wire can be seen as an exchange of driver intent and vehicle interpretation of the driving environment which leads to a joint accomplishment of the driving task. In the current version Conduct-by-Wire is controlled over a tactile touch display, which is embedded in a steering wheel (see fig. 1). The display enables the direct choice of maneuvers and thereby the direct communication of driver intentions. The chosen interface is only one way of communicating driver intentions and does not have to be the final implementation of Conduct-by-Wire.

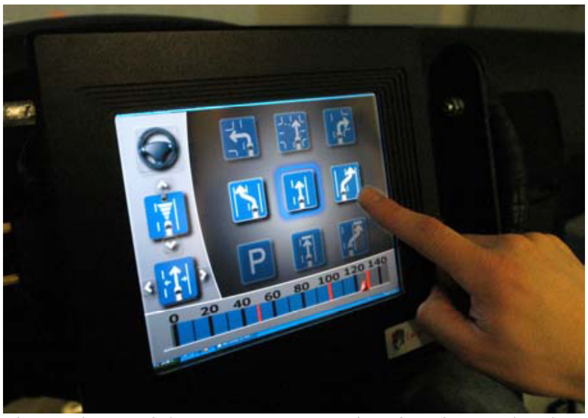

Fig. 1. Picture of the current maneuver interface for Conduct-by-Wire.

There already exist a number of papers (see e.g. [12] and [16]) which are concerned with the question, if maneuver-based driving is possible and which implementations this kind of driving has on driving habits. Within this paper the focus is set on user acceptance which will be defined in the next paragraph.

2.2. User Acceptance According to the Technology Acceptance Model

In IT research the Technology Acceptance Model [3] is a well-established model when it comes to explaining user acceptance of technical products. It originates from the Theory of Planned Behavior by

[7] and states, that the intention for doing something is the best predictor of later actions. TAM has – in its original version – three main predictors of technology acceptance: “perceived usefulness” (“The prospective user's subjective probability that using a specific application system will increase his or her job performance within an organizational context“[3]), “perceived ease of use” (“The degree to which the prospective user expects the target system to be free of effort” [3]) and external variables, which can be seen as characteristics of the system in question. The system characteristics influence the perceived ease of use and the perceived usefulness which in turn determine the intention to use. Since TAM was developed for the working context, the definition of perceived usefulness does not fit the context of maneuver-based vehicle guidance. It is therefore changed to “the degree to which the Conduct-by-Wire system is perceived to be able to support the drivers’ goal fulfillment”. The TAM is used as conceptual basis for the consideration on user acceptance because it can be seen as one of the best validated and most economic models [17], [18] in technology acceptance research.

Within the Technology Acceptance Model acceptance is often defined as the actual usage of a system [3]. In its current status, Conduct-by-Wire is a prototype which is not available for use. Therefore a different measure for acceptance has to be chosen. The authors follow the assumption of [5] that acceptance can be seen as positive attitude towards a certain technology in combination with the intention to use the technology in question. This understanding of user acceptance was used for all three studies presented in the following section of the paper.

2.2.1. Extension of the TAM for Online-Study

The original TAM included Perceived Ease of Use and Perceived Usefulness (which was adapted to the context of maneuver-based driving). Later modifications [2], [4], [9] included Perceived Enjoyment (“enjoyment refers to the extent to which the activity of using the computer is perceived to be enjoyable in its own right, apart from any performance consequences that might be anticipated” [4]) into the TAM. The questionnaire used in this study included some additional constructs. Those constructs were: Perceived Safety (The degree to which the usage of a system is perceived to be free of personal risk), trust, Perceived Identification (The degree to which a system enables a person to communicate his personality and values to others based on [8], [10], and [18]), Perceived Control, and Perceived Cooperation (The degree to which the interaction which a system is perceived to be a joint goal fulfillment). Safety and trust were added, because all studies with traditional TAM were conducted in a non-critical environment. It can be assumed that safety and trust are perceived to be relevant in the context of driving. Additionally, Perceived Identification was added, because cars can be seen as prestige objects with high hedonic value. Therefore, a reduction of this perception may be critical for the acceptance of such a system. The concept Perceived Identification goes back to [18] and [10] who divided 4 pleasures: Physio-, Socio-, Psycho-, and Ideopleasure. Sociopleasure is considered pleasure related to the community with others and Ideopleasure is related to personal values. The herein used definiton of Perceived Identification is a mixture of both. Perceived Control was added to the questionnaire, because Conduct-by-Wire is a highly automated system and the perception of loss of control might lead to a decrease in user acceptance. Finally, Perceived Cooperation was added, because Conduct-by-Wire follows the idea of a cooperative driving between driver and vehicle [1]. Therefore, it is essential to see if driving with Conduct-by-Wire is perceived to be cooperative by the drivers.

In the next section, the methodological approach and the results of each study will be presented separately. Overall, three studies are presented, yet only the last one used the extended TAM as a basis.

3. Methodological Approach and Results

To clarify the question if drivers are willing to use a cooperative maneuver-based vehicle guidance three different approaches were used, which are built upon each other. The following sections describe each study and the according results separately.

3.1. Simulator study

During the first project phase a simulator study with 56 participants (41 experienced drivers (ex) and 15 non drivers (inex)) was conducted. The participants had the opportunity to use Conduct-by-Wire for almost 2 hours. Main goal of this study was to clarify, if it is possible to complete a driving mission on a highway with the Conduct-by-Wire system and if the system influences the accustomed driving behavior of the participants.

The test-track goes along a 120 km freeway, with 2, 3, and 4 lanes in each direction. The horizontal roadway arrangement was imitated from a real course from a freeway between Darmstadt and Würzburg (Germany). The speed limits were 80, 100, 120, and 140 km/h. Due to restrictions of the performance of the driving simulator, the simulation runs were divided into two parts with 60 km length. The first part was used to train the participants to use the simulator and to ensure that the subjects became familiar with the Conduct-by-Wire-system. The second part was used to collect data for the evaluation. For the third part, participants drove the second part of the test track again in manual mode to enable comparison of the driving behavior between both modes. Objective as well as subjective data was collected. Since the main focus of this paper is on user acceptance, the results will be restricted to subjective evaluation of the system. This paper presents only some aspects of the study related to acceptance. For an overview of all results see [15].

Within the simulator study participants attested to the Conduct-by-Wire-system a high ease of use (experienced (ex): 2.14 SD = 0.75; inexperienced (inex): 2.15 SD = 1.04; 7-point likert scale from 1 to 7 with low data being good) and a high novelty (ex: 3.02 SD = 0.78; inex: 3.18 SD = 0.61). Although participants generally had a positive attitude towards our system, (ex: 2.742 SD = 1.41; inex: 2.93 SD = 1.53) the overall intention to use the CbW-system was limited (ex: 4.01 SD = 1.56; inex: 4.98 SD = 1.64). This might be due to two reasons: First, participants experienced no identification with the system (ex: 4.22 SD = 1.37; inex: 4.96 SD = 1.23) and second, no certain usage scenario was given. This lead to the question, if a higher acceptance of Conduct-by-Wire can be expected, if particular usage scenarios are given and which of those scenarios would be accepted.

3.2. Focus Groups

To identify relevant usage scenarios and driving tasks two focus groups were conducted. 20 persons were invited to attend the focus groups, 11 of the participants were male, mean age was 22 years for the first focus group and 30 years for the second one. Within these focus groups, participants were introduced to the concept of Conduct-by-Wire and each participant was asked to formulate scenarios in which he would use a Conduct-by-Wire system and why he would do so.

Summarized, there are three main findings (see [13] for more details): 1. the usage of Conduct-by-Wire is independent of the kind of street, the number of passengers, and/or time of the day. 2. Almost all participants are willing to accept Conduct-by-Wire for routine driving tasks like commuting and in situations when they are tired or distracted. 3. About half of the participants are not willing to use the systems at all. For a possible explanation see [11]. The focus groups lead to some usage scenarios which seemed relevant for users. Those scenarios were used in an online study which is described in the following paragraph.

3.3. Online study

To quantify the results of the focus groups an online study was conducted. Aim of this study was to identify relevant driving scenarios for Conduct-by-Wire and to obtain a non-scenario-specific overall rating of the system.

Overall, 246 persons participated in the study. 118 participants finished the whole study. All results presented in this paragraph are limited to participants who finished the complete study. 22.9 % of the 118 participants were female, mean age was 28.34 years (SD = 7.67) with a minimum of 18 years and a maximum of 55 years. The education level of the participants was above average (see fig. 2).

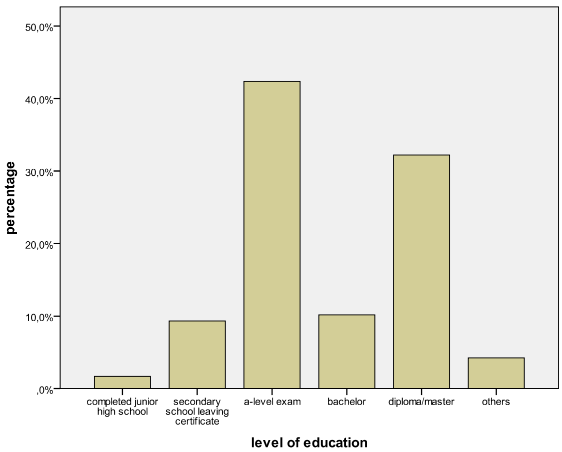

Fig. 2. Level of education of participants.

All participants were in possession of driving license except for 9 participants. 60.2 % of the participants drive more than 10,000 km per year. Over 80 % of the participants described their typical driving behavior either as sporty or as average (see fig. 3).

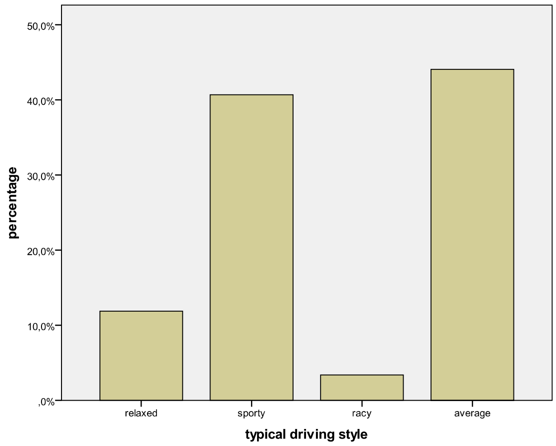

Fig. 3. Typical driving style of participants.

3.3.1. Reliability of Constructs

In a first step, the reliability of the constructs was tested. Cronbach's Alpha was computed, to see if all items of a construct measure the same. Cronbach's Alpha can vary between 0 and 1 whereas 1 is a perfect fit. If a Cronbach's Alpha for one constructs lies below 0.7 it cannot be assumed that all items measure the same. Table 1 gives an overview of the investigated constructs and the according Cronbach's

Table 1
Cronbach's Alpha and descriptive measures for each construct

Construct	Cronbach's Alpha	mean	SD
Perceived Usefulness	.915	3.98	1.50
Perceived Ease of Use	.745	5.07	1.24
Perceived Enjoyment	.768	3.17	1.32
Perceived Identification	.786	2.61	1.27
Perceived Safety	.787	3.81	1.47
Perceived Control	.726	4.18	1.22
Perceived Cooperation	.774	3.37	1.33
Attitude	.875	3.99	1.77
Acceptance	.910	3.89	1.77

Alphas. All constructs have an acceptable internal consistency. Trust and intention were measured with a single item; therefore no Cronbach's Alpha could be computed.

3.3.2. Linear Regression

A simple linear regression as computed to measure the impact of each of the above mentioned constructs on acceptance of the Conduct-by-Wire concept. The independent variables were: Perceived Usefulness, Perceived Ease of Use, Perceived Enjoyment, Perceived Identification, Perceived Safety, Perceived Control, and Perceived Cooperation. The dependent variable was acceptance, which was measured as the mean of behavioral intention to use the system and the attitude towards the system.

As result of the backwards regression a model with 4 relevant independent variables was generated. Those variables were: Perceived Usefulness, Perceived Enjoyment, Perceived Identification, and Perceived Cooperation. The model explained 87 % of the observed variance and is highly significant.

3.3.3. Scenarios

In a last step, the online study compared different driving scenarios to see which are acceptable to drivers and which are not. Overall, eight scenarios were presented: Picking a friend up from an airport, shopping in the inner city, commuting to work, going on a business trip, driving home from a party at night, racing the Nürburg Ring (a famous German racing track), driving on holidays with the family, and cruising with friends. Each scenario was described in 3 to 5 sentences and for each scenario participants had to decide whether they would use the Conduct-by-Wire system or not. Additionally, they were asked to explain their decisions. Afterwards, each participant had to do a pair-wise comparison (28 comparisons) to allow for a ranking of the driving scenarios.

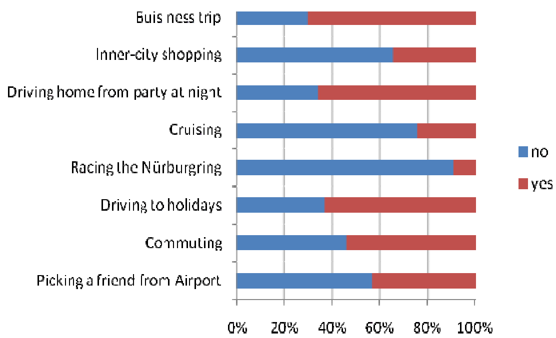

Fig. 4. Percentage of participants who would/would not use Conduct-by-Wire for each scenario.

Figure 4 gives an overview of the scenarios and the percentage of participants who are willing to use the Conduct-by-Wire system in the scenario in question.

Results show that there is no scenario where all participants agree in using the Conduct-by-Wire-system, but there are several scenarios where most people would like to use Conduct-by-Wire. Figure 5 shows the ranking of all scenarios derived from the pair-wise comparison. It can be seen that the first four ranks are almost equal, whereas the differences in the later scenarios are larger.

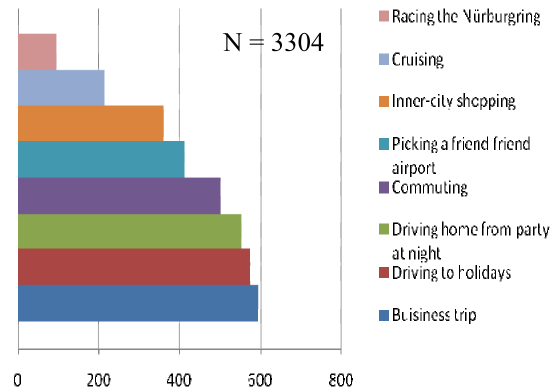

Fig. 5. Ranking of the scenarios derived from pair-wise comparison

Summarized, the online-study mirrors the results from the focus groups. Participants are willing to use the systems for routine tasks and when they are distracted or tired. For both scenarios which are associated with driving pleasure (racing and cruising) the Conduct-by-Wire system was chosen only by a few drivers. In the next section, implications for future work are discussed and a critical review of the studies closes this paper.

4. Discussion and Future Work

The presented studies in this paper are only the starting point for acceptance research in the field of maneuver-based cooperative driving. Still, the theoretical framework of the online-study will be the basis for future studies. Overall, the results of the online study verify the results of the focus groups. The ranking of the scenarios is not surprising. A more surprising result is that Perceived Cooperation and Perceived Identification are seen to be relevant for the acceptance of a cooperative system. In itself this is not a remarkable result, but in combination with the fact that Perceived Safety and Trust did not influence acceptance this leads to the implication that an online study is not sufficient to analyze acceptance in a safety-critical area. Another interpretation would be that our participants did not perceive safety as relevant. There are two possible explanations: 1. since it was an online study, participants focused on other aspects like Perceived Identification and Perceived Cooperation rather than on safety. 2. Participants expected the system to be safe. However, experimental data revealed that this is not the case (mean = 3.81, SD = 1.47).

4.1. Restrictions

While this paper gives the first overview of the acceptance of the Conduct-by-Wire system, there are some major restrictions: 1. the theoretical model was changed between simulator and online study, therefore no comparison between the data was possible. 2. The online study revealed some surprising results (safety as not relevant for acceptance of the system), which might be due to the restrictions of an online study. This leads to the need for a re-evaluation of the model in a simulator and later in a real driving context. 3. The test group of the study cannot be considered as the average population because their level of education was far above average. Therefore, it is not possible to generalize these results.

4.2. Future Work

On the basis of this work, a simulator study will be conducted to verify the results on impact factors for acceptance of maneuver-based driving. One of the main questions will be if Perceived Safety gains importance in a simulator study compared to an online study. Furthermore, it will be investigated if acceptance of maneuver-based driving varies over time. For this purpose, a simulator study with repeated measurements will be carried out.

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