How the driver wants to be driven - Modelling driving styles in highly automated driving

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***Abstract* — In recent years considerable research has been carried out in the field of autonomous driving as it opens up new opportunities for individual mobility. The increasing level of automation associated with changes in the driver's role from active to passive raises new questions of driver-vehicle-interaction. This research focuses on a fundamental aspect of this change: Is it possible to model a customized automated driving style based on manual driving that makes the driving experience comfortable for the driver? A driving style experienced as comfortable is a basic condition for the wide acceptance of automated driving. Two studies will be presented in an overview. First, a driving simulator study was used to derive driving parameters to provide an automated driving style experienced as comfortable. Some of the thereby found parameters essential for the perceived comfort like acceleration and braking is tested in a subsequent field study on the test track Sachsenring. Preliminary results indicate that driving parameters concerning longitudinal control have a high impact on subjectively perceived comfort.**

Keywords—autonomous driving; highly automated driving; driving style modelling; driver-vehicle-interaction; driving comfort

I. Introduction

The technology of driver-vehicle-interaction is improving quickly. Driver assistance systems in vehicles open up new opportunities by taking over parts of the driving task, i.e. lane-keeping, detecting critical situations (emergency brake assistant, pedestrian warning), or by assisting in complex maneuvers (crossroad assistance). The development in the field of driver assistance is towards a consolidation of these still largely separately operating systems to an autonomous vehicle, which takes over the driving task of the driver. By now, cars drive without any involvement of the driver in the United States [1]. Under the condition that these technologies are successfully implemented, autonomous driving offers new potentials and possibilities for maintaining mobility especially for the elderly and people with disabilities [2].

The technical implementation of autonomous driving is often in the focus of research, such as areas of sensors-actuators [3] or maneuvering [4]. Only a few studies are discussing the converting role of the driver as he changes from an actively operating driver towards a more passive system monitoring passenger. Thus, little is known about how the driver wants to be driven and how the change in the driver's role is experienced. This knowledge is, however, essential in order to conceive autonomous driving experienced as comfortable to increase the acceptance of this new type of driving.

The main objective of the presented research project was to derive parameters of comfortable driving in a driving simulator study and to review them in a field study. In this context, the relation between manual driving style and the experience of different automated driving styles was investigated. In conclusion, the main research question of the project was, how autonomous driving should be designed so that it is experienced as comfortable.

The research question was addressed in two studies that took place in the driving simulator at the Technische Universität Chemnitz and on the test track Sachsenring. The driving simulator study contained the collection of data (questionnaires and interviews as well as data from a handset control for a continuous assessment of comfort) to determine the subjectively perceived comfort experience during highly automated driving. From those data, evidence can be derived about which driving parameters have relevance for autonomous driving and how these parameters should be integrated into autonomous driving algorithms. In the subsequent field study, individually identified parameters of the longitudinal control in the driving simulator study were tested under natural conditions. Collected data were driving data, questionnaires and interviews as well as data from a handset control. To complete the project, results will be discussed at industry level by conducting an expert workshop. This allows recommendations of preferred driving styles of an autonomous vehicle to make the autonomous trip as comfortable as possible.

This paper is an overview of the two studies including the theoretical background as well as the methodology.

A. Automation of driving task

The complexity of driver assistance systems and the range of functions have changed over the years. For example, the functions of some driver assistance systems were limited to the stabilization of the vehicle without having a direct and conscious interaction between system and driver, e.g. ABS or ESC. While technology advances, it is possible to warn or

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inform the driver and allows, in addition, to enhance the safety and the comfort of the driver while driving [5]. With the introduction of the first known adaptive cruise control, also referred to as ACC, for the first time, it was possible to execute parts of the driving task partially in an automated way [6].

The future vision is autonomous driving with a complete takeover of the driving task. Since there are still development needs from driving supported by driver assistance systems to autonomous driving, five levels of automation have been defined by Gasser [7]: driver only, driver assistance, partial automation, high automation, full automation. Current driver assistance systems are still at the first stage of automation with a typical driver-vehicle-interaction. With increasing level of automation the driver's responsibility changes. Therefore, a new way of interaction between driver and vehicle arises as the driver's role changes from active to passive driving. Thus, little is known about how the driver wants to be driven and which situations, driving maneuvers or automated driving styles have an effect on the driver that he perceives as uncomfortable.

B. *Driving comfort*

Ammon [8] derived dynamic requirements for autonomous driving from real-driving data with conventional vehicles. Accordingly, lateral and longitudinal accelerations play an important role in the design of an optimized driving style for autonomous vehicles. On motorways low longitudinal and lateral acceleration often occur in moderate speed ranges. Only 0.5% of all detected values on the highway are above $1.7m/s^2$ for longitudinal acceleration and $2m/s^2$ for lateral acceleration. These limits are indeed essential for the design of an optimized driving style; however, it has not been studied how such a driving style is perceived by the driver, especially if he does not actively drive by himself. For traveling with autonomous vehicles, it is necessary for the driving style to be parameterized appropriately in order to ensure a high market acceptance of the system and this new way of driving, because positive driver experience is a key factor for the success of an automobile [9]. One frequently discussed possibility to ensure the maximum comfort is to choose suitable acceleration values, which should be maintained as low as possible [10, 11].

To model highly automated driving as comfortable as possible for the driver, intra- and interindividual differences between the drivers can be considered with respect to their operating modes [12]. Over the years, drivers develop their own driving styles, which can be divided into different driving types such as aggressive, dynamic or normal/moderate [12, 13]. There is a chance that drivers have different preferences regarding the automated driving style due to their own driving styles. In order to fulfill this aspect, it is necessary to determine relevant driving parameters and their configuration to ensure comfort while driving with an autonomous vehicle.

II. METHOD OF THE DRIVING SIMULATOR STUDY

To determine the effect of different driving parameters on the driver's experience, a two-tiered simulator study was conducted with drivers of different age groups (for more details on methodology and results: see Hartwich, Beggiato, Dettmann, and Krems [14]).

A. *Participants*

A total of 40 people, among them 20 younger (25-45 years) and 20 older drivers (> 65 years) participated. The mean age of the younger participants was 27.8 years (SD = 2.1), the older participants' mean age was 71.3 years (SD = 6.0). All participants were in possession of a driver's license for at least 6 years and had a minimum annual mileage of 1,000 km.

B. *Experimental setup and used material*

The study was carried out in the static driving simulator of the Technische Universität Chemnitz. The simulated route included eleven scenarios with a wide range of driving maneuvers (see Table 1 for an overview of selected scenarios). The scenarios were selected on the basis of e.g. Van Mierlo et al. [15] and Kedar-Dongarkar et al. [13]. There are different driving parameters that provide information about a driver's driving style. These parameters include inter alia the acceleration and deceleration of the vehicle, driving at different speeds as well as the driver's activity on the accelerator pedal. The scenarios had been selected so that these driving parameters are covered and therefore statements can be made about personal driving styles.

TABLE 1: SELECTED SCENARIOS

Scenario	Relevant maneuvers
Rural road: signposted intersections	Speed regulation in indifferent situation
Rural road: traffic light scenario	Braking down to a complete halt Starting up
Rural road: following another vehicle	Lane keeping Maintaining the distance to the preceding vehicle
Motorway: narrow lanes with obstacle	Slowing down behind a moving vehicle

To determine the perceived discomfort between 0 (very comfortable) to 100 (very uncomfortable) during the automated ride, a handset control [16] (Figure 1) connected to the driving simulator was used. With this instrument, maneuvers and situations can be assessed continuously by pressing the lever of the handset control. The more the lever was pressed by the participant, the more uncomfortable he felt. To support the driver in doing so, a visual feedback was integrated in the dashboard.

Figure 1: Handset control for continuous recording of comfort

C. Test procedure

The driving simulator study was divided into two sessions which each lasted about two hours. At the beginning of the first appointment, the 40 participants passed through the route driving manually with their individual driving styles. This ride was played again as a replay after a short break so that the participants experienced their own driving style as a highly automated drive with no possibility of intervention. Throughout the ride, the participants pressed the lever of the handset control with which they were able to report continuously the level of perceived discomfort. Afterwards, interviews and standardized questionnaires were conducted to get more information about the experienced driving comfort as well as joy of driving. These data were triangulated with the driving data and data from the handset control and thus provided assistance in interpreting the handset control profile over driving time.

The participants were then invited to the second appointment in the driving simulator to compare different automated driving styles in a randomized order. Three automated driving styles were presented, one based on the own driving style and two on other participants' driving styles. Those rides based on 16 existing manual rides from the first appointment in the driving simulator. Only those rides without any driving mistakes or false driving maneuvers (e.g. missing the exit of the highway) were taken into account. Once again, data were recorded via handset control during the ride as well as interviews and questionnaires after the ride.

D. Derivation of relevant driving parameters and driving comfort

The analysis of the interviews revealed that some driving parameters are apparently more important for the experience as they were mentioned by the participants more frequently. Following a ranking of the most frequently mentioned comfort parameters: longitudinal safety margin was mentioned by 87.5% of all participants, braking by 77.5%, velocity by 55%, acceleration by 27.5%, lane-keeping by 25%, steering by less than 25% as well as indicator usage.

A first analysis of the data from the handset control indicates that demanding situations are motorway accesses, traffic light controlled junctions and situations of following another vehicle. An overview of the results out of the two simulator studies is presented in Hartwich et al. [14]. In a next step, out of the three rated rides in the second simulator session, the main scenarios rated as uncomfortable were split into time frames to further investigate the detailed progress of e.g. acceleration and deceleration curves and the respective subjective handset control curves. Thus, a more specific understanding of the relation between driving parameters and subjective perceived comfort was achieved. Then, all results were applied to the driving style modelling, so that a comfortable automated driving style can be generated in the near future.

As parameters of longitudinal control were highlighted by the participants to describe uncomfortable situations, therefore the focus in the field study was set on the longitudinal control. This includes in particular the parameters *Braking* and *Acceleration*. Especially those parameters were perceived as uncomfortable across various situations over the entire course. Even though in the driving simulator such important facets of real driving like acceleration and braking forces were absent [6], the importance of these parameters is clear by the frequency of mentioning. To determine exactly how the progress of parameters like acceleration and braking have to be designed in order to be perceived as comfortable, they underwent a reexamination in a field study.

III. Driving Style Modelling

In this section, a possible methodology to model an automated driving style is described. To fulfill the driving task on a planned route the drivers had to execute different driving maneuvers in compliance with the current road conditions and other road users. The execution of the driving maneuvers depended on the driving styles and on the comfort preferences of the drivers of the simulator study. Thus, the detailed modelling of specific driving maneuvers provides the basis for highly automated driving. The automated driving style is here defined as a variation of the parameter set of an automated maneuver which depends on the comfort preferences of the driver.

A. Exemplary analysis results of the driving simulator data

Based on the results of the simulator study mainly the longitudinal maneuvers like acceleration and deceleration including stopping were addressed in the field study. In the following section, the methodology for modelling the automated driving style will be described exemplarily with the specific maneuvers deceleration and stopping. To illustrate the longitudinal control the speed profile over driven meters was used.

Figure 2 shows the speed and acceleration signal over driven meters which were measured in the simulator study for a stopping situation at a traffic light. There are different phases of deceleration before stopping some meters in front of the traffic light. From driving meter 1790 m there is a slight deceleration without pressing the brake pedal, which resulted from the driving resistances. A braking and greater deceleration starts from driving meter 1780 m. This is followed by a plateau with no brake pedal actuation. At 1920 m the driver decelerates the vehicle to standstill 8 m before the stop line of the traffic light. The measurement data of all subjects showed this characteristic switching between different deceleration and rolling phases during stopping maneuvers. The number of phase changes varied depending on the participant and the stopping operations.

The simulator data showed basic parameters which are important for the maneuver description. For the stopping maneuver it is the point of starting the maneuver, the beginning and ending of the different deceleration phases, the value of the deceleration at the begin and end point of the phases, and its gradient such as the point of standstill. To parametrize an algorithm that estimates the automated driving style, the distributions of these parameters can be collected from the simulator data for different comfort preferences of the drivers. For example, the average value of the distance between the beginning of the first braking phase and the stop line of the traffic light situation, shown in Figure 2, is 148 m with a standard deviation of 32 m.

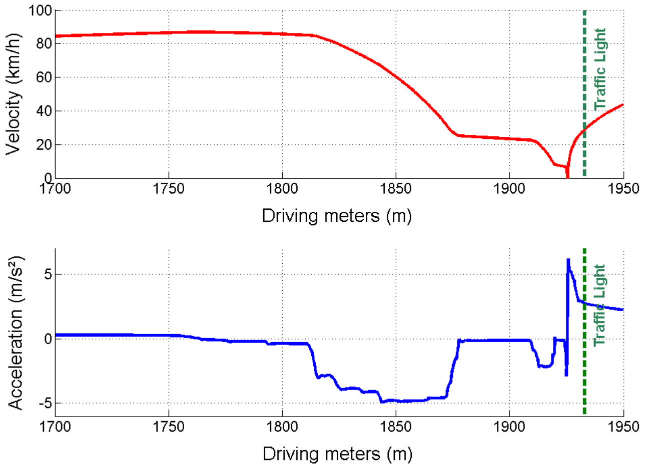

Figure 2: Velocity and longitudinal acceleration signal over driving meters during a stopping maneuver at a traffic light

The signal of the handset control gave hints of the driver's comfort preferences and it can be used to derive essential parameters of a maneuver. Figure 3 shows the signal of the handset control by one driver for three different automated drives. It can be seen that the driver feels more comfortable with the solid blue velocity signal. The dashed red velocity signal shows a higher speed until the vehicle is stopping than the other vehicles. It also contains no distinct velocity plateau like the other two signals. The doted green handset control signal has a peak when the vehicle stops. The according velocity signal shows in relation to the other two signals the highest deceleration at this point. These information can help to better understand the driver's preferred driving style.

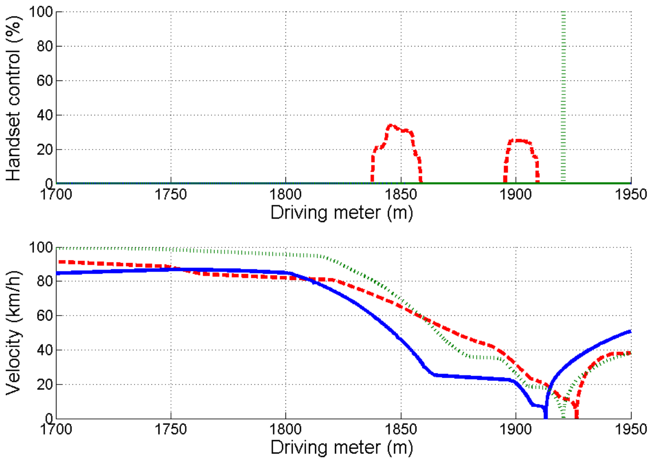

Figure 3: Signals of the handset control by one driver for three different automated drives

The analysis of the simulator data uncovered several conditions which need to be considered for modelling an automated driving style. There were also recommendations for the values of the maneuver parameter set. The results were taken into account in the modelling approach of the automated driving style.

B. *Driving style model approach*

To model a highly automated driving style a generic and modular approach has been chosen. The driving profile of a known track is modeled with splines. These consist of several segments with fifth-order polynomials. A segment of such a spline has to be defined by the value of a starting and end point and the values of the first and second derivation at the starting and end point, see Figure 4.

This approach makes it possible to create maneuver dependent velocity profiles in all variations. This also meets the requirements that have been derived from the driving simulator data. Deceleration phases can be defined depending on track meters by inserting additional spline segments. Individual maneuvers can be composed to specify a whole track section. To take the driving style of a driver or group of drivers into account, the spline segment points have to be learned from collected measurement data of this driver or group of drivers. This allows to model individual variations of a driving maneuver.

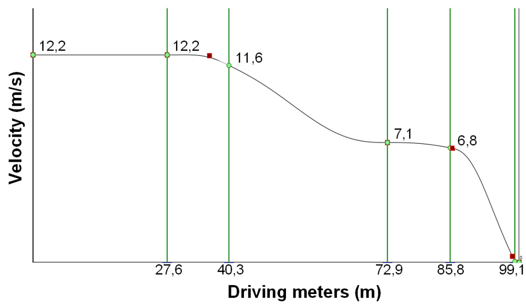

Figure 4: Example of a spline which depicts a stopping maneuver

C. *Methodology to transform manual driving parameters in automatic driving parameters*

The theoretical approach to transform manual driving parameters into optimized automated driving parameters is shown in Figure 5.

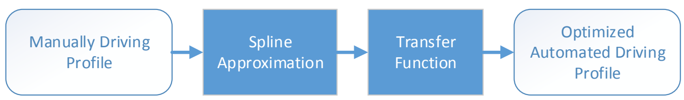

Figure 5: General structure of the transformation of manual driving parameters into optimized automated driving parameters

The splines allow to mathematically approximate and describe the recorded manual driving profile. This step provides the basis for the transfer function, which consists of a set of rules to adapt characteristic features in the driving profile. These were identified by their properties in the spline and adjusted by the defined parameter set of the underlying driving style. For example, the beginning of the deceleration phase during a stopping maneuver at a traffic light can be adapted on the drivers comfort preferences for an automated drive. The parameter set can be determined from the underlying training data of a special driving style. This methodology was used in the field study.

IV. Method of the Field Study

Although the driving simulation offers currently the possibility of experiencing highly automated driving today, important aspects of real driving, such as braking and acceleration forces, are missing. However, these are necessary in order to provide results about how the driver wants to be driven automatically. Therefore, comfort parameters of the longitudinal control identified in the driving simulator were examined in a field study on the test track Sachsenring.

A. Participants

Within the study, a total of 20 participants, aged between 25 and 45 years, completed a test drive with the instrumented test vehicle BMW i3. Most of them also participated in the driving simulator study and thus already have experience with highly automated driving.

B. Experimental setup and used material

The study was executed on an enclosed test track. The focus was mainly put on the acceleration and deceleration forces which account for a large part of the longitudinal control. One of the eleven scenarios tested in the simulator study was transferred to real driving: the scenario "braking down to a complete halt and starting up". The course (Figure 6) was passed through multiple times with the test vehicle to obtain several reference values of the participants.

Figure 6: Test track of the field study

The test vehicle was equipped with sensor technology for highly accurate position determination using DGPS and inertial sensors. The recording of the surroundings of the test vehicle was realized with camera and laser sensors. In the vehicle interior two cameras were installed, which were directed to the footwell and the driver. This enabled the recording of the participant's behavior during the experiment. Furthermore, there was an interface to the vehicle bus system for acquisition of relevant metrics. To record the perceived comfort, the same handset control was installed in the test vehicle like in the driving simulator. Once again, a visual feedback was installed in the test vehicle in form of the 0-to-100 scale to inform the driver about the currently entered value of discomfort.

The automation of the longitudinal control of the test vehicle was realized by a modular redundant system to actuate the driving function. Due to the redundancy, the system was completely deactivatable. The automation was controlled and monitored by a security system that was also connected to the vehicle bus. Additionally, sensors were used to detect the driver's overtaking request, e.g. built-up pressure sensors at the pedals. Thereby, the driver was able to override the system in any situation.

The path planning for the automated longitudinal control was realized by a spline with GPS coordinates of the planned track. Based on this path spline, an overlying velocity spline fulfills the driving task of the maneuver level. The implementation of the braking and acceleration maneuvers were carried out in compliance with the participant's overdriving.

C. Test procedure

At the start of the study a familiarization ride after being briefed on the test vehicle was conducted. Subsequently, a manual ride under test conditions followed which was then presented as an automated ride analogous to the simulator study. To examine the effects of the driving style model approach, the participants experienced two additional automated rides. Their task was to press the lever of the handset control to assess continuously their subjective discomfort. Following the respective rides, a verbal feedback was given in the form of interviews and questionnaires. Throughout the study, driving data of the vehicle (e.g. acceleration and braking times, acceleration and braking curve) were recorded.

V. Discussion and Practical implications

Autonomous driving offers, besides an increase of comfort and safety on the roads, a significant potential to provide and maintain personal mobility and independence especially for the elderly and people with disabilities. The change in the active driver's role towards the more and more passive system supervisor raises fundamentally new questions of the driver-vehicle-interaction. This project provides a basic approach to model autonomous driving, which should be a starting point for application-oriented follow-up research. The modelling of a driving style experienced as comfortable in autonomous driving provides a fundamental condition for the acceptance and dissemination of this new technology. Achieving this objective, two studies were executed within the project. Using the driving simulator study, different driving parameters were found which are essential for the perceived comfort while driving autonomously. In particular, parameters of the longitudinal control were mentioned which are similar to those named in [13]. The mostly mentioned cross-situational parameters were braking and acceleration which will be examined once again in a field study with the implementation of a driving style modelling algorithm.

The objective of the driving style modelling is to optimize various driving parameters towards an automated driving style which is experienced as comfortable. The aim was to detect if subjective driving behavior should be considered for autonomous driving and thus a learning mechanism should be incorporated or if a "one fits all" driving style for autonomous vehicles is sufficient. Hereby, the driving style can be optimized towards technical, ecological, economical and traffic variables but it has to be questioned if driving autonomously then still is perceived as comfortable. In the future, acceptance problems can occur as a lot of early adopters of autonomous vehicles will still be used to their own respective driving style and therefore their own comfort perception. While this won't be as problematic for people who never got to drive themselves, the overall comfort problem in autonomous cars will concern them as well. To resolve this problem, further studies based on the presented methodology need to be conducted. The next step of the project is to complete the field study and evaluate questions regarding perceived comfort in autonomous driving. In order to ensure the understanding of the empirical field out of a stakeholder's view and to have a direct transfer of the results into industry, a workshop will be organized with representatives of the automotive manufacturers, suppliers and research partners.

REFERENCES

[1] Spiegel Online, Testfahrt in Google Self-Driving Car: Dieses Auto kommt ohne Sie aus. http://www.spiegel.de/auto/aktuell/google-auto-unterwegs-im-selbstfahrenden-auto-a-969532.html, accessed 27.07.2015, 2014.

[2] D. J. Fagnant, and K. Kockelman, "Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations for capitalizing on self-driven vehicles". Transportation Research Part A, 2014, p. 1-20.

[3] K. Sung, and D. Kwak, "System architecture for autonomous driving with infrastructure sensors," in Signal Processing and Communication Systems (ICSPCS), 2012 6th International Conference on, vol. 1, no. 6, p. 12-14, Dec. 2012. doi: 10.1109/ICSPCS.2012.6508023

[4] J. Langenberg, A. Bartels, A. Etemand, „Ansätze für hochautomatisiertes Fahren", in 30. VDI/VW Gemeinschaftstagung Fahrerassistenz und Integrierte Sicherheit, VDI-Berichte 2223, 2014, p.289-300.

[5] M. Jentsch, „Eignung von objektiven und subjektiven Daten im Fahrsimulator am Beispiel der Aktiven Gefahrenbremsung - eine vergleichende Untersuchung", Universitätsverlag Chemnitz, Chemnitz, 2014.

[6] H. Winner, „Fahrerassistenzsysteme – Stand der Technik und Ausblick". 1. Autoforum Sachsen – Sachsen wieder Autoland. VDI-Berichte Nr. 1702. VDI Verlag, Düsseldorf, 2002.

[7] T. M. Gasser „Herausforderung automatischen Fahrens und Forschungsschwerpunkte", in 6. Tagung Fahrerassistenz. TÜV-Süd Akademie GmbH - München, 2013.

[8] D. Ammon, „Systemtechnische Überlegung auf dem Weg zum automatisierten Fahren", in Der Fahrer im 21. Jahrhundert Bd. VDI-Berichte Nr. 2205. Braunschweig: VDI Verlag GmbH, 2013, p. 201-212.

[9] M. A. Tischler, and G. Renner, „Ansatz zur Messung von positivem Fahrerleben. Die Messung von Fahrspaß und Ableitungen für die Fahrzeuggestaltung", in Fahrer im 21.Jahrhundert. Human Machine Interface. VDI-Berichte 2015, (S. 105-117), Düsseldorf: VDI-Verlag GmbH, 2007, p.105.

[10] A. Lange, M. Albert, K. Bengler, M. Maas, and K.-H. Siedersberger, „Automatisiertes Fahren – So komfortabel wie möglich, so dynamisch wie nötig", in 30. VDI/VW Gemeinschaftstagung Fahrerassistenz und Integrierte Sicherheit, 2014, p. 215-228.

[11] B. Heißing, M. Ersoy, and S. Gies, Fahrwerkhandbuch. Wiesbaden: Vieweg + Teuber, 2011.

[12] S. Griesche, D. Käthner, and M. Krähling, "CONFORM – A visualization tool and method to classify driving styles in context of highly automated driving", in 30. VDI/VW Gemeinschaftstagung Fahrerassistenz und Integrierte Sicherheit, VDI-Berichte 2223, 2014, p. 101-108.

[13] G. Kedar-Dongarkar, and M. Das, „Driver Classification for Optimization of Energy Usage in a Vehicle", Procedia Computer Science 8, 2012, p. 388-393.

[14] F. Hartwich, M. Beggiato, A. Dettmann, and J. F. Krems, Drive me Comfortable: Individual Customized Automated Driving Styles for Younger and Older Drivers. Paper accepted for 8. VDI-Tagung. Der Fahrer im 21. Jahrhundert, Braunschweig, 2015, 10.-11.11.2015. In press.

[15] J. Van Mierlo, G. Maggetto, E. Van de Burgwal and R. Gense, "Driving style and traffic measures-influence on vehicle emissions and fuel consumption", Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 218:43, 2004, p. 43-50.

[16] I. Totzke, N. Rauch, E. Ufer, H.-P. Krüger, S. Rothe, „Workload-Management im Verkehr: Prädiktion von Fahrerbeanspruchung durch Informationen in digitalen Karten", in J. Schade, A. Engeln, (Hrsg.): Fortschritte der Verkehrspsychologie. Wiesbaden: VS Verlag für Sozialwissenschaften, 2008, p. 159-182.G. Eason, B. Noble, and I.N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," Phil. Trans. Roy. Soc. London, vol. A247, pp. 529-551, April 1955.