ADAS for the Communication between Automated and Manually Driven Cars

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***Abstract*—With the increasing development of automation in traffic, the automated vehicle seems to be within reach. However, with this upcoming technology several problems arise. As long as the automated vehicle is in its infancy, there will be mixed traffic on our roads. Whereas cars equipped with the new technology will have the possibility of sharing and exchanging various information, conventional vehicles will lack an interface for this information exchange. In order to make a step towards the interaction between automated and manually driven cars an assistance system for a manually driven car is developed, implemented and evaluated. It serves the purpose of enabling manually driven cars with the ability to receive, understand and distribute information provided by automated cars to the human driver via an intuitive HMI. Finally, it might avoid critical traffic situations in which human drivers misunderstand or misinterpret the behavior of automated cars. In order to follow the recommendations and information of the assistance system, the acceptance and the trust in such an ADAS is a prerequisite. Therefore a user study is conducted focusing on the willingness of drivers to cooperate with automated cars. Furthermore the intuitiveness as well as the distraction is investigated in the user study. Since the interface is important for the user acceptance, two interaction systems, gesture control and touch control, are compared and evaluated regarding the usefulness, satisfaction and trust.**

I. INTRODUCTION

With the arising technology of automated driving, human drivers will experience new driving behaviours and maneuvers on roads. Areas with indistinct road lines or uncategorized objectives for example might cause difficulties for automated cars. As a consequence slow and defensive automated driving might be executed and might effect the traffic flow negatively. One possibility to increase the acceptance and the safety of mixed traffic is to inform human drivers of current automated maneuvers. Besides indicator (lateral control) and brake light (longitudinal control) conventional cars lack an interface to communicate with automated cars. In order to overcome this lacking communication, it is possible to expand conventional cars by an appropriate system. This upgrade should provide the missing interface to automated cars and transfer the exchanged information to a communication level that is understandable for humans. This advanced driver assistant system (ADAS) and the corresponding human-machine-interface (HMI) has to be designed thoroughly. At the moment automated driving is less accepted than conventional driving [1]. Despite all challenges the benefit of automated driving is highly regarded [2], [3], [4], [5], as security and traffic flow are supposed to be improved and drivers are relieved from their driving task. Smaller distances between cars and faster travel speed result in a higher throughput capacity than conventional traffic. Information can be transmitted to a car by means of Car2Car-, Car2Infrastructure- and Car2Server-Communication. The larger the penetration of such equipped cars is, the larger is the effect on the traffic flow.

This paper focuses on the concept of two ADAS and the development, implementation and evaluation of an HMI contributing to the communication in a mixed environment. In the context of future HMI, Augmented Reality (AR) offers an intutive solution which is chosen here for displaying information. AR glasses are portable, flexible in usage and can be retrofitted. Instead of a permanently installed ADAS, a mobile solution can be utilized in different cars, for example within a car sharing company, while the user always keeps his/her device. The two ADAS including the HMI were implemented in a static driving simulator complemented by AR glasses. The evaluation was conducted within a user study comparing gesture control versus touch control. The following aspects are investigated:

1) Does cooperative driving improve the traffic flow?
2) Do drivers follow the instructions without being aware of the communication with automated cars?
3) Does an Augmented Reality application effect the interaction between human and machine positively?
4) Which control mechanism reveals a better usability, when an Augmented Reality application is applied?

II. RELATED WORK

A. Autonomous and Cooperative Driving

Five levels of autonomy have been introduced by the NHTSA [6] and are characterized by the function ratio in human and technical control. Level 0 considers only manual driving. Whereas Level 1 includes function-specific automation such as electronic stability control. Level 2 means combined function automation, where lateral and longitudinal vehicle control is automated. The driver observes the driving performance and intervenes under special or hazardous conditions. Level 3 includes limited self-driving automation. Under normal driving conditions all control is kept automated except for occasional conditions. Handover of control takes place within a sufficiently comfortable transition time. Level 4 requires a full self-driving automation, so that the vehicle fulfills all safety requirements and arrives at a given destination without the drivers interference.

With the increase of automation level, the meaning of Car2X-communication grows. Car2Infrastructure for example improves the detection of traffic lights. Car2Backend-communication for example is used to predict the friction coefficient of close street surfaces [8]. Especially Car2Car-communication is considered to provide important information such as the approach of vehicles being out of sensor range. By means of Car2Car-communication, automated vehicles are enabled to cooperate with each other. The main goal of Car2Car-communication is the extension of security and improvement of traffic flow. Cooperative perception, for instance, is used to expand the sensor detection area. Cars can match their maps and detect cars hidden by obstacles. Kim [7] utilizes cooperative perception, when a broken down car transmits information to one approaching from the back. Thus this car can pass the first car hazard-free. Mitropoulos [8] implemented a wireless local Danger Warning System in order to investigate cooperative foresighted driving. The main contributions are the automatic hazard detection, the position-based relevance check and the application-based routing and information dissemination [8]. Based on intervehicular communication, this kind of cooperative ADAS supports the driver by hazard detection and warning. The friction detection and self positioning within the critical path were tested successfully [8]. Li [9] investigated the effect of Cooperative Driving on traffic flow based on Cooperative Adaptiv Cruise Control (CACC). They proved that incorporation of motion information results in distinct reduction of the amplitude of congestion waves [9]. Furthermore, Khaisongkram [10] deals with cooperative driving in the context of platooning. He investigated decentralized cooperative driving within the framework of linear-time-invariant (LTI) systems with generalized frequency variables. The simulation results of the platoon in merging scenario show that the follower spacing is suggested to be around half of that of the predecessor spacing.

The advantage of cooperation between automated cars can be outlined by the examples of CACC and cooperative perception. Mixed traffic includes human drivers, though. The related work metioned does not yet include human drivers in cooperative communication. With the involvement of humans a system is needed which translates computational information into information comprehensive to humans. In the next subsection such interior communication between the driver and the maschine is put on the basis of Augmented Reality.

B. *Automotive Augmented Reality Applications*

Concepts with the focus on cooperation and security are implemented i.a. within Augmented Reality applications. For example, Zimmermann [11] proposed an HMI for a cooperative lane change assistance with the focus on driver - machine interaction. The approach differentiates between five levels of cooperation within a mutual control: driver and system intention, mode of cooperation, allocation, interface and contact. The content of cooperation is shown with the help of augmented indicators. Moreover auditory speech information, haptic advice and alert sound are used to escalate the request [11]. It was found that interaction itself was not able to improve the willingness to cooperate [12]. Though qualitive feedback was positiv about the supporting effect in cooperative actions, though [12]. Singh [13] presents SideEye, a mobile assistant for blind spot monitoring and alerting. A smartphone is installed next to the steering wheel in the car und its front camera is used to record the blind spot. The Augmented Reality approach is based on intensity variation and counter matching of the video. Singh succeeded in an about 85% precision of identifying the scene in the blind spot area. They proved to detect a vehicle in the blind spot and to alert the driver.

C. *Gesture Control in Automotive Context*

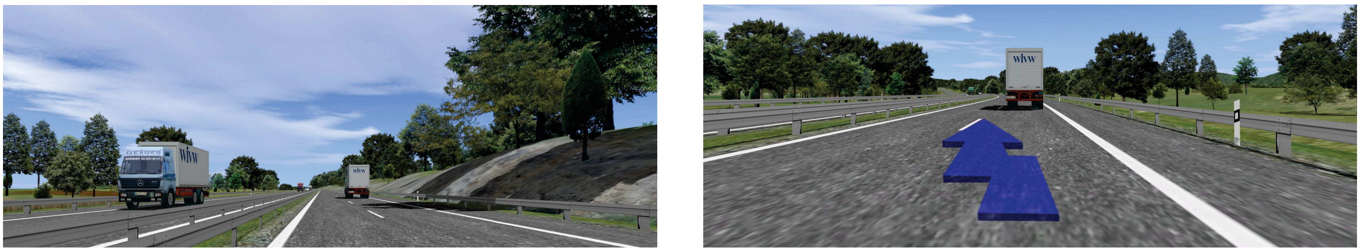
Gesture control is investigated as an extension or replacement of touch interaction within typical automotive functions, such as navigation. Parada [14] prossessed the video stream of a visible-infrared camera with computer vision algorithms in order to track hand gestures. Edge-based foreground-background model, a micture of Gaussians background model and a maximum stable external region segmenter was used parallel to analyze the frames and to segment a hand. 23 volunteers evalutated the control of infotainment equipment in cars by comparing gesture control and touch-screen interface. The users slightly prefered the gesture control. A multimodal gesture interface is developed and investigated by May [15]. On the basis of the consumer-oriented infrared hand tracker Leap Motion the gesture interface is combined with and without auditory feedback. In addition, visual feedback supports the interaction between user and the vehicle menu navigation. This multimodal gesture interface was compared with a current standard haptic interface. Though a user study revealed that participants distributed secondary task dwell time more safely than direct touch. Overall, the gesture interface were more difficult to use overall, though.

This paper applies gesture control in order to execute novel functions in automotive context, the communication between human driven and automated cars. The driver receives visual feedback via augmented reality glasses and interacts via gestures. In comparison to gesture control the effect of touch control is investigated. Yet, the touch interaction is not conducted with automotive buttons and screens, but with a special controller device.

III. AUGMENTED REALITY ASSISTANCE SYSTEMS

For the proposed assistance system, specific traffic situations both on highways and in urban environments are chosen. On the one hand, the state of the art with emphasis on traffic cooperation is integrated into the decision process for suitable traffic situations to be investigated. Such situations up to now are dangerous and disturb the traffic flow, causing traffic congestion and unnecessary emissions which could be avoided by means of cooperative driving. On the other hand, scenarios are chosen for which no assistance system is available, yet. To this end we decided on one highway scenario and one urban scenario (fig. 1). The highway assistance system addresses overtake situations of trucks, whereas the urban situation investigates unclear obstacles with only one traffic lane for both directions. Since a future assistance system is being developed the following assumptions are made:

- Traffic consisting of both automated cars (level 2-4) and manually driven vehicles (level 1)
- Communication between the vehicles with automation level 1-4 and the infrastructure



(a) Overtake scenario on highway

(b) Contact-analog arrow, indicating best overtake time

(c) Obstacle scenario in city

(d) Contact-analog stop bar, indicating oncoming vehicles

Fig. 1: Exemplary traffic scenarios

Consequently, it is assumed the trajectories of other road users as well as traffic light phases, constructions sites and obstacles are available for the decision of the developed application. Compared to the state of the art in cooperation between and automation of vehicles these assumptions seem to be realistic.

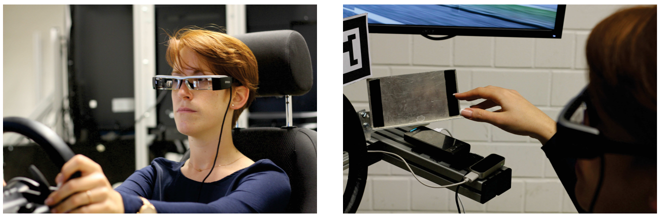
A. Hardware Setup

The hardware used for the prototype implementation consists of three parts: firstly, 3D-glasses serving as the graphical HMI, secondly a touch as well as a gesture based interaction controller and thirdly a static driving simulator (fig. 2).

The graphical visualization of the AR application is realized with the EPSON Moverio BT-200, a pair of multimedia head-mounted AR glasses. The graphical output is displayed on two half-transparent projection surfaces, each for one eye, allowing so called side-by-side stereo rendering which is a prerequisite for showing 3-dimensional outputs. The AR glasses are purely Android based which makes it easy to implement own applications. In addition, the glasses features various sensors, including a Video Graphics Array (VGA) camera, a gyroscope, a GPS interface and an acceleration sensor. The input interface is implemented by default via a multitouch controller within the scope of delivery.

The interaction concept with the AR application is realized with the aforementioned multitouch controller of the data glasses. Moreover, the user study investigates a gesture based input. This input option is implemented on basis of the Leap Motion controller. This hardware part allows to recognize predefined gestures and hand movements in real-time. It uses infrared cameras to detect the human hand in an area of up to 30cm above the controller.

Finally, the AR application is evaluated in a user study. Predefined driving scenarios are implemented on a static driving simulator, using the simulation software SILAB 4.0 [16]. The simulator itself consists of a standard car seat, a mockup with pedals and a steering wheel and three monitors arranged in a trapezoidal manner for displaying the driving scene. The setup does not show a central display, since it could interfere with the contents shown by the AR application.



(a)

(b)

Fig. 2: Hardware setup within the driving simulator: (a) head mounted display (b) input controller

B. Implementation of the AR-Application

The implementation of the AR-application follows several design criteria in order to warrant a user-friendly HMI. The layout of the application on the one hand is based on the principles presented by Wickens [17]. These criteria distinguish between recognition, mental model and awareness of the proposed system. On the other hand AR-applications in turn require special criteria for the layout of which the most important ones are declared by Toennis [18]. Since AR content is directly displayed into the user's field of view minimizing the content and distraction by animations and information are prerequisites for an ergonomic HMI. Following the investigations in [19] a grid layout is chosen in order to provide structure and transparency. The overall layout of the application implemented is shown in fig. 3. In terms of

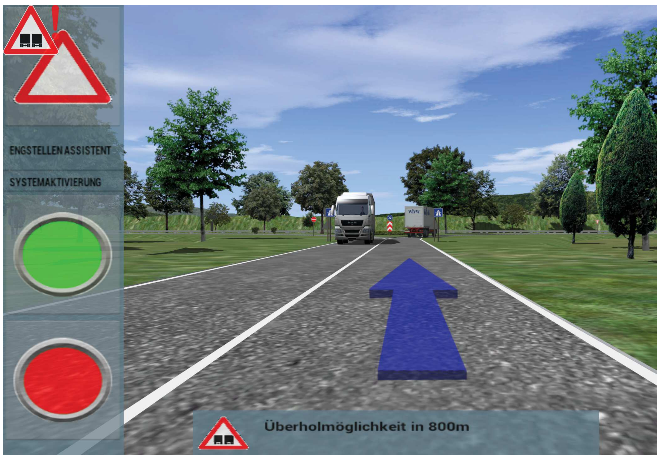


Fig. 3: Layout of the AR application (synthesized view of overall content, half-transparent objects projected on the HMD)

inputs the user has two possibilities of interacting with the application. The touch pad directly connected to the head mounted display (HMD) allows simple drag and drop inputs as well as tapping and clicking. The contact-free interaction concept via the gesture input enables the user to control the application via swipe gestures and contactless timed clicking.

The software implementation is realized using Java and the mark-up language XML, combined with the Android software development kit (SDK). In addition, the Metaio SDK is utilized to render the 3-dimensional contents. The traffic scenarios within the driving simulator are programmed using the simulation software Silab [16]. Finally, the connection between the HMD, the gesture input controller and the data provided by the driving simulation is implemented via the Android Debug Bridge (ADB) and the TCP/IP-protocol.

IV. EVALUATION OF THE ASSISTANCE SYSTEMS

The AR-application is evaluated by means of a user study. The main objective of this user study is to answer the questions formulated in the motivation, i.e.

- Does cooperative driving improve the traffic flow?
- Do drivers follow the instructions without being aware of the communication with automated cars?
- Does an AR-application positively effect the interaction between human and machine?
- Which control mechanism reveals a better usability, when an AR-application is applied?

Therefore user acceptance and system trust are evaluated besides the distraction and the workload the driver is confronted with during the test drives in the driving simulator.
For the analysis of the test drives we rely on subjective and objective observations. The subjective evaluation is covered by a questionnaire which is answered by the participant amongst the different driving situations. The questionnaire itself consists of several standardized forms for evaluating the usability and the acceptance of a technical system as well as the trust in such a system. These forms include the NASA task load index for measuring the workload [20], the system usability scale [21], the trust scale [22] and the acceptance scale by Van der Laan [23].

A. *Test Procedure*

The user study is designed, using the within-subject design meaning that every participant is exposed to all possible combinations (traffic scenarios and interaction concepts). It consists of six test drives, the highway scenario (approx. $10km$) followed by the urban scenario (approx. $5km$), each driven three times.
The highway track is composed of two overtake situations: the first overtake scenario is implemented on a slope where the truck in the front significantly slows down (e.g. due to high load). The system indicates an appropriate overtake point with no hindrance of the following traffic (fig. 1 a, b). The second overtake is different since the assistance system suggests to stay on the right track. The reason is fast following traffic and the truck in the front leaving the highway at the next exit such that overtaking is unnecessary. During the urban scenario the system features the obstacle assistant. As mentioned this system supervises the driver in unclear traffic situations where the oncoming traffic is difficult to foresee. The first obstacle is a construction side blocking the driver's lane. With no system present the driver has to carefully drive onto the opposite lane whereas the active system shows an arrow in case of a free lane. The second critical situation in the urban test procedure is an accident on the opposite road lane (fig. 1 c, d). In contrast to the construction site, there are oncoming vehicles present in this case. However, they are very hard to be detected since they are hidden by rescue trucks. The assistance system warns the driver of these oncoming vehicles when active.
In addition, the participants complete a training run in order to get used to the driving simulator, the scenario and the HMD. With no assistance system present during the first drive of each scenario it serves as a baseline for the following investigations. The second and the third test drives are subsequently driven with an active system. The input concept, gesture or touch pad control, hereby is randomly chosen for each participant in order to avoid learning effects. Prior to first time driving the participants complete a demographic questionnaire. The other questionnaires are completed right after each test drive. Furthermore, a final form at the end of the user study inquires the overall impression of the system.

B. *Participants*

Overall 23 persons between the age of 21 and 28 participated in the user study (mean M: 25.4, standard deviation SD: 1.79). The random sample mainly consisted of students and research assistants. All drivers were licensed and had normal (57%) or corrected vision (43%). However, two data sets had to be excluded from the analysis due to a system crash and incomplete data respectively. Thus, 21 complete data sets were available for the analysis.

V. RESULTS AND DISCUSSION

The results are obtained by the analysis of the questionnaires and the data sets. In the context of driving performance, speed, lane deviation and longitudinal acceleration were recorded. In order to evaluate the interaction concepts

TABLE I: Subjective measurements: results from acceptance scale (usefulness, satisfaction; min/max: −2/+2) and trust scale (trust; min/max: 0/+6)

Overtake Assistant

	mean	sd	min	max
usefulness	0.87	0.49	0.00	1.60
satisfaction	0.67	0.66	−1.00	1.75
trust	4.28	0.76	2.58	5.58

Obstacle Assistant

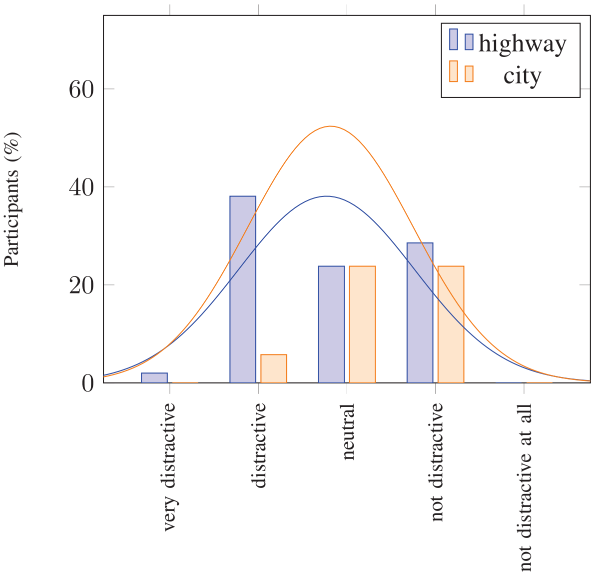
	mean	sd	min	max
usefulness	1.01	0.43	0.00	1.80
satisfaction	0.89	0.60	−1.00	1.75
trust	4.40	0.64	2.58	5.92

with the assistance system, the average interaction time the participants needed to activate the different systems is collected. The questionnaires represent the subjective data, whereas the recorded data sets constitute the objective measurements. The statistical analysis is conducted by the pairwise t-test.

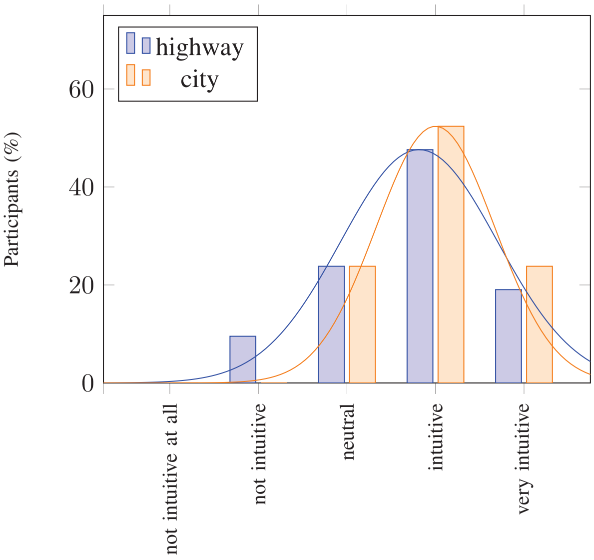
A. Subjective Measurements

The two assistance systems are assessed according to van der Laan in the dimension usefulness and satisfaction, where a maximum value of +2 and a minimum value of −2 can be selected [23]. The trust in the technical system according to Jian is represented by a maximum value of +6 and a minimum value of 0 [22]. The values attested to the different assistance systems are depicted in TABLE I.

Obviously, both systems are perceived to be useful (overtake assistant 0.87, obstacle assistant 1.01). The satisfactory value around +1 indicates a solid implementation of the system function. The participants assign the system a high level of trust (overtake assistant 4.28, obstacle assistant 4.40). This high rating on the trust scale implies the promising potentials for such an application. The subjective impression of the participants coincides with the objective measures which show that the drivers follow the system instructions in 97.5% of all investigated cases. For this reason it can be assumed that drivers don't have to be aware of the communication with automated cars.
When comparing the two interaction concepts for the AR-application, the participants rate the grade of distraction and intuitiveness on a five-dimensional Likert scale (fig. 4, fig. 5). Whereas especially in the beginning of the test drives on the highway scenarios, the gestures control achieves restraint grades in terms of distraction and intuitiveness, this impression vanishes during the five minutes of completing the urban track. This development can be easily seen, when the data sets are represented by a synthesized Gaussian distribution. Especially in the urban scenario a right-shift of the Gaussian curve is observable, denoting a better rating of the intuitiveness and the distraction of the ADAS. However, both interaction concepts are interpreted highly different within the set of participants (depicted by large standard deviation within the data sets). It is observed that some participants need a long learning phase before they can use the input methods correctly and reliably. If comparing both interaction concepts with respect to learning, it can be seen, the learning effect is more noticeable for the gesture control (stronger shift of the Gaussian curve).



(a)

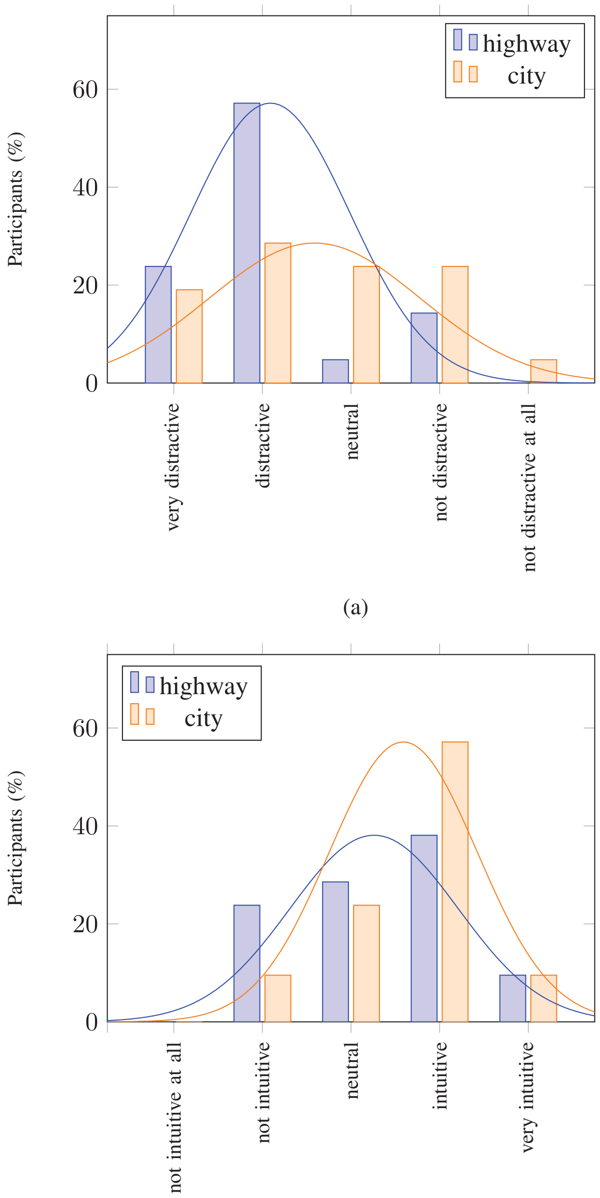


(b)

Fig. 4: Rating of cursor control (a) distraction (b) intuitiveness

B. Objective Measurements

The performance with respect to driving is evaluated according to lane deviation and speed profile. Fig. 6 depicts the average lane deviation during the interaction with the application, i.e. the interaction within the time period between the moment when the participants first recognized the possibility to activate an assistance system and the point in time when the ADAS was actually activated. It can be seen that the lane deviation improves a little with the assistance



(a)

(b)

Fig. 5: Rating of gesture control (a) distraction (b) intuitiveness

systems present. This effect can be interpreted due to learning since the baseline without assistance system is always the first of the driving scenarios. It is apparent from the figure, the average lane deviation does not change with the assistance systems. However, the deviation from the mean lane deviation is significant with respect to the significance level $\alpha = 10\%$ when the assistance systems are present (see fig. 7). This means that interaction with the application negatively influences the driving performance of the test participants. However due to the minor influence on the mean lane deviation, the decrease in the driving performance is still acceptable.

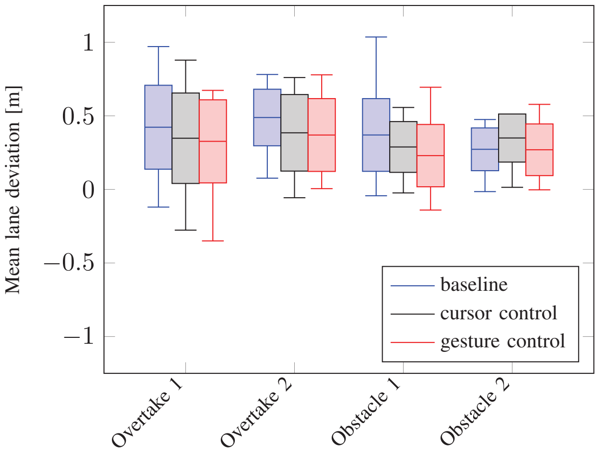


Fig. 6: Mean lane deviation

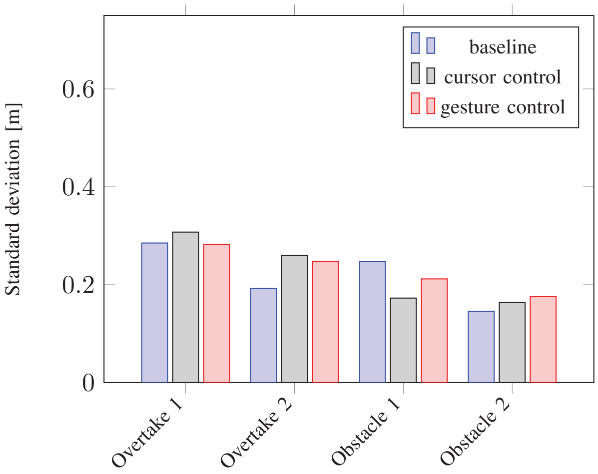


Fig. 7: Standard deviation of the mean lane deviation

The second driving parameter investigated is speed. Comparing the baseline data to the others, no significant difference with respect to the speed driven can be obtained. Fig. 8 shows the speed profile at an urban obstacles. Whereas the test car hardly decelerates with the active obstacle assistance (orange line), the car almost comes to a standstill with no assistance system (blue line). It is evident that with the active assistance system the exemplary test driver does not decelerate as much as with no assistance system. This shows the potential of such assistance systems in order to improve the traffic flow, especially in urban environments.

Fig. 9 illustrates the average interaction times which the participants need to activate the assistance systems. The objective measures confirm the subjective impressions of the test drivers: The different opinions of the participants when evaluating the interaction concept can be traced back to the large spread in interaction times within the set of participants.

The results show that the application as well as the different interaction schemes influence the driving behavior of the test

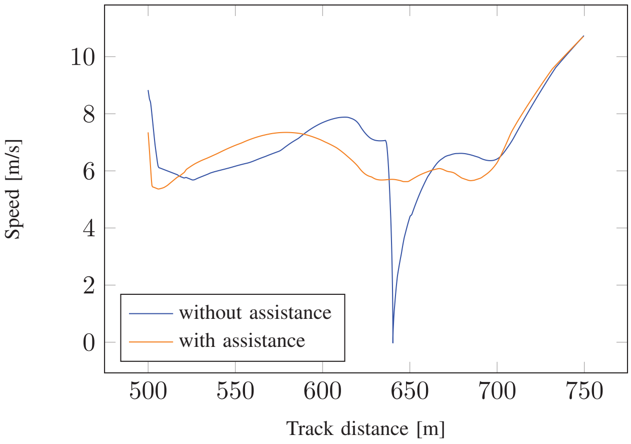


Fig. 8: Speed profile at urban obstacle

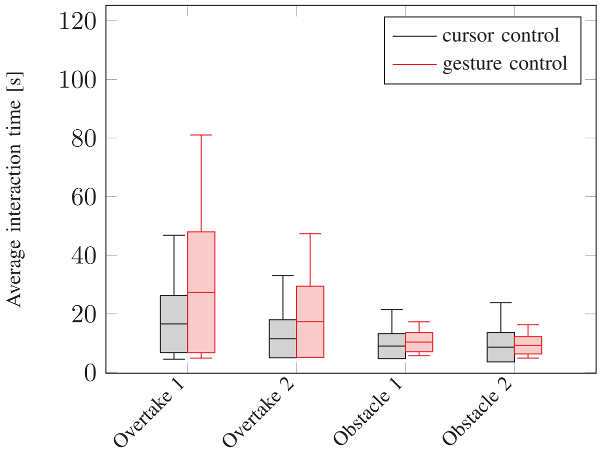


Fig. 9: Average interaction times

participants. In the context of interaction concepts, both control schemes show a long interaction time in the beginning of the test drives. However, this observation diminishes as the participants get used to the system. To summarize, no final recommendation for an interaction concept can be made. Whereas the objective data demonstrates the shortcomings of both interaction schemes, the test drivers cannot clearly decide for one of the interaction concepts to be superior. Similar results can be found for navigation systems whereas gesture control and direct touch are compared [15], [14].

VI. Conclusion

Two assistance systems including an HMI (AR glasses, gesture control vs. touchpad control) have been developed in order to investigate the interaction between automated and manually driven cars. These assistance systems, overtake assist and obstacle assist, receive information from automated cars, process them and transmit them to the driver. With the given information the driver decides in favour or against a cooperation. It could be proved that assistance systems prevent unnecessary stops. Thereby, the communication between manually driven and automated cars effect traffic flow positively. The drivers follow the instructions without being aware of the communication with automated cars. When looking at the driving data, the standard deviation of the mean lane deviation with active assistance systems reveals a significant negative influence on the driving performance related to the baseline. Since the mean lane deviation does not show a variability within the different test drives, the negative influence of assistance system on driving performance is still acceptable. In conclusion, an AR-application is not a sufficient condition for improving the communication to automated cars. Though it is helpful in displaying important information at the point of interest. Both interaction systems, gesture and multitouch controller, respectively, are perceived to be useful. This points at a solid implementation. Since the participants give the system a high rating on the trust scale, it indicates an intuitive and trustful AR-HMI. The results reveal the necessity of an adaption period in order to get used to gesture and touch control within the AR-application. Nevertheless the interaction systems are not regarded as an compensating, but complementary HMI.

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The project was independently funded by the Institute of Automotive Technology at the Technische Universität München. L. Gauerhof created the concepts for the ADAS und worked on the development and the evaluation. This article contains results of Masters theses from Alexander Kürzl that was supervized by L. Gauerhof. He implemented the ADAS and evaluated the results of the conducted user study. The authors would like to thank him for his contributions.

M.L. contributed essentially to the conception of the research project. He revised the manuscript critically for important intellectual content. M.L. gave final approval of the version to be published and agrees for all aspects of the work. As a guarantor he accepts responsibility for the overall integrity of the manuscript.

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