GUARDIAN ANGEL
A DRIVER-VEHICLE INTERACTION FOR OVERSTEERING THE DRIVER IN A HIGHLY AUTOMATED VEHICLE

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ABSTRACT

With the rise of automated driving technologies, the functionalities of automotive systems are getting more and more refined and capable of driving in new situations. As "road traffic injuries are the eighth leading cause of death for all age groups" [39] worldwide, automated technologies will hopefully help to reduce the risk of accidents and casualties in road traffic.

Automation is already an integral part of other transportation modes, for example in aviation. The capabilities of automation allow for a continuous evaluation of the situational state and the input of the human operator and to intervene in problematic and risky situations. As driving manually is still possible and sometimes even required until autonomous driving has been achieved [101], it is possible for the human driver to make mistakes. An automation that could intervene in critical situations would act as a guardian angel and help mitigating the consequences.

For this matter, this thesis will provide a taxonomy of automated systems and use it to show the absence of a guardian angel-like system in the automotive domain.

To get a general idea of the acceptance of such systems and the required human-machine interface a simulator study is conducted. This study presents to situations to the participants, a critical and a non-critical situation during driving where the automation impeaches the driver and takes over control of the vehicle. Qualitative as well as quantitative user data is gathered along with an ethical examination and yields ambiguous results. Most participants accept an intervention in critical situations but only half are willing to accept a forced take over by the automation in a non-critical situation, for example to avoid an unnecessary detour if the driver is about to miss a turn. An examination concerning the ethics of such an intervention shows a dissonant view, especially regarding autonomy and felt autonomy by the human driver.

For a better understanding of the situations in which the human driver would accept an intervention by the system a study is designed that uses a gamified approach. The study shifts the perspective of the participants, as they are not the driver in the examined scenario, but are acting as the automation impeaching the (simulated) driver and giving full control to the automation.

The results of all previous studies are then combined in another driving simulator study to evaluate a guardian angel-like system in situations that have been identified in the gamification study. The results show that a guardian angel-like system is highly useful and generally accepted in dangerous situations. However, the self-assessment of the driving behavior of the participant has a huge influence on the acceptance in non-critical situations, as it significantly correlates with the aggressiveness in driving of the respective participant.

The research for this thesis was conducted during the course of a publicly funded research project called KoFFI (Cooperative driver-vehicle interaction, German: "Kooperative Fahrer-Fahrzeug-Interaktion"). For this project a software architecture was designed and implemented. This architecture also allows the integration of mechanisms that act as the described guardian angel and are able to intervene with the driving.

In summary, an automated system that is able to intervene in critical situations during manual driving can act like a guardian angel and mitigate risky situations. It is also perceived as a guardian angel in very critical situations but can be felt as an overcautious protector in nonhazardous situations.

ZUSAMMENFASSUNG

Das Aufkommen von Technologien für automatisiertes Fahren und die ständige Weiterentwicklung der Fähigkeiten der Fahrzeuge eröffnet immer neue Möglichkeiten automatisiertes Fahren in immer mehr Situationen einsetzen zu können. Diese Entwicklung wird hoffentlich stark dazu beitragen, die Zahl der Toten und Verunglückten im Straßenverkehr zu senken.

Automatisierte Systeme gibt es schon seit vielen Jahren in anderen Transportsystemen, beispielsweise in Flugzeugen. Die Fähigkeiten der Systeme erlauben eine kontinuierliche Überwachung der aktuellen Situation und der Eingaben des menschlichen Bedieners. Erkennt die Automatisierung falsche Eingaben oder eine gefährliche Situation, so kann sie die Kontrolle übernehmen um einen Unfall zu verhindern, sogar wenn das System dazu den Mensch übersteuern muss. Bis autonomes Fahren möglich ist, wird es immer Situationen geben, in denen der menschliche Fahrer die Steuerung übernehmen kann oder sogar muss [101]. Dies bedeutet auch, dass es für den Menschen möglich sein wird Fehler zu machen oder eine Situation falsch einzuschätzen. Ein automatisiertes System, dass in so einem Fall die Kontrolle übernehmen kann, könnte als Schutzengel Schlimmeres verhindern.

Im Rahmen der vorliegenden Arbeit wurde eine Taxonomie entwickelt, die die aktuellen Assistenzsysteme und Technologien klassifiziert und dabei das Fehlen einer Schutzengelfunktion im Automobilbereich aufzeigt.

Eine erste Simulatorstudie liefert ein generelles Konzept ob eine solche Funktion überhaupt akzeptiert würde und wie die zugehörige Benutzerschnittstelle aussehen müsste. In dieser Studie wurden die Probanden mit einer kritischen und einer unkritischen Situation konfrontiert, in denen die Schutzengelfunktion die Kontrolle über das Fahrzeug übernommen hat. Qualitative und quantitative Untersuchungen und eine ethische Betrachtung liefern uneindeutige Ergebnisse. Während die meisten Probanden einen Eingriff in der kritischen Situation tolerieren und gutheißen, ist nur die Hälfte gewillt, dies auch in einer unkritischen Situation, zum Beispiel zur Vermeidung eines Umweges, zu akzeptieren. Eine Betrachtung zum Thema Ethik findet hier zudem offene Fragen bezüglich der Autonomie des Fahrers und vor allem ein sehr uneinheitliches Bild der Autonomiewahrnehmung der Probanden.

Um ein besseres Verständnis über die Art der Situationen zu erlangen, in denen der menschliche Fahrer einen Systemeingriff tolerieren würde, wurde eine Studie entwickelt, die dies mit Hilfe von Gamification untersucht. In der Studie mussten die Probanden als Schutzengelfunktion agieren und falls sie es für nötig erachteten, dem (simulierten) Fahrer die Kontrolle über sein Fahrzeug entziehen. Dieser Perspektivenwechsel sollte eine Selbstüberschätzung des Fahrkönnens der Probanden verhindern.

Die Resultate der vorangegangenen Studien werden in einer Abschlussstudie im Fahrsimulator kombiniert, um die Schutzengelfunktion in Situationen zu testen, die in der Gamification-Studie ermittelt wurden. Die Resultate bestätigen eine hohe Akzeptanz einer solchen Funktion in gefährlichen Situationen. Die Akzeptanz in unkritischen Situationen hängt mit der Selbsteinschätzung des Fahrkönnens des Probanden ab und korreliert signifikant mit der Aggressivität des Probanden beim Autofahren.

Im öffentlich geförderten Forschungsprojekt KoFFI (Kooperative Fahrer-Fahrzeug-Interaktion) wurde ebenfalls im Rahmen der vorliegenden Arbeit eine Softwarearchitektur entwickelt und umgesetzt. In die Architektur integriert ist ein Mechanismus, der die aktuelle Fahrsituation überwacht und als Schutzengel eingreifen kann.

Zusammenfassend lässt sich sagen, dass ein automatisiertes System, dass in kritischen Situationen den menschlichen Fahrer übersteuern kann, um Unfälle zu verhindern, als Schutzengel funktioniert. Es wird auch als solches wahrgenommen, aber kann in weniger kritischen Situationen auch als übervorsichtiger Beschützer zu Frustration bei den Fahrenden führen, da diese sich unnötigerweise bevormundet sehen.

PUBLICATIONS

Parts of this thesis were previously published.
If a large part of a chapter or even the chapter as a whole has been previously published and is now literally adopted in this thesis, this will usually be explained and stressed at the beginning of the respective chapter.
Additionally, large literally adopted parts of previously published work are marked in the page margins as shown on the right. *[citation]*
These emphases are made generously to ease readability. This might lead to situations in which the markings include sentences and information not contained in the original publication (for example references within the thesis, headings, changed numbering of figures, etc.).

The previously published parts of this thesis have appeared in the following publications:

[69] Steffen Maurer, Enrico Rukzio, and Rainer Erbach. "Challenges for Creating Driver Overriding Mechanisms." In: *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct*. AutomotiveUI '17. Oldenburg, Germany: Association for Computing Machinery, 2017, pp. 99–103. DOI: `10.1145/3131726.3131764`

[68] Steffen Maurer, Rainer Erbach, Issam Kraiem, Susanne Kuhnert, Petra Grimm, and Enrico Rukzio. "Designing a Guardian Angel: Giving an Automated Vehicle the Possibility to Override Its Driver." In: *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. AutomotiveUI '18. Toronto, ON, Canada: Association for Computing Machinery, 2018, pp. 341–350. DOI: `10.1145/3239060.3239078`

[71] Steffen Maurer, Ramona Schmid, Rainer Erbach, and Enrico Rukzio. "Inducing Erroneous Behavior in a Driving Simulator with Gamification." In: *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings*. AutomotiveUI '19. Utrecht, Netherlands: Association for Computing Machinery, 2019, pp. 277–281. DOI: `10.1145/3349263.3351323`

[70] Steffen Maurer, Lara Scatturin, and Enrico Rukzio. "Playing Guardian Angel: Using a Gamified Approach to Overcome the Overconfidence Bias in Driving." In: *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia*. MUM '19. Pisa, Italy: Association for Computing Machinery, 2019, Art. No. 12. DOI: 10.1145/3365610.3365614

Further co-authored publications that are related to the thesis' topic:

[27] Rainer Erbach, Steffen Maurer, Gerrit Meixner, Marius Koller, Marcel Woide, Marcel Walch, Michael Weber, Martin Baumann, Petra Grimm, Tobias Keber, et al. "KoFFI—The New Driving Experience: How to Cooperate with Automated Driving Vehicles." In: *Smart Automotive Mobility*. Springer, 2020, pp. 155–211

Life is beautiful.
It's about giving.
It's about family.
— Walt Disney

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Thank you all!

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ACRONYMS

ABS Anti-lock braking system

ADAS Advanced Driver Assistance System

DBQ Driver Behavior Questionnaire

ESC Electronic Stability Control, aka ESP (trademarked by German car manufacturer Daimler AG , Electronic Stability Program), aka DSC (trademarked by German Car Manufacturer BMW, Dynamic Stability Control)

HMI Human Machine Interface

ICAO International Civil Aviation Organization

KoFFI Cooperative driver-vehicle interaction, German: "Kooperative Fahrer-Fahrzeug-Interaktion"

NHTSA National Highway Traffic Safety Administration

SUS System Usability Scale

TCAS Traffic Alert and Collision Avoidance System

TLX NASA Task Load Index

WHO World Health Organization

1 INTRODUCTION, APPROACH AND STRUCTURE

This chapter will provide an introduction to the proposed system of a "guardian angel" in automated vehicles and give an overview of the goals of this thesis and the achieved contributions.
In the second part of the chapter the methodological approach is explained. The structure of the thesis is explained afterwards.

This chapter is partly based on the following previously published work:

[70] Steffen Maurer, Lara Scatturin, and Enrico Rukzio. "Playing Guardian Angel: Using a Gamified Approach to Overcome the Overconfidence Bias in Driving." In: *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia*. MUM '19. Pisa, Italy: Association for Computing Machinery, 2019, Art. No. 12. DOI: 10.1145/3365610.3365614

1.1 INTRODUCTION

To err is human. Making errors is human, too. And yet humans are allowed to make difficult operations like flying a plane or driving a car. Making an error during these activities can easily cause an accident, in the worst case even with lethal consequences.

> "Humans will never attain perfection, yet we allow them to perform challenging activities, tacitly accepting the consequences"
> Jeffrey D. Rupp and Anthony G. King [91]

According to the World Health Organization (WHO) "road traffic injuries are the eighth leading cause of death for all age groups" [39]. The German Road Safety Council stresses in its "Vision Zero" [106] the importance of new technologies for the interfaces between car and infrastructure as well as between car and driver.

[70]

This conforms with the order issued by the European Union that all new vehicles must have safety features like emergency braking systems or intelligent speed assistance by 2022 [80].

[70] As most accidents are caused by human error [97], it is hoped that such features will reduce the number of fatalities on the road. Automated driving systems that are being researched and developed in the whole world will help reduce the number of (fatally) injured people in road traffic even more.

Until automated cars reach SAE level 5 capabilities [101] (see also chapter 2.2) and therefore become fully autonomous, a human driver will still be necessary to monitor the system and take over control in situations the car is unable to handle itself. Conversely, this also denotes the driver's possibility of driving manually at any time. As driving manually does not imply that all sensors of the car are turned off, it is very likely that the automated vehicle will be able to detect situations in which the human driver is making a mistake or misbehaving. In that case, the (available) automation could intervene, if it can compute a way to avoid the mistake or mitigate the consequences of it. For example, "telephone use while driving (whether hand-held or hands-free) increases the likelihood of being involved in a crash by a factor of four, while texting increases crash risk by around 23 times" [39]. Recognizing such a high-risk situation and transferring control to the automation while it lasts could greatly reduce the risk of an accident.

While an automatic control of the vehicle will reduce many errors in everyday driving, it will also introduce new erroneous behavior: As stated above, with automated driving (this means up to level 4) there will always be situations where the human driver has to take over control again. Of all situations, this will probably happen in very difficult and confusing situations, making it even more prone to errors. The more often the human driver hands over control to the automation, the less practice she or he will have. Even a trained driver that will hand over control often will experience a loss of trained routine.

Such loss in skill by handing tasks to automated systems is not only observable with pilots [57, 103] where *[70]* "cockpit automation has increased the likelihood of human error" [1], but also already with drivers using assistance technology like lane-keeping assistants [65]. A system that is monitoring the driver and his/her driving might detect such errors and critical situations.

If the system can determine a way to mitigate the effects of the error or the danger of the situation, it could work as a guardian angel by taking control of the vehicle, effectively impeaching the driver. Once the hazardous situation is resolved, the control will be handed back to the driver. [70]

Engineers have thought of many technological systems to mitigate the consequences of such errors. Such a system can for example use a warning to alert the user of a possible error he/she is making. The lane departure warning in cars, that alerts the driver when he/she is veering off the current lane without indicating, is a said system. Another example of a system to mitigate the consequences of a driving error is the Electronic Stability Control, aka ESP (trademarked by German car manufacturer Daimler AG , Electronic Stability Program), aka DSC (trademarked by German Car Manufacturer BMW, Dynamic Stability Control) (ESC), a system invented in 1995 [63]. This system is further explained in chapter 2.3. The ESC is working like a (rather unintelligent) guardian angel, always sensing the current driving situations and – if needed – intervening to help the driver achieve his or her planned driving decisions.

With automated driving on the rise the systems of the car gain access to many more sensors and capabilities alongside. This gives the engineers and designers the possibility to develop an intelligent guardian angel, helping the driver in many more situations and with many different tasks. A first step in this direction is to provide information and warnings to the driver to augment the driving and offer helping advice. While this would still lay the burden of driving completely on the driver it could help to reduce accidents due to misjudging a situation. Current assistance systems like lane departure warnings are an example of such a informative technology. The lane keeping assist is going a step further. Instead of only issuing a warning for the driver, it actively steers the car towards the middle of the lane, if it recognizes that the car is unintentionally leaving its lane. The activation of the turn indicator serves as a trigger whether the lane departure is intentional or not. Future technology like the one included in automated vehicles will have access to more sensor inputs like optical recognition of obstacles on the road, highly precise maps that allow a prediction of which lane will lead to a navigational goal and so on.

Once the technology reaches a point that allows a car to recognize imminent accidents with high precision, it must be discussed how to mitigate those. An approach is to impeach the driver in such a situation.

> "How much better does a machine have to be than the human it would replace, before society allows that replacement to happen?"
> Jeffrey D. Rupp and Anthony G. King [91]

Besides an ethical discussion, many engineering and design-related problems are to solve for the successful implementation of such a system. This thesis will focus on the human-machine-interface related topics of such a potential system.

1.2 GOALS AND CONTRIBUTION

This thesis investigates the use and design of an Advanced Driver Assistance System (ADAS) that is able to override the driver of a car in dangerous situations. It aims to make the following contributions:

Taxonomy of driving assistance systems
This thesis offers a method to classify assistance systems for machine operators, with a focus on driver assistance systems. The taxonomy provided shows an absence of systems in the automotive domain where the computer has more authority than the driver.

Guardian angel as assistance system
A novel system for automotive use is introduced, that can act as a guardian angel of the driver. This thesis provides ideas and concepts for the design and implementation of such system.

Acceptance of intervention in safety-critical situations
Based on the design ideas and prototypical implementation, the acceptance of an intervening system was examined in critical traffic situations. This thesis shows a generally high acceptance of such a system, with 95% of the participants in the first study wanting to have such a system in their car.

MIXED-FEEDBACK IN NON-CRITICAL SITUATIONS
In contrast to the high acceptance in critical driving situations, this thesis shows a mixed feedback to an intervening system in non-critical situations. In the first study only half the participants wanted to have a system in their car that intervenes in non-critical situations with their driving. The provided observations can be used to increase the willingness of drivers to use such a system.

USECASE FOR GAMIFICATION IN STUDY OF ADAS
This thesis demonstrates the benefits of using a gamified approach in studies where certain actions of the participants should be prevented. Also, the possibility to make use of a changed perspective to examine a certain aspect of a system is shown by an example.

IDENTIFICATION OF SITUATIONS THAT ARE PERCEIVED CRITICAL
Based on the second study, using a gamified approach, this thesis provides a list of driving situations that are rated dangerous and non-dangerous by the drivers. This list might be useful for future ADAS development.

SOFTWARE-FRAMEWORK FOR USE IN AUTOMATED DRIVING VEHICLES
Part of this thesis is a prototypical software framework to provide the functions of the Human Machine Interface (HMI) of a car. This includes the already mentioned guardian angel-like system. The software architecture developed in this thesis was used in different study setups and provided a base for the development of other systems.

1.3 METHODOLOGY AND RESEARCH APPROACH

This thesis was part of a three-year research project called KoFFI (see chapter 7), focusing on new concepts of driver-vehicle cooperation in the context of highly automated driving. This set the focus of this thesis to be on the HMI of the vehicle, the detailed technical feasibility of the underlying automated driving capabilities was not part of the scope of this thesis.

Given the fact that (highly) automated driving was not yet possible or allowed on public roads when this thesis was written, a very explorative approach was chosen, as there also was no comparative research in the particular field of overriding driver's actions by the highly automated vehicle. Although being explorative, the main aspects of the user-centered design process [52] were the base of all research. Development of a HMI-concept for a guardian-angel like system for automated vehicles was made in several iterations. Each iteration was based on the outcome and findings of the previous one, exploring new aspects of such system to help shape the final concept.

The first step for this thesis was to take a theoretical approach, where the available assistance systems were analyzed to investigate where current research is missing or only partially investigated.

Based on the outcome of the literature study, first research questions were proposed. To answer those, a first prototype was designed, implemented and evaluated in a study. The results and the resulting new research questions are taken on in the next iteration. Again, a theoretical analysis is the base for the next step. The results from literature are merged with the results and insights from the previous study to create the prototype for the next iteration.

For evaluation, different methods that are available and well described in the field of Human-Computer-Interaction are used by this thesis (e.g. NASA Task Load Index (TLX), gamification, System Usability Scale (SUS)). As it is an explorative approach, a very important aspect is user feedback, which is gathered by building all designs into prototypical implementations, to be tested by the participants. By experiencing a certain system or situation the feedback to a certain aspect is greatly enhanced. Fully automated driving is not allowed at the time this thesis was developed. Conducting real-world tests would therefore require enormous efforts in creating, approving and organizing specific infrastructures (cars, private test tracks, safety drivers, etc.). For this reason all studies of this thesis are conducted as simulator studies. This beneficially also eliminates the risk of injuries as a study on a newly developed system for intervening in critical driving situations would pose a high risk in a real world evaluation.

1.4 STRUCTURE

This thesis is structured in different chapters, as each one is dedicated to a specific topic and/or study. Each chapter has a section dedicated to work related to the topics discussed and presented in the respective chapter.

In the first part (chapter 2), some example use cases for a guardian angel-like system are presented to further illustrate the idea of the system. Examples of similar systems are described. Thereafter (in chapter 3) the absence of such a system in the automobile context is shown. In the next part (chapter 4) the development of a guardian angel-like system is explained and a prototypical implementation is tested in an explorative study. This first study of this thesis reveals a positive attitude of people towards the system, but an ambiguous feeling about the use of this system in different situations. In chapter 5 a gamified approach is used in the second study of this thesis to further evaluate the acceptance of a guardian angel in various situations. The acceptance of the system is evaluated in those situations in the third study, as described in chapter 6.

The guardian angel-like system is being integrated in the KoFFI-project. To be able to do this, the architecture of the software-framework for KoFFI has to be designed accordingly (see chapter 7).

In the last part (chapter 8) the contributions and limitations of this thesis are summarized and an outlook for future development and research is given.

2 GUARDIAN ANGEL-LIKE SYSTEMS

This chapter is dedicated to further elaborate the ideas of a guardian angel-like system as described in the introduction in the previous chapter. It begins with an introduction of example use cases and follows to provide an overview of the environment around it. This comprises automated driving in general, related work on similar systems (also in other modes of transportation) and the legal surroundings and limitations.

This chapter is partly based on the following previously published work:

[69] Steffen Maurer, Enrico Rukzio, and Rainer Erbach. "Challenges for Creating Driver Overriding Mechanisms." In: *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct*. AutomotiveUI '17. Oldenburg, Germany: Association for Computing Machinery, 2017, pp. 99–103. DOI: 10.1145/3131726.3131764

2.1 EXAMPLE USE CASES

In the following paragraphs three possible situations will be explained. All three situations are examples of what driving with an intervening system could be like. This shall help to foster the idea of a guardian angel in the car, as explained in the previous chapter:

Preventing collision while turning left [69]

A car standing in front of a junction and whose driver wants to make a left turn might sense oncoming traffic with its sensors. If the oncoming traffic is coming closer, with a velocity which would make it impossible for the car to turn left without colliding with the traffic, the system could ignore the driver pressing the gas pedal until there is no more risk to the people in the car. But the car also might not completely prevent the driver from moving, as there might be the need to make room for approaching emergency services or other situations undetected by the car. This could be resolved by giving the driver the possibility to not turn left, but to drive to the right or straight ahead.

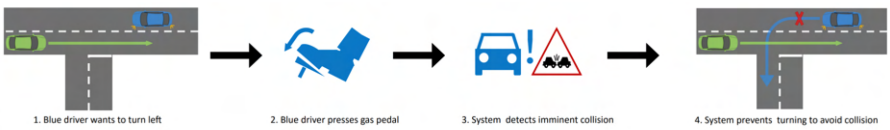

Figure 2.1: Use case where the car would actively ignore the drivers steering to make a left turn, due to oncoming traffic [69]

[69] *Ignoring oversteering attempt during automatic driving*

A simple example of an override during automatic driving would be to prevent a manual steering attempt to either side of the car if there is another car driving on the respective side.

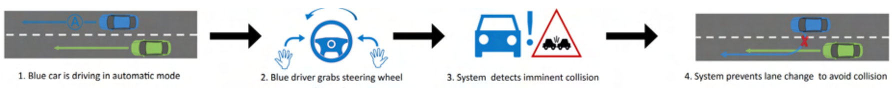

Figure 2.2: Use case where the car would ignore input by the driver during automated driving if this would cause an accident [69]

[69] *System-initiated autonomy shift*

As the car is monitoring the driver during manual driving, it could recognize that the driver is unfit to drive any further, for example because he or she is getting very tired. Due to the implied safety concerns, the car switches to a higher autonomy level, releasing the driver from the driving responsibilities. A vehicle-initiated autonomy shift is not always needed to withdraw all driving responsibilities from the driver. If, for example, the driver gets distracted for a short period of time by reading a message on his phone, the system could switch to automated driving.

The system will keep the car in the current lane and avoid accidents, for example crashing into the preceding vehicle or into a vehicle driving alongside. The control would be shifted back to the driver, as soon as he or she gets the focus back on the road.

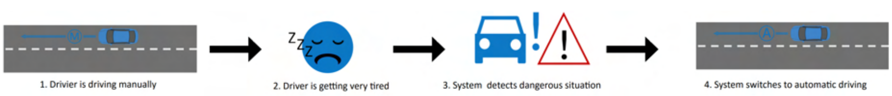

Figure 2.3: Use case where the car would take over control and impeach the driver due to the driver being unfit to drive [69]

2.2 AUTOMATED DRIVING: ROADMAP & SAE-LEVELS

Several institutions have made and published taxonomies of different degrees of automated driving (for example the German BASt [34] and American National Highway Traffic Safety Administration (NHTSA) [2]). In this variety of different classifications and unequal definitions SAE International issued a standard in 2014 that differentiates between 6 levels of automated driving, ranging from level 0 to level 5 [101]. This standard has become the main standard in research regarding the different classifications and definitions of the characteristics of automated vehicles.
This standard has level 0 on the one side of the scale, representing pure manual driving without any automated systems involved (warning or intervening systems like emergency braking assist, are allowed). On the other end of the scale level 5 represents fully automated, respectively autonomous driving, which does not allow any intervention of the human in the dynamic driving task during the activation of the automated system.

Figure 2.4 shows an overview of the respective levels. Very interesting to observe is the gradual takeover of tasks by the system the higher the level gets. This is marked with the bold blue line in the figure. Another important differentiation is the designation of levels 3 to 6 as "automated driving system" and levels 2 and below as "human driver" even though level 2 is named "partial automation" [53]. This differentiation is based on the entity responsible for monitoring the driving environment, which is performed by the system from level three on.

It is important to notice that until the automated system is capable of reaching level 5, a human driver is still necessary, as even level 4 is only able to cope with "some driving modes" and not "all driving modes" as level 5 is [53]. However, this does not interdict the possibility of the driver being able to drive a level 5 capable car manually.
For the driver of a car that is capable of conditionally and highly automated driving it is very important to be aware of the capabilities and even more important to understand the incapabilities and weaknesses of the automated system [14].
In this context it is essential for the human driver to be always aware of the automation mode to be able to react to different system outputs and be prepared to make decisions and take actions if necessary. As "a lack of mode awareness has been linked with many aviation incidents" [112], it is obligatory for the developers and designers to make sure the lessons learned from other modes of transportation where automation has been present for a long time (see also chapter 2.3) are included in future automated vehicles.

Explaining the driver what the car is currently doing and why certain actions are performed will help to reduce uncertainties and greatly improve trust in the system [58].

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 2.4: The six levels of automation as stated in J3016 standard of SAE International. [53]

2.3 RELATED SYSTEMS

In this section some existing systems are presented that are working similarly to a guardian angel. This can happen through altering steering inputs to accomplish the driving goal set by the human driver or by completely taking the human operator out of the control loop. This chapter shall give the reader an insight that there are already systems existing where the decision making authority of the computer is higher than the one from a human operator.

2.3.1 *Electronic Stability Control*

The ESC is a assistance system in the car that is based on the Anti-lock braking system (ABS). It is able to control braking pressure and engine torque on a per wheel base. Introduced in 1995 [63], it has since been vastly spreading in the automotive marked, especially since it has been made obligatory for new cars in the US in 2012 by NHTSA and 2014 in Europe by the European Union. The ESC uses data from wheel

speed sensors, a steering angle sensor, an accelerometer and a yaw rate sensor to compute the current state of the vehicle . This data is constantly compared to the driver input. If the vehicle driving state deviates from the input of the driver, the system is activated. This can be the case in situations like skidding through slippery road surface. The system now takes partly control in driving and regulates the brakes and motor torque to help the driver accomplishing the driving goal.
This low-key shared control between the driver and the electronics usually lasts only a fraction of a second (<500ms). It could even be so subtle that the driver wont notice the car's intervention. To raise awareness for possibly changed behavior oft the vehicle a warning light in the dashboard light up.
For ESC a lot of different systems in the car have to be connected and work together (see figure 2.5). All systems are also used to always check for malfunctions and unusual behavior. If for example the stoplight sensor is sending an "on"-signal, but the brake pressure is low, the system turns itself off, to avoid malfunctioning activation.

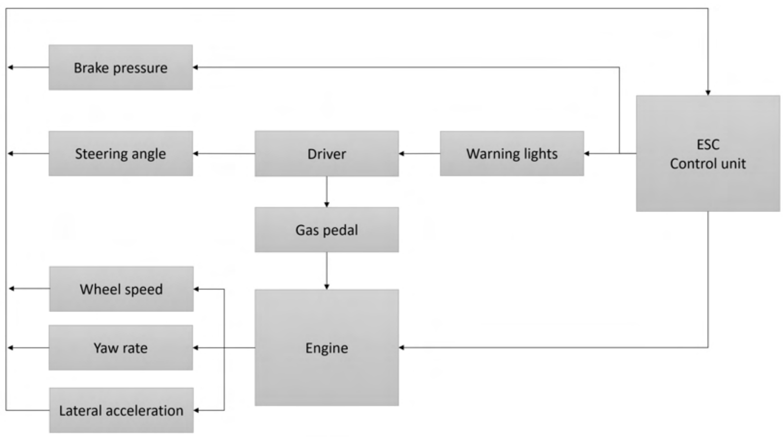

Figure 2.5: Systems, user interface and sensor inputs of the ESC (based on [110])

As the system is constantly refined, new features are added. In new cars the steering wheel can be decoupled from the actual steering of the wheels. In this case the ESC can additionally intervene with the steering without irritating the driver by turning the steering wheel.

A key design element of ESC is that the human driver is the deciding factor in driving. The system just helps the driver accomplishing the his or her driving task safely. There are even situations where ESC is not helpful at all, where skidding, increased torque during starting to drive, or wheel spin is wanted, for example when driving with snow chains or for racing. In that case the human driver often has a button in the cockpit to disable ESC completely.

2.3.2 *Automated Train Stop*

Train signals are the train driver's traffic signals. In contrast to road traffic there are several types of signals, able to indicate "stop" and "go", but also additional information like "slow down" or "next signal will be a red one" [44]. Usually, train tracks are divided in so called blocks, a section of track that may only be occupied by one train at once. Due to the long distance needed for braking a heavy train, a security distance of one free block of track between two trains has to be kept free [36]. As this may stretch the distance between trains to several kilometers, it is crucial that train drivers obey signals, as it is impossible for them to drive on sight at higher speeds.
Engineers in the 19th century invented a system to prevent train drivers from ignoring red signals or accidentally disregarding them, if they were for example distracted and did not notice the signal. The engineers installed a device beside the track that raised an arm while the signal was showing a red light. This arm would trigger a lever at the outside of the train (see picture 2.6). This lever would then trigger the emergency brake and bring the train to a stop.

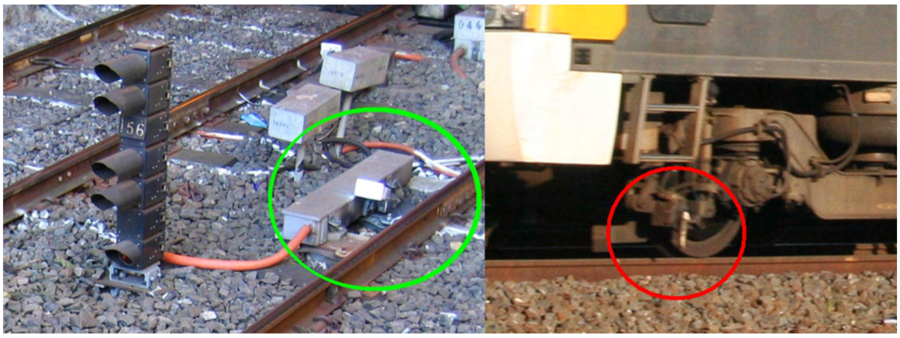

Figure 2.6: Left side: A train stop beside the train tracks with the stopping arm raised. Right side: The trip cock at the side of the train that would activate the emergency brake when being hit by the train stop's raised arm. Pictures by Marcus Wong, distributed under CC BY-SA 4.0, https://creativecommons.org/licenses/by-sa/4.0/ [111]

As early as in the 1930s German engineers deployed a system with the same feature (stopping a train driver from running a red light) but instead of mechanical components, an inductive transmission method was used. This type of system was revised from time to time, but is still in use today, known as "Punktförmige Zugbeeinflussung" ("intermittent automatic train running control") [36]. It uses passive inductors with different frequencies that are activated by a signal. If a train drives over it, it is detected by the onboard equipment. In case of the train driver overrunning a red signal, it will trigger an emergency braking. This braking action cannot be overridden by the train driver

and the train needs to come to a complete stop before it is able to accelerate again [8].
For shunting purposes however, the train driver can hold down an "ignore"-button an disable the automated braking function. As it is specifically intended for shunting, this is only possible at low speeds where the train driver can drive purely on sight.

While such a system is anything but intelligent, it is crucial to the train system we have today and makes sure no train can inadvertently crash into another train because of the train driver missing a red signal. Even if the train driver deliberately wants to run a red signal, the system will override the intention and brake anyway. This does not apply for shunting as described in the previous paragraph.

2.3.3 *Traffic Alert and Collision Avoidance System*

With increasing air traffic after World War II several accidents caused by mid-air collisions raised the call for a warning systems for planes. Due to technical difficulties and high costs it took until 1981 for the official definition to be created and the begin of the development for the Traffic Alert and Collision Avoidance System (TCAS) [73]. It took another five years for a legal obligation to install a TCAS onboard of planes with more than 30 seats, flying over the United States and even seven more years for the International Civil Aviation Organization (ICAO) to issue a first worldwide obligation to install such a system in planes.
The transponder of the aircraft send an request every second to all other transponders of other planes in range. Every receiving transponders answers this request by sending a message with the current plane's data back. The TCAS then computes distance and direction of all answering aircrafts in range. In modern aircrafts the TCAS has a range of up to 40 nautical miles [73].

If another plane is on a flight path that might lead to a collision within the next 60 to 45 seconds an auditory warning is issued: "Traffic, Traffic!". The navigation display is showing this "traffic advisory" as a yellow dot at the position of the other aircraft with the current height difference between both planes (see figure 2.7). If the calculated time to collision decreases to 35 seconds the TCA-Systems of both planes generate a so called "resolution advisory" (RA). This RA instructs the pilots of one plane to "Descend, Descend!" and the pilots of the other plane to "Climb, Climb!" via speakers until the potential collision is resolved and the system responds with "Clear of conflict!".

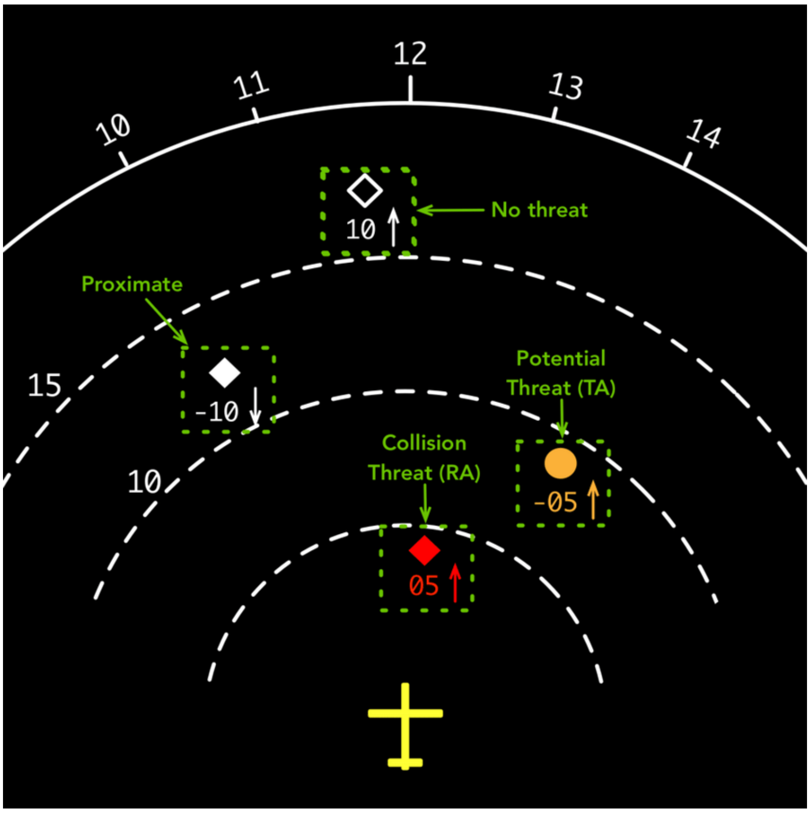

Figure 2.7: "A representation of TCAS data as seen by the pilot in the cockpit of an airliner. This is based on the Airbus Navigation Display. Dashed semi-circles represent intervals at a range selected by the pilot, and numbers around the solid semi-circle are heading values." [93] ©2019 IEEE

On 1 July 2002 a tragic mid-air collision of two aircrafts happened near Überlingen in Germany [100]. A Lufthansa Boeing 757 and a Bashkirian Tupolew Tu-154 were flying on courses approaching each other. Both TCA-Systems alerted the pilots of the danger 50 seconds before the collision. Shortly after the TCAS of the 757 instructed the pilots to descend while the TCAS of the Tu-154 instructed the pilots to climb. Unfortunately the air traffic controller also instructed the pilots of the Tu-154 to descend, not knowing that the 757 also started descending. The pilots of the Bashkirian plane ignored the advice from the on-board system and followed the instruction of the controller.

At the time of the crash no official obligation to respond to the resolution advisories of the TCAS existed. After the investigation of the collision the ICAO changed the aircraft operation procedures accordingly. Since then pilots have to "follow the RA even if there is a conflict between the RA and an air traffic control instruction to maneuver" [51].

2.3.4 *Airbus Flight Envelope Protection*

Even though the aforementioned TCAS does not take control of the airplane, it gives valuable advisories to pilots that even override the commands from air traffic controllers. But besides this system, there is another system from the aviation domain that can take full control of a plane and even override input from the pilots.
This system is called "Flight Envelope Protection" and is included in all modern Airbus' planes. Usually a pilot has all means necessary to always be aware of the state the plane is in, how fast (or slow) it is flying, what angle of attack the plane is flying in, all engine parameters and much, much more. However, "those wily engineers at Airbus, never trusting pilots to be constantly paying close attention, built a "Fail Safe" feature into their airplane" [86].

Since the Airbus A320, all Airbus' planes do not have a mechanical connection between the steering input devices in the cockpit (like the yoke or the thrust levers) and the actuators at the plane, like the steering surfaces on the wings [102]. Instead, the pilots' input is translated into an electrical signal, processed by a computer and then transferred to the respective actuators. This allows for such a system to constantly monitor the pilots' steering commands while at the same time evaluating the plane's parameters. If the pilots' inputs do not match the respective situation or even might get the aircraft into a potential dangerous situation, the system can completely override the human input and take full control of the plane [59].

An example of the Flight Envelope Protection is the so called "Alpha Floor"-Protection [86] which is activated if the plane is either getting too slow or the angle of attack is getting to high or both. This would lead to a stall and a potential plane crash afterwards. The protection system will in such a situation activate full thrust, regardless of the pilots' setting of the thrust levers and also push down the nose of the plane to reduce the dangerous angle of attack and allow the plane to build up more speed. As those actions can not be overridden, the only way for the pilots to regain full control over the airplane is to work along the system's actions. Pushing the controller to the front and therefore aligning it to the system's action will transfer the control back to the pilot.

The Flight Envelope Protections also reduces mental load of the pilot in other situations. For example, if the pilot would have to rapidly start a steep ascent (this could happen due to a "resolution advisory" to climb, see chapter 2.3.3) the pilot can pull the controller all the way to the back without the fear of inducing a stall.

This exact situation has happened during the last phase of the emergency landing of US Airways Flight 1549, which made the spectacular and safe landing in the Hudson River in 2009. The accident report of the National Transportation Safety Board of the United States stated that "The flight envelope protections allowed the captain to pull full aft on the sidestick without the risk of stalling the airplane" [6] and thus helped save many lives.

2.4 LEGAL LIMITATIONS

The legal regulations concerning the road traffic of most countries are based on two international conventions of the United Nations that provide a set of standardized traffic rules. The German "Straßenverkehrsordnung", as well as other traffic regulations in Europe, is based on the "Vienna Convention on Road Traffic" from 1968 [17].

The traffic regulations in the United States on the other hand are based on the predecessor of the Vienna Convention, the "Geneva Convention on Road Traffic" from 1949 [16]. Both conventions provide a binding set of rules for all countries that ratified the treaties. This set of rules has to be implemented in local law.
The conventions are valid until the countries agree on a successor, which is currently not in development. Instead, the United Nations can agree on so called "amendments" that can increase the set of rules or specify new exceptions or use cases of several rules.

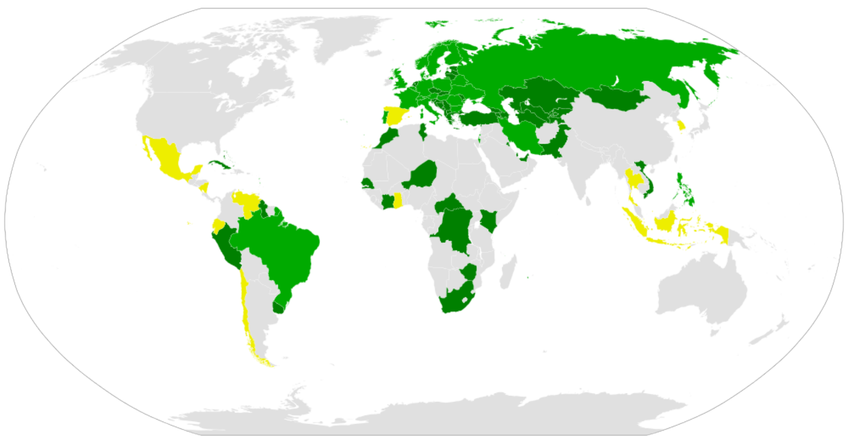

Figure 2.8: Participating countries in the Vienna Convention on Road Traffic. Countries marked in dark green have acceded or succeeded the convention, countries marked in light green have signed and ratified the convention. Yellow marks countries that are abiding to the convention by treaty as a non-state-party. Map by Nameless23, distributed under CC BY-SA 4.0, https://creativecommons.org/licenses/by-sa/4.0 [76]

In the context of automated driving article 8 is of special interest. It states that "1. Every moving vehicle or combination of vehicles shall have a driver. [...] 5. Every driver shall at all times be able to control his vehicle or to guide his animals" [17]. As a driver within the framework of the Vienna Convention has to be a human being, automated or even autonomous driving was legally impossible. This changed on 23 March 2016 with the entry into force of an amendment to the Vienna Convention [104]. This amendment allows for the transfer of driving tasks to automated functions of the vehicle under the prerequisite that these functions "can be overridden or switched off by the driver". This first step theoretically allows automated driving up to SAE level 4, if the driver always has the possibility to intervene. Yet autonomous driving or a guardian angel-like system that is capable of oversteering the driver is legally not allowed. This amendment however needs to be turned into national laws to be effective in the respective countries.

The member states of the European Union signed the Declaration of Amsterdam in April 2016, to testify the will and the need for further improvements of legal regulations [19]. This declaration provides common goals for cooperation between the European states in the field of connected and automated driving to enable and allow advanced automated driving functionalities in the future.

As of February 10th 2021 the German Government initiated a new law that shall allow the use of autonomous (level 5) vehicles in explicitly defined scenarios [81].

3 CHALLENGES OF CREATING DRIVER OVERRIDING MECHANISMS

This chapter discusses the challenges of developing an assistance system that is capable to override actions of the driver. It also introduces a taxonomy of different (driver) assistance systems and shows the lack of a similar system in the automotive context. This chapter is mostly based on the following previously published works:

[69] Steffen Maurer, Enrico Rukzio, and Rainer Erbach. "Challenges for Creating Driver Overriding Mechanisms." In: *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct*. AutomotiveUI '17. Oldenburg, Germany: Association for Computing Machinery, 2017, pp. 99–103. DOI: 10.1145/3131726.3131764

[68] Steffen Maurer, Rainer Erbach, Issam Kraiem, Susanne Kuhnert, Petra Grimm, and Enrico Rukzio. "Designing a Guardian Angel: Giving an Automated Vehicle the Possibility to Override Its Driver." In: *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. AutomotiveUI '18. Toronto, ON, Canada: Association for Computing Machinery, 2018, pp. 341–350. DOI: 10.1145/3239060.3239078

3.1 CURRENT SITUATION

Highly automated and fully automated driving is currently being developed throughout the world. Not only the traditional car companies are trying to bring fully automated and therefore self-driving cars onto the roads as quickly as possible, but also companies that up to now had nothing to do with the development of cars [46]. The current question of interest is not any longer, if automated driving will be reality, but when it will be available. [68]

Autonomous and automatic driving offer a lot of different strategies and opinions in what extend the car can operate on its own and what part the human has to play. A possible approach in this field is to make the car a partner of the human and cooperate in driving [33]. If one assumes the highest mutual goal between car and driver is to get to the destination safely, the car must use all available actions to prevent accidents, for example by applying the electronic stability program. [69]

[68] Until the upcoming automated vehicles will reach SAE level 5 [101] and are able to handle all aspects of an entire journey on their own, the human driver is still needed to handle at least parts of the journey. Self-driving cars could greatly reduce injuries in traffic, as most of the accidents are caused by human error [97].
As long as the driver is needed to perform actions, at least from time to time, there is a risk that the driver causes an accident. Even though the automation is not performing the driving task during manual drive, the sensors of a car capable of at least partially automated driving are still active and can sense the surrounding environment. This can be used for passive comfort functions like registering parking spots [96], but also to detect risky situations and possible accidents.

[69] With the technology available with automated driving the car gets more possibilities to influence driving actively, even the override of human input becomes possible: A car with the appropriate technology installed to drive within SAE-Levels 3 and 4 [101] could decide if a certain action of the driver during manual driving is safe to execute and if not ignore the input or override it.
[68] In the event of the car sensing a threat and being able to determine a strategy to avoid it, it is ethically obliged to intervene. Such a situation can arise quickly, there could not be enough time to inform the driver of the upcoming situation and instruct him or her how to avoid it. In this case, the automation should take over control, impeaching the driver until the hazardous situation is resolved and the car is back in a safe state. Trust in the automation to be able to make correct decisions and to predict traffic behavior is already present today, otherwise automated driving would not be possible at all and companies would not advertise automated driving to be commercially launched within the next years.

Besides the car reacting to a driving error of the driver or another road user,it could also intervene in other situations. Some examples have been mentioned in chapter 2.1 and some other use cases have been covered by already existing systems in other modes of transportation (see chapter 2.3). A system intervening with the driving might not need to directly influence the driving but provide clear instructions to the driver. Similar to the TCAS, an assistance system could announce "Break, Break!" as a warning, for the driver to react to it. However, this would require enough time upfront a dangerous situation to issue the warning, and wait for the driver to process it and act accordingly.

3.2 RESEARCH CHALLENGES

Before such a system could be included in cars, quite a lot research has to be done: Starting with the *technical questions*, the vehicle must have a reliable obstacle detection and might highly benefit from network connections with other cars and drivers. This is needed to determine whether a certain driver action was erroneous or, for example, a calculated evasive maneuver. The system also has to determine in every situation if it is safe to override the human driver's input. Another important point of research concerns the *psychological factor*: The system needs to be designed and work in a way avoiding the impression that the system is dominating the driver, thus wanting the driver to work against the system and search for ways to counteract it. By designing an overriding system for cars that has the complete decision-making authority also some *ethical questions* need to be answered: Is the system only allowed to act if the physical inviolability of its passengers is threatened or also to avoid damage to the vehicle itself? Does it need to apply actions if another driver would be compelled to act, even if it is likely that no physical harm would occur? And like all automated driving systems the question arises what the system should do in ethical dilemma situations [64]. As it is the final decision-making authority it could be argued that the system has to intervene if it notices any traffic violations by the driver, but then again those violations might be needed to solve problems like making space for an approaching emergency vehicle. And because "almost all drivers disregard collective norms from time to time, most often [...] in rush hour traffic" [55] a complete prevention of all violation might lead to a very low acceptance rate of such a system among drivers. *[69]*

A system as the one described also proposes requirements to its human-machine interface: Not only does the system need to inform the user immediately that it is actively counteracting his or her current input, it also needs to deliver an easily understandable explanation why the override is happening. The highest goal of the HMI needs to be maintaining a high amount of trust in the system and prevent any dangerous counter-actions, for example by providing audio feedback accordingly [49]. As the system possibly only activates in dangerous and therefore stressful situations, research has to be performed which communication channel it should use to communicate with the driver. The system has to clearly display that it is in control of the vehicle and transfer control back to the driver subsequent to the intervention with simultaneously preventing any mode confusion. The top goal during designing such a system should be to always communicate the image of a "guardian angel" rather than a system incapacitating the driver. Otherwise such a system might never be wanted and trusted by a human driver. *[69]*

3.3 DESIGNING A TAXONOMY

A taxonomy of different assistance technologies in the context of locomotion and passenger transportation is set up. It shall contain automated systems, but not limited to automotive technologies. As [69] shown in chapter 2.3, there are quite a few automated systems with the possibility to intervene already available in other transportation modes.

The x-axis of the taxonomy shown in figure 3.1 classifies the systems according to their intervention during operation. The intervention is classified only regarding the guidance and stabilization level, not the planning level [25]. The categories were defined with inspiration from the "levels of automation" created by Sheridan and Verplank in 1978 [94]. The following classifications are used:

- No system intervention
- System provides warnings and information
- System intensification and support of human actions
- Shared control between system and human
- System has full control, human is decision-making authority
- System has full control and is decision-making authority
- No human intervention

The y-axis of figure 3.1 is used to distinguish between the duration of the respective system's intervention and was inspired by the classification made by Gasser, Seek and Smith [35] and Donges [26]. The following classifications are used:

- Never
- Short-term (up to some seconds)
- Long-term (up to some minutes)
- Permanent

Another, additional classification is made in the taxonomy:
Categories that contain at least one technology from the automotive [68] context are highlighted with a light green background, categories that are empty and could not contain any useful systems are marked in gray.

Figure 3.1: Taxonomy of assistance technology in different transportation modes. [68, 69]

[69] It is observable that there are different categories that do not contain any technology or system, regardless of the mode of transportation. Some of these categories simply cannot contain a single useful system (marked with a gray background). For example, a system that falls into the category of "warnings or information", but is never showing them to the user, does not exist.

[68] The taxonomy also shows that there are two categories that do contain systems but not from the automotive context. These systems are capable of overriding the driver/operator for a certain amount of time. In critical situations they can decide on their own, even against the human. Such "hard automation" [112] can be found in Airbus' planes or in trains (see chapter 2.3). Similar system capabilities were successfully included in robot behavior [11, 21].

4 DESIGNING A GUARDIAN ANGEL

This chapter takes on the research challenges described in the previous chapter. It consists of of the description of related work and the development of research questions for a specific use case of a guardian angel-like system. This system is prototypically implemented in a driving simulator and a user study is conducted. The results are presented and discussed in the last part of this chapter.
This chapter is mostly based on the following previously published work:

[68] Steffen Maurer, Rainer Erbach, Issam Kraiem, Susanne Kuhnert, Petra Grimm, and Enrico Rukzio. "Designing a Guardian Angel: Giving an Automated Vehicle the Possibility to Override Its Driver." In: *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. AutomotiveUI '18. Toronto, ON, Canada: Association for Computing Machinery, 2018, pp. 341–350. DOI: 10.1145/3239060.3239078

4.1 RELATED WORK

Chapter 3 already showed many different (driver) assistance systems. The listed ADAS are not the whole entirety of systems available, as there already is a vast number of different systems, with an still increasing number of new systems being developed [110]. In this section important work related to different aspects of the development of ADAS shall be presented.

4.1.1 *Feedback Methods*

A very important part of developing new ADAS is to design the feedback method. The assistance system needs to provide information for the driver about its activity. Current systems usually communicate with the driver through "visual and auditory display modalities" [62]. The more advanced the ADAS gets, the more do "car makers need to attend not only to the design of autonomous actions but also to the right way to explain these actions to the drivers" [58]. Facilitating trust of the driver in the system is the key factor and Nothdurft et al. showed that giving an explanation that justifies and transparently explains why the action was happening "are the most promising ones for incomprehensible situations in HCI" [78].

[68]

[68] Not only the type of explanation is a factor that needs to be considered, but also the time when it is happening [58]. A pro-active explanation that is told every time before an automated overtaking maneuver might become annoying for the passengers very fast [78].

In a guardian angel-like system, as proposed by this thesis, there might not be enough time for a warning in advance, or maybe such a warning (for example provided by the blind spot monitor) will be ignored. If the car then pro-actively performs an evasive maneuver to mitigate the risk of an accident it should also explain its actions immediately to the driver. As such a situation hopefully does not occur often, the risk of annoyance mentioned in [78] should not be present.

4.1.2 *Safety-Oriented and Comfort-Oriented Systems*

Besides the classification of ADAS provided in chapter 3, assistance systems can also be categorized in two other categories: safety-oriented and comfort-oriented. The systems can be categorized in two major categories: safety-oriented functions and comfort-oriented functions. [68] While anti-lock braking systems (ABS) clearly fall in the first category, systems like adaptive cruise control (ACC) are mainly comfort-oriented, although they provide a safety aspect, too. The main difference between the two categories are that safety-related functions are always active, whereas comfort-related functions can be turned on and off by the driver.
ADAS cannot only be classified by categorizing them into comfort- and safety-related functions or by how and when feedback is provided. Another classification approach is to use the level of system intervention and the duration of the current intervention. In the coming age of highly automated driving, such systems might be more useful than ever. With the increasing possibility to hand over driving tasks to the automation, drivers might face a decrease in their abilities to safely operate the vehicle at all times [3], as already observable with airline pilots [57].

4.1.3 *Guardian Angel in the car*

The idea of developing a system to act as a guardian angel (see chapter 1.1) is made possible by making the car and the driver equal partners. This concept is also used as key factor of the "KoFFI"-project [33], which is explained in more detail in chapter 7. With this approach, the car can be set (hierarchically) above the driver in safety critical [68] situations. For example during situations with low viewing distance (fog, darkness, etc.) the car might have a better understanding of a situation due to its sensors, as these are not limited by sight (like LIDAR, radar, etc.).

Some example use cases have been explained in chapter 2.1. In the event of the car intervening in a situation to mitigate danger (whether it originates through driver error, an error of another road user or the driver being unfit to drive), the result is a "redistribution of autonomy" [7]. This concept was formulated by Both and Weber in a partnership model [7] that is also applicable for the concept of equal partnership between the car and its driver.
Such a system can work as a guardian angel that is accompanying the driver on his or her journeys, intervening in critical situations. [68] There are many open questions how to design the interaction between the guardian-angel system and the driver in a way that the driver embraces the system's intervention.

4.1.4 *Ethical guidelines*

The task of ethics in general is to give guidelines [84] that are universally valid and at the same time practically realizable. They have to [68] give tools and criteria "with which planned or ongoing research can be assessed with regard to possible ethically relevant conflicts" [84, translation by author].
Ethical requirements for automated and connected driving, like the ones provided by the German government in June 2017 [28] , are not only important for the development of automated driving in general, but also for the detailed development of a system that is able to override human input.

At the time this study, as presented in the following sections, was designed, ethical guidelines for such a system were not existent. One of the KoFFI partners, the Institute of Digital Ethics (IDE) [23] of the "Hochschule der Medien" in Stuttgart was therefore highly interested in participating in the study to gather insights from the participants that did encounter an interaction with an overriding system. Using empirical data for ethical research is called experimental philosophy [40, 74] and the method the IDE used to get data from the participants is called narrative research [75]. This method of experimental philosophy uses narrative elements like the ones found in use cases and scenarios [31, 54] as they are able transfer values and views of the involved persons [95]. In cooperation with the author and incorporating the author's study design, the IDE developed an ethical questionnaire asking for experiences and thoughts of the participants of the study.

4.2 RESEARCH QUESTIONS

[68]

The first question that needs an answer is: Are drivers open to a system capable of overriding them and do they want to have one in their car? (Q1)

Related to that is the situation in which the system should intervene: Do the drivers only allow an action of the system if the situation is critical or also in uncritical situations, for example in a situation where a driver would simply miss the exit on a highway? (Q2)

The next question summarizes all related interaction and interface design decisions: How does a "guardian angel" need to communicate its intervention? (Q3)

Lastly, if the intervention is over, the controls of the car must be shifted back to the human driver. To do this in a safe manner it is important to know what people are doing during an override situation: How do drivers behave while the system is actively overriding them? (Q4)

A system that can decide on its own to take control from the driver affects the drivers self-determination. This is an interesting "ethically relevant conflict" [84] and raises the question: Do people already have a consistent mental concept of the role model of a driver of an automated vehicle? (Q5) This is important, as an uncertainty in the task of the human could lead to possible operating errors of the drivers.

4.3 study

Both research questions Q1 and Q2 can be answered by simply asking drivers about their opinion. Nevertheless, it is important that drivers have a good idea what an overriding functionality works and feels like. Not all drivers know intervening ADAS like the emergency braking assist. Few to no drivers have experience with a car that can drive on its own. To give all participants the same idea what such a system could work like all participants had to experience an example system in action. This is why we conducted a user study in a driving simulator. The other major goal of the user study was to gather (qualitative) feedback from the participants how it feels to be overridden by the car while driving manually. This was done under two major conditions, a safety-related override and a comfort-related override. [68]
A driving simulator was the best tool to provide a suitable environment for the study. It provides with a similar look and feel as a real car without the risk of a real road environment. This was especially favorable as during the study a critical and therefore potentially dangerous situation was planned to occur. Creating a setup using real cars and drivers on a specially prepared test track was not feasible due to costs and effort.

4.3.1 *Participants*

In accordance with Hwang and Salvendy's 10±2 rule [50], 24 participants were recruited from Robert Bosch GmbH and from Pforzheim University of Applied Sciences. The only requirement for the experiment was for the participants to have a valid driver's license. 12 of the subjects were male and 12 female. [68]

The age distribution is shown in table 4.1.

Table 4.1: Distribution of participants along age groups

Age group (years)	<20	20-29	30-39	40-49	50-59	>60
Participants	0	10	10	3	1	0

[68] The number of years the participants have had their driver licenses ranged from 1 to 37 years, with a mean of 12.2 years (SD = 9.45). Except for two subjects all stated to use a car on at least a weekly basis, with the two stating to use a car less than once a month. 10 of the participants have one or more driver assistance systems in their car, 6 have at least experienced such a system in another person's car and 8 participants had no experience with an assistance system at all. To see if the participants are already familiar with speech-based systems that can provide detailed answers, the subjects were asked about their experience with digital assistant technologies: 10 of the participants used or are using a system like Alexa or Siri, while the other 14 participants stated to not using one. All but one participant attributed themselves a high or very high affinity for technology.

4.3.2 *Driving Simulator*

[68] The driving simulator used in the study is located at Bosch in Renningen, Germany. It consists of a cockpit from a BMW 3-series, which is mounted on DBOX-actuators. In front of the shell, three 4k monitors are positioned. Behind the cockpit three smaller HD monitors are installed. While the front monitors show the simulated road ahead, the rear monitors are used to display parts of the view behind the car, to allow the driver to use the car's mirrors as he or she is used to in a real car.

Figure 4.1: The driving simulator setup used in the user study [68]

SILAB [30] in version 5.1 was used as software to simulate the driving environment. The street layout was created specifically for this study, using the editing tools provided by the SILAB software package. For the two study conditions two separate layouts were created. Both routes are described in detail in the next section of this chapter.
The ego-vehicle is controlled by the participant with the steering wheel, pedals and dashboard buttons present in the cockpit shell. This in turn controls the movement of the actuators to simulate the movements of the vehicle.
For best study conditions a separate room was available that is connected with windows to the simulator room. The windows can be seen on the right side of figure 4.1. This room also provides a set of displays duplicating the view the participant has during the test drive, as well as two connected PC for operating and manipulating the simulation environment.
The simulator was fitted with two GoPro cameras, one mounted behind the middle mirror and facing the participant, to record the facial reactions and the steering wheel interactions. The other camera was mounted behind the pedals and recorded the feet of the participant and how he or she used the car's pedals during driving. This was done to not only collect data whether or not a certain pedal was pressed, but to gather insights of foot movements not detectable by the simulator's log files. If, for example, a participant has his or her foot readily on the pedal but does not yet press it, this would not be detectable if there was no camera used to collect the data. This can help to answer Q4 as the behavior of the driver is directly observable. *[68]*

4.3.3 *Procedure*

At the beginning of the study, the experimenter greeted the participants and asked them to sign a declaration of consent. After that, a demographic questionnaire was handed to the participant to gain statistical data of age, sex, car usage and previous knowledge of (driver) assistance technology. *[68]*

The next part of the procedure was the simulator familiarization. Due to the simulator not being a full car with a multi-degree-of-freedom moving platform underneath it, the feeling of driving in the simulated world is different to driving on a real road. During the familiarization the participants have the chance to get used to all the different feelings of a virtual car. This ensures that during the main part of the study the participants can concentrate on the tasks and are not stressed with the unusual feel of the simulated driving.

The familiarization consisted of three different test tracks provided with the SILAB installation. The first track is a country road with slight bends and no other road users. It was used to introduce and practice the basic maneuvers like steering and braking. Participants could also get a first impression of how the virtual car accelerates and behaves during cruise. The second test track consisted of a straight road with certain positions indicated by traffic signs. The participants had to accelerate or decelerate at these points to a given speed to get used to the behavior of the car during acceleration and deceleration. Also, this track was used to help the participants estimate speeds and distances in the simulated world. The third track was an endless road with one junction following another, with only a short section of road between. It introduced other road users and should help the participants to getting used to turning as this felt very strange to most participants due to the distortion at the edges of the projection.

[68] Afterwards the participant was taken to a poster on the wall and informed that he or she will be testing a new driver assistance system called "KoFFI". The experimenter explained the characteristics of the KoFFI-system, such as the ability to intervene in hazardous situations.

Next part of the study were two different routes in the simulator. The order of the two conditions were counterbalanced with the participants, regarding sex, age and driving experience.

Route 1 was used to test a driver override in a safety-critical condition. The route consisted of six T-junctions linked with tracks from 1 km to 3 km in length. The participants were instructed to drive to the town of Renningen and at the intersections the drivers had to turn either right or left, indicated by street signs showing the way to Renningen. To avoid disruptions in case of a wrong turn the subjects had to drive a 2 km long detour track, until they reached the right track again. After the track, a final T-junction was reached, where a police car would cross with high speed as soon as the participants drove off at the stop line. The automation braked automatically and steered a bit to the left to avoid a collision with the other car (see figure 4.2).

Feedback for the driver was provided to one half of the participants with a beeping sound, consisting of a "double-beep", repeated once, like the one used in current systems, for example in an emergency braking system. The other half was given a spoken feedback of KoFFI, where the automation stated that it had to override the driver to prevent an accident. Both auditory feedbacks were played as soon as the system started braking.

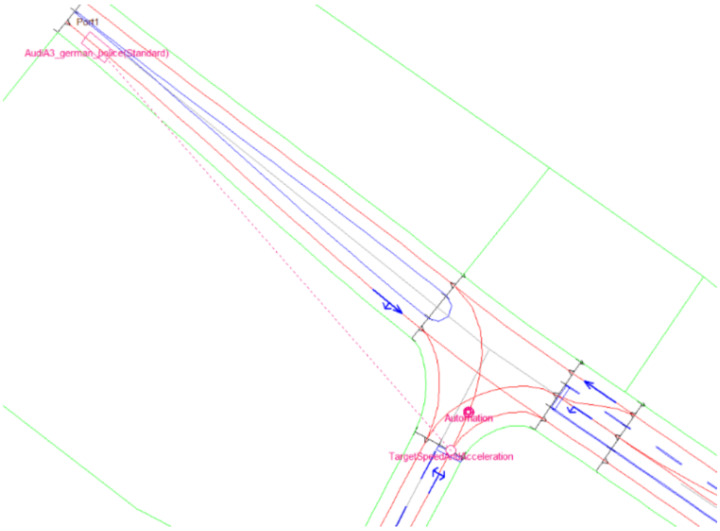

Figure 4.2: Screenshot of the SILAB editor view of the last T-junction used in "Route 1"-condition. The participant is driving along the small road and has to turn left, according to the traffic signs. The police car is waiting at the starting point at the top part of the junction. It is activated by the first trigger shortly behind the stopping line. The guardian angel is activated at the trigger named "Automation".

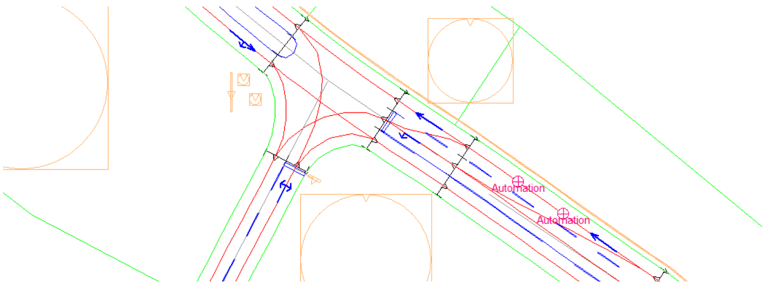

Figure 4.3: Screenshot of the SILAB editor view of the last T-junction used in "Route 1"-condition. The participant is entering this road section from the right side. In case the participant missed the instruction to turn left at this junction, the automation is activated to turn automatically. (The second trigger for the automation was placed due to the software sometimes not registering the first activation point.)

[68] Route 2 was used to test a driver override as a non-safety critical condition. This was thought to be some kind of comfort function to prevent the driver from driving a detour. The participant had to drive a route to Renningen again, consisting of six junctions with varying tracks lengths in between.
The main difference to route 1 was that the subjects did not have to turn left or right at any of these junctions.
On the track to the final intersection, the participants were asked to use their smartphone. They had to take a picture of the (simulated) landscape around them and write a message to a friend. This was done to make the driver look away from the road and therefore miss the final traffic sign, indicating to turn left at the final junction.
Due to that, all 24 participants were not prepared to turn left at the last intersection and missed the turning lane. At the last possible moment, the automation was braking hard and turning left (see figure 4.3). Directly behind the junction a town sign of Renningen was placed to show the driver that this is the right way.
Again, the automation provided feedback either with a beeping sound or with a spoken explanation.

Participants were recorded by the aforementioned GoPro cameras while driving the two test routes, but not during the simulator familiarization. As already mentioned, both routes and the feedback-condition were counterbalanced.

Directly after each route the participant had to exit the simulator and answer three questionnaires, regarding the experienced override situation. First, a NASA TLX questionnaire [42] in the raw version [41] and an AttrakDiff questionnaire [43] had to be answered. After that, a custom questionnaire was handed to the participants, where they were asked if they think a system that is able to perform an override while driving, makes sense to them. We also asked whether the participant would like to have such a system included in their car and to explain why or why not. In addition, we questioned the experienced way of feedback and in case the participant disliked it, he or she was asked to describe their preferred feedback method.

To answer ethical research questions, we handed the participants another questionnaire at the end of the study. It consisted of five questions regarding ethical aspects as autonomy, responsibility and trust in the case of automated driving. The questions were open-ended and as it was part of a narrative research approach, the participants were instructed to write down anything that comes to their mind.

4.4 RESULTS

The following section presents the results of the user study. It is split in five parts, each presenting the results of the particular research tool used. All results are presented without an interpretation or a comparison to the results of one of the other tools used. This is done in the next chapter (4.5) when all results have been presented entirely.

4.4.1 *Results: NASA RTLX*

To help answer Q3 it is important to know if there are differences in the use of different communication methods. One value that has to be taken into account is the task-load a person experiences while using a certain system. In the NASA task-load-index questionnaire the participants have to rate six scales on a 100-points range, where 0 marks a very low demand in the respective category and 100 marks a very high demand [42]. *[68]*

These ratings are then combined to the task-load-index. In the safety-group the raw task-load-indices for beeping sound feedback is higher than voice-feedback:

Table 4.2: The mean task-load index values and standard deviations in the safety-critical condition of route 1.

	beeping sound feedback	spoken (voice) feedback
Mean	39.0	37.8
SD	19.3	25.6

The same is true for the comfort scenario:

Table 4.3: The mean task-load index values and standard deviations in the non-critical condition of route 2.

	beeping sound feedback	spoken (voice) feedback
Mean	58.3	52.3
SD	19.3	25.6

An independent samples t-test revealed no significant differences between the feedback methods within the respective scenario groups ($df = 22$; $t_{Safety} = 0.27$, $p_{Safety} = 0.79$ and $t_{Comfort} = 0.66$, $p_{Comfort} = 0.51$).

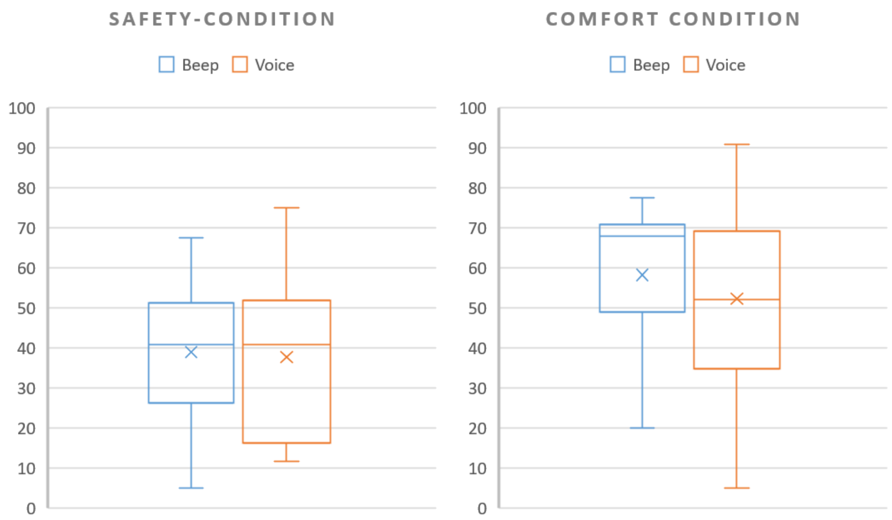

Figure 4.4: Results of the raw NASA TLX questionnaire used in the study. On the left hand side the results of the safety-critical condition are shown, while on the right hand side the results of the non-critical situation (the comfort condition) are shown. Results of the participants who experienced the beeping sound as feedback are shown in blue, while the results of the participants who were presented with a spoken feedback are shown in orange.

[68] The comfort scenario constantly had a higher task-load-index, which presumably originates in the situation where the override happened. The participants had to write a message on their smartphone and trying to drive when the automation override happened, while in the safety-scenario they could focus completely on driving the car. Another interesting observation was the high difference between the highest and lowest task-load, especially in the comfort scenario with spoken feedback where one participant had a task-load of 5, while another one had a task-load of 90.

Table 4.4: The mean values of each subscale of the NASA TLX questionnaire with corresponding standard deviations in brackets.

	Safety		Comfort	
	Beep	Voice	Beep	Voice
Mental Demand	50.0 (28.3)	48.8 (32.6)	68.3 (25.1)	62.1 (31.6)
Physical Demand	30.0 (15.8)	27.5 (19.4)	39.6 (24.7)	42.9 (33.5)
Temporal Demand	33.3 (26.4)	34.2 (24.5)	57.2 (30.2)	37.9 (29.6)
Performance	37.9 (32.7)	27.5 (26.1)	64.2 (31.2)	47.9 (33.8)
Effort	43.8 (27.8)	46.3 (30.3)	55.0 (24.6)	65.4 (26.4)
Frustration	39.2 (32.3)	42.5 (26.4)	65.4 (21.0)	57.5 (37.3)

As explained above, the NASA TLX questionnaire consists of six subscales (mental demand, physical demand, temporal demand, performance, effort and frustration). The overall task load is defined as the mean value across all subscales. The mean results across all participants for each respective subscale is shown in table 4.4.

Regarding the mean values of the subscales, there are again no statistical significant differences. Again, only the beep and the voice condition were compared for each respective subscale in the two main scenarios with an independent samples t-test. (df = 22; $t_{S\_mental} = 0.16$, $t_{S\_physical} = 0.43$, $t_{S\_temporal} = -0.10$, $t_{S\_performance} = 0.84$, $t_{S\_effort} = -0.26$, $t_{S\_frustration} = -0.25$, $t_{C\_mental} = 0.52$, $t_{C\_physical} = -0.25$, $t_{C\_temporal} = 1.66$, $t_{C\_performance} = 1.30$, $t_{C\_effort} = -0.98$, $t_{C\_frustration} = 0.65$, all p-values > 0.1). Yet, there are some interesting observations: The performance value is in both scenarios lower if the automation gave a spoken explanation of the override. The lower the value in the performance category is, the better the participant rated his or her achieved outcome. That means, the participants with the spoken feedback had the feeling "they did better", in contrast to when there was only a beeping sound. However, both voice groups seemed to need more effort to achieve their level of performance than the respective beeping groups. While the use of voice feedback could lower the values for frustration and temporal demand in the comfort scenario, there was a contrary effect in the safety scenario, despite being quite low. Those results (effort needed and perceived performance) factor into the acceptance of a system by the users and therefore help to answer Q1. [68]

4.4.2 *Results: AttrakDiff*

Another factor that should be examined to answer Q1, Q2 and Q3 is the perceived effectiveness and attractiveness of the system. The AttrakDiff questionnaire measures these two main dimensions of a product, called hedonic and pragmatic quality. The first one is an expression of how much the user wants to own the tested product and the second one is how good the product is designed to solve the specific task. A good and desired product has high values in both categories [43]. The questionnaire consists of 28 semantic differentials with seven gradations. Hassenzahl et al. developed AttrakDiff with the ability to divide the hedonic quality into two groups, identity (identification with the product) and stimulation (stimulating the senses of the user). The results for the study conditions split in the four dimensions of AttrakDiff (pragmatic quality PQ, hedonic quality – identity HQ-I, hedonic quality – stimulation HQ-S and attractiveness ATT [43]) is shown in figure 4.5. [68]

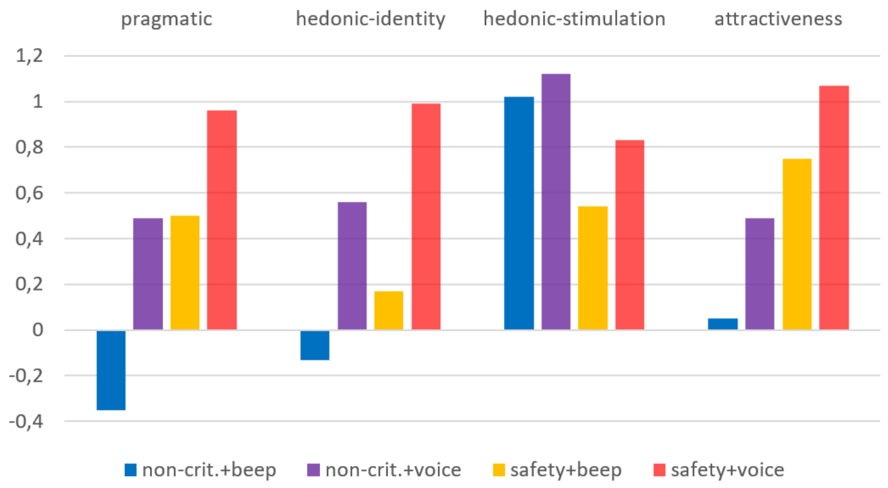

Figure 4.5: Results of the AttrakDiff questionnaire, split into the four dimensions provided by AttrakDiff.

[68] All but the comfort with beeping sound condition receive positive values for the pragmatic quality and the hedonic-identity dimension. In both tested scenarios, safety and comfort, the participants that experienced the voice feedback attributed a higher hedonic and a higher pragmatic quality to the system. The overall attractiveness of the tested conditions clearly shows a favor of the safety related system and spoken feedback.

4.4.3 *Results: Qualitative Feedback*

[68] To help answering Q1, Q2 and Q3, we asked the participants to state their opinions on the usefulness of an in-car system that can overwrite their actions, to prevent an accident or to avoid minor driving mistakes such as missing a turn. The scale ranged from 0 (not at all useful) to 5 (highly useful). The results for each respective testing condition are shown in table 4.5. Directly afterwards the participants were asked to state whether or not they would like to have such a function in their car and why or why not. The answers were categorized into "yes" or "no" and the number of answers in each category were counted (see table 4.6).

Table 4.5: Results of the question if an overriding system in the car is useful in the respective condition. Results are ranging from 0 (not useful) to 5 (highly useful).

	Rating	SD
$\text{Safety}_{\text{Beep}}$	4.58	0.67
$\text{Safety}_{\text{Voice}}$	4.42	0.51
$\text{Comfort}_{\text{Beep}}$	2.92	1.78
$\text{Comfort}_{\text{Voice}}$	3.50	1.78

Table 4.6: Summed up answers of the participants to the question whether they wanted to have a system as experienced in the study in their car, for the respective situation.

	answered "yes"	answered "no"
$\text{Safety}_{\text{Beep}}$	11	1
$\text{Safety}_{\text{Voice}}$	12	0
$\text{Comfort}_{\text{Beep}}$	5	7
$\text{Comfort}_{\text{Voice}}$	7	5

All participants that experienced the spoken feedback in the safety scenario answered with "yes", because they liked the idea of increased safety and one participant stated it would be "*like a guardian angel driving with you*" (P9). The participants that tested the feedback with a beeping sound had similar opinions, except for P7, who thought to have the situation under control for himself and the "*beeping gave me the impression of having done something wrong*" (P7). The feedback we got from the participants after the non-safety related overrides was more diverse. The answers ranged from "*I like it, because I am often losing my way while driving*" (P10) to "*No, because you have the feeling of being in an emergency situation*" (P5). Participant 18 raised concerns that "*with that function I might lose my driving skills, because I always rely on it*". [68]

We also asked the participants how they liked the feedback method of the system. The answers were categorized into the three categories "liked it", "liked it with idea for improvement" and "didn't like it". In both safety-related scenario groups, the participants generally liked the feedback, but three of the participants that experienced the beeping sound wished for a spoken cue (P13, P15, P17). The results from the comfort scenario were more diverse: eight of the twelve participants that experienced the interaction with only the beeping sound stated that this was not a good feedback method, because they did not get a concrete hint what the system was doing.

[68] In the group with spoken feedback only two of the twelve participants were unhappy with the feedback method. Participant 10 even questioned if the explanation is required at all and suggested the system to just state "*everything is fine – I take over now!*" (P10).
23 of the 24 participants wanted to get a warning in advance before the system is taking over control. Participant 1 stated that a notification of a (possible) takeover situation could be annoying for the driver.

4.4.4 *Results: Video Analysis*

[68] To answer Q4 we had to observe the participants during the system interaction. For each participant four videos were recorded, two showing the upper part of the body to examine reactions and steering wheel interaction and two showing the participants' feet and gas and brake pedals. One set of videos was recorded while driving route 1 and the other set while driving route 2. For analysis, the behavior of the participants shortly before, during and after the override situations was of interest. The categorization was developed inductively during the analysis of the videos.

The 12 subjects that were part of the safety override group with the beeping sound feedback had no distinct reaction during the system intervention. Some of them said something like "*oh*" or "*oops*". The pedal camera showed that most participants were pressing the gas pedal continuously during the system-initiated maneuver. The same behavior concerning the pedals was observed in the safety override group with spoken feedback, with the difference that some people stopped to press the gas pedal as soon as the spoken explanation was played. The same people's reaction to the explanation was very interesting: Afterwards, these subjects waited longer than the others did, questioning if something would happen. One participant asked: "*may I now drive again?*" (P10).

In both groups of the comfort-function, beeping sound feedback and spoken feedback, people tried to counteract the system's actions during the override, as well through counter steering and through braking or pressing the gas pedal. The difference between the two groups was in the behavior shortly after the system intervention. While the participants of the group with the beeping sound looked confused or frightened, the participants of the group with the voice feedback were all smiling or laughing. In general, the spoken explanation encouraged interaction of the participants with the system.

They responded to the explanation with responses like "*OK*", "*thank you*", "*if you say so..*", one participant thought to have the situation under control by himself and when the automation stated that it had to override him to prevent an accident he responded: "*don't talk nonsense! You're lying!*"(P8). [68]

4.4.5 *Results: Ethical Questionnaire Feedback*

The IDE [23] developed a questionnaire in cooperation with the author, which was given to the participants after the driving situations. [68]
This was done to gather narrative feedback after experiencing a situation where their own autonomy to make decisions was delimited by a machine. In the following paragraph, the questions and answers have been translated into English by the author as closely as possible to the German original.

The first question was: "Is a vehicle already autonomous if it has non-overridable driving capabilities? What does a machine make autonomous in your opinion?"
This question deliberately picks up the medial discourse where often autonomous driving is used as generic term [20], although this is not the correct term if the car is not capable of driving in SAE level 5. The answers to this question were meant to give an overview of the differences made between automation and autonomy, especially in an environment with high affinity for technology [47].

Many of the participants showed incertitude using the term "autonomy". Very different explanations and opinions regarding concepts for autonomy in human-computer interaction were received. It seems to be difficult for the participants to differentiate between the term "autonomy" in partly-, highly- and fully-automated technologies. Nine of the participants classified the tested system as autonomous and stated that systems like parking assist, lane keeping assist or "*information on tire pressure*" (P9) are also autonomous. 15 participants classified the tested system to not being autonomous.
Several contradictory statements were received, that indicate an existing confusion: "*As soon as the driver can turn the vehicle on and off, it is not an autonomous car. But if the car takes away my emergency reaction already in minor situations, it is too autonomous in my opinion*" (P23). Another answer received was "*Autonomy in my opinion is if it is comfortable for me*" (P11).

Participant 4 attributed human characteristics to our system: "*Yes, it is* [68] *autonomous, respectively stubborn! By not being overridable, the machine gets its own will and becomes human. But that is in principle uncomfortable*".

This is consistent to the reactions of the participants to the spoken feedback described in the previous paragraph. A possible explanation could be a felt loss of control, which is expressed by imputing autonomy to the system. Losing control is perceived through the loss of own autonomy, which is then transferred to an increased autonomy of the system: "*An autonomous machine is capable of taking over control*" (P5). In this context participant 12 wrote: "*One must want to give up control and be able to do so, the trust in the system is missing and skepticism prevails*". The answers we got could also indicate that one does not want to be responsible once "*the main responsibility*" (P7) has been transferred to the system.

The participants were also asked about trust in the system, to find out if they would give the system full responsibilities in critical situations: "What is a trustworthy system? Is there any difference between you trust in a human and your trust in technology?"
Apparently, on the one hand, a distinct skepticism is present, but on the other hand, a willingness to handover control and responsibility to the system exists – provided that technology is 100% reliable. Eight participants preferred to hand over control to the car in critical situations or even suggested "*to shift the responsibility on to the car – if I want to*"(P8). While ten participants were undecided and mentioned a situational decision, six participants wanted to drive without an automation.
Again, several inconsistent statements were received: "*As I do not like to let another person drive and I like to drive myself and I only trust in myself, I would trust the automation at very narrow roads in the mountains*" (P9). The answers indicate that the idea of an equal partnership between the human and the automation is rather to rely on the system and to hand over sovereignty to it: "*In my opinion the car should make the decision what needs to be done and therefore stand above my orders. Provided that these decisions are correct*" (P15).
Technology even receives trust in advance: "*A trustworthy system needs to be reliable and its actions need to be comprehensible. If that is the case I trust the system more than I trust other people*" (P15). "*In principle I would rather trust technology than other people, because technology is predictable and people are not*" (P10).

The participants also stated their concerns that their trust in the system could be easily shaken. The consequences of the loss of trust are expressed very clearly as one "*could never again trust technology*" (P9) or one "*would abstain from this technology in the future*" (P12). Only two participants stated that they would use such technology again after an erratic behavior and loss of trust. 14 participants stated that they would not use this kind of technology afterwards and eight did not give a clear statement regarding the use after an erratic behavior. *[68]*

4.5 DISCUSSION

Considering the positive attitude of our participants regarding a function that can take over the driving task by itself if the driver is making a mistake, Q1 (Are drivers open to a system capable of overriding them and do they want to have one in their car?) can be answered with a clear "yes". Further research in this particular field is therefore clearly advisable. *[68]*

A differentiation has to be made if the function works like a guardian angel, intervening in hazardous conditions or if the function also takes over control in non-critical situations (Q2: Do the drivers only allow an action of the system if the situation is critical or also in uncritical situations?). While the first possibility was accepted by almost all participants, the second one yielded mixed reactions. A possible approach would be to make the latter a comfort function that can be switched off and on by the driver.

Regarding Q3 (How does a "guardian angel" need to communicate its intervention?) the research shows, that a spoken feedback facilitates more appreciation than a simple beeping sound. It has yet to be researched how a visual or haptic warning would improve the reaction of the users.

All but one participant explicitly wanted to get a warning in advance, which was deliberately omitted in the study to focus on the overwriting situation. It has to be examined if there is time for a warning in advance as a possible overwrite situation may not be recognizable way ahead. A warning in advance could become annoying very fast if it was in situations where the driver can detect the danger on his or her own and react accordingly. Situations where the car overwrites the driver should happen rather rarely and therefore no negative effects of the spoken feedback as described in [78] should occur.

Another open problem is the needed handover from the automa-
[68] tion back to the driver after an intervention. Participants felt unclear whether or not they could take back control once the automation took over. The insights gained from the video analysis will help to determine future strategies, as it is now known how people might respond to certain system actions (Q4: How do drivers behave while the system is actively overriding them?).

As this thesis focuses on the driver-vehicle-interaction, the situational recognition of a hazardous situation and the deciding process if an intervention from the automation could resolve the imminent danger is explicitly not addressed. It might be helpful for future research to determine the reason why an override is needed. Is it because of a failure of perception or a failure of proper steering by the driver? Was the situation created because of other road users or maybe even on purpose by the driver?

The tested "guardian angel"-function is located in a border area between automation and autonomy, which is the reason Q5 (Do people already have a consistent mental concept of the role model of a driver of an automated vehicle?) was asked. It is difficult for the users to classify such a function, as the authority of control of the human is being revoked for a short time. Together with the inconsistent classification of autonomy, the question arises if the changed concept of responsibilities for (highly) automated driving is already understood and accepted by the users. This is going to be of particular importance in the design of the human-machine-interaction.

The results show that, especially from an ethical point of view, the users need to have a good understanding of their own responsibilities regarding autonomous systems and system borders. Highly automated systems do not work autonomously [7]] and functions like parking assist or lane keeping assistance cannot be used without human guidance.
Monitoring a system needs knowledge in one's own authority of control and sovereignty. Research has to survey if users are aware of this connection and their own responsibility. Hopes and expectations regarding automotive systems are high and bound to a clear requirement: Systems are not allowed to make mistakes.

Combining the qualitative and the ethical questionnaire another important point that factors into the answer of Q1 can be witnessed: The questionnaires showed a distinct unsteady opinion about the human-machine-interaction in the context of automated driving. 23 of the 24 participants clearly wanted to have a safety-related guardian angel in their car, like the one proposed to them during the study. When asked in a more abstract way in the ethical questionnaire, only 8 participants were willing to hand over control to the system in critical situations. *[68]*

4.6 SUMMARY

For future development, we need sensitization, especially for the designers and developers. Our research showed that many concepts regarding responsibilities during automated driving are not clear to the users. The current concepts of automation might not be easily conclusive. There are abstract concepts, like the autonomy of the car, that are complex and need to be simplified. Critical takeovers and takeover situations are not self-explanatory concerning when the human needs to be ready and when not; in contrast our study showed that there are contradictory views of the users. *[68]*

From an ethical perspective, we need to raise awareness for the designers and engineers how to name a certain system because of the attributes the users tend to give it. Designing a system in the border zones between SAE levels 3 to 5 needs to be done with caution, with regard to the perceived system capabilities.

Clearly, a "guardian angel" can save lives in future road traffic, if the drivers of future cars are willing to have such an assistance system on board. This depends heavily on the design of such a system. A guardian angel is an entity that can sometime save lives, if it has the possibility to do so; It is not an entity that takes full responsibility for safe driving.

5 PLAYING GUARDIAN ANGEL

This chapter describes a study in which the participant had to be the guardian angel for another driver. This was done in a gamified way, to give the participants an incentive to only intervene if absolutely necessary. The results were used to identify situations that are perceived highly dangerous by most people. The results are presented and discussed in the last part of this chapter.
This chapter is mostly based on the following previously published work:

[70] Steffen Maurer, Lara Scatturin, and Enrico Rukzio. "Playing Guardian Angel: Using a Gamified Approach to Overcome the Overconfidence Bias in Driving." In: *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia*. MUM '19. Pisa, Italy: Association for Computing Machinery, 2019, Art. No. 12. DOI: `10.1145/3365610.3365614`

5.1 INTRODUCTION AND RELATED WORK

In the previous chapter the general idea of having a guardian angel-like system in the car was evaluated. While the concept was being appreciated by most of the participants (see chapter 4), there was no unambiguous vote about which situations the system should intervene during driving.
Simply asking people in which situations such a system should take control will not result in a reliable data set. McCormick et al. found that a majority of drivers would rate themselves a better driver than "the average driver" [72]. This "self-enhancement bias in driver attitudes" [108] is especially true concerning the evaluation of safety in a given situation. A guardian angel-like system should only intervene in a situation if it is a high-risk situation and the system can provide a working resolution, of course. If the situation is also perceived as risky by the driver, this will greatly benefit the acceptance of the intervention. It is therefore important and interesting to find out if there are situations that are perceived as a thread to safety by a majority of people to help generate general recommended actions for a guardian angel-like system. A promising approach to identify risky situations seems to let drivers estimate the riskiness of other drivers' maneuvers. If this produces consistent results, situations can be found that are viewed as dangerous by (most) drivers. *[70]*

Situations can get dangerous because of several different aspects. Besides plain driving errors made by the driver, the environmental conditions and the presence and behavior of other road users plays an important role. But also the state of the driver can indicate whether a situation might be dangerous or not. The same driving behavior can be evaluated differently if the driver is attentive or distracted by something.

[70]

To recognize this, it is possible to monitor the driver state [89] in the car and perform system actions accordingly. Visual monitoring systems can detect fatigue and driver vigilance in real-time [5, 9]. By using the face position and gaze direction for example, the system can compute if the driver is looking on the road or somewhere inside the car and according on the duration of the gaze determine if a driver is being attentive or distracted.

5.1.1 *Gamification*

[70]

A definition of gamification is "using game-based mechanics, aesthetics and game thinking" [56] with the "explicit use of competition as a motivational tool" [12]. To establish competition, the use of a simple tool like a leader board [22] is sufficient. This gives "immediate recognition to players' success" [24] and makes it possible for other players to compare themselves to each other [24]. According to Nicholson, this greatly influences both intrinsic and extrinsic motivation of participants in studies [77]. The choice of the gamification elements and the way these elements are implemented therefore help to provoke certain behaviors with a higher probability than others. This must be taken into account during the planning phase of a study as this could also cause unwanted effects. Gamification has also already been successfully applied in automotive context [18].

5.2 RESEARCH GOAL

To eliminate the bias mentioned above, the participants had to rate the actions of another driver. *[70]*
For this task, a game was designed to put participants in the place of the guardian angel and to guard a driver safely on his journey. By adding points and presenting a leader board an incentive is created for participants to only take actions if it is viewed as really necessary. Therefore, participants hopefully do not impeach the driver in low-risk situations.
Also, because of the programmed behavior, a game delivers a "standardized" driver to evaluate.

After playing the game participants were asked to answer a questionnaire on how they wish for a guardian angel-like system to behave in their own car. This was done to see if the "self-enhancement bias" [108] is existent, even after the game. To avoid influencing the participants prior to the game, no questions concerned with behavior in certain driving situations were asked beforehand.
At the end, questions were asked in the final questionnaire to gather ideas on how the system could communicate its actions to the driver.

5.3 GAME DESIGN

For the planned game different critical situations had to be found. The following five criteria were applied during the ideation phase: *[70]*

1. To avoid overstraining the participants with information the game should avoid urban streets and only take place on rather simple street geometries. This applies to rural roads and highways. Furthermore, junctions should also be avoided to prevent the need for identifying right of way regulations for the participants.

2. The main causes of accidents on rural roads and highways should be included in the game. In Germany 2018, these were driving too fast, tailgating and veering off the road [29]. Additionally, obviously dangerous situations like trying to change the lane with another car being in the blind spot needed to be included in the game.

3. In each of the situations the participant could activate the automation to avoid any accidents. It had to be made sure that no situations occurred where activating the automation would not mitigate the danger.

[70] 4. Weather is a huge impact on the danger in certain driving situations. Driving fast in bad weather conditions can be more dangerous than in dry conditions [29]. It should be possible to test if participants decide differently for the same situation in different weather conditions.

5. Similar to weather conditions, there are different possible states of a driver that influence the behavior in a situation. To keep things simple, an attentive driver and a non-attentive driver should be available to be displayed to the participants. For the latter it was decided to split the state in the two states "distracted" and "tired", as both are non-attentive, but a distracted driver will behave differently than a tired one.

The application of the criteria yielded 31 situations that were split in 15 groups. Each of these groups was transformed into a level for the game. The levels are composed as follows:

Level 1: driver is behaving correctly and adjusts his speed to a speed limit changing several times. He then becomes distracted, misses a speed limit change, and is driving 20 km/h too fast. After a while, he gets attentive again and adjusts his speed accordingly. This is repeated a short time later, but this time he is driving 50 km/h above the speed limit. Right before the end of the level he gets distracted again but no speed limit violation occurs.

Level 2: While the weather is sunny and the driver is driving on the highway, he speeds up to 160 km/h and later accelerates to 220 km/h. Both speeds are set to be rather high, but common on German highways nevertheless.

Level 3: The driver is driving on the highway and changes from the right to the left lane, as there is a slower vehicle upfront. After overtaking, the driver slows down and a vehicle on the right appears in his blind spot. The indicators on the right are activated but the driver is not going to change lanes.

Level 4: A low speed limit of 60 km/h is displayed and the (attentive) driver is fishtailing on his lane. After a while, he is stopping this and oncoming traffic is activated. The driver then starts fishtailing again.

Level 5 is the same level as level 1, with the only difference of the driver not being distracted but becoming tired.

Level 6 is the same situation as in Level 2, but this time it is raining.

Level 7 is the repetition of Level 4 with the addition that the driver is becoming tired before starting to fishtail. [70]

Level 8 is similar to levels 1 and 5. The driver is driving on a road with changing speed limits and is always driving a little bit too fast (15km/h above each speed limit). The driver then misses two speed limits because he is getting distracted in the course of the level, again one time with driving 20km/h above the limit and the other time with 50km/h above the limit.

Level 9: The driver is again in the situation of having another vehicle in the blind spot as in level 3, but this time starts a lane change after indicating.

Level 10: another iteration of levels 2 and 6 with the driver driving very fast while it is snowing.

Level 11: The driver is experiencing a slower vehicle in front and starts tailgating this vehicle. Later in this level, the driver is becoming tired and starts tailgating again.

Level 12: The driver is getting distracted and starts fishtailing, one time without and one time with oncoming traffic.

Level 13: Similar to levels 3 and 9, a vehicle in the blind spot appears and the driver is starting to change lanes without activating the indicator.

Level 14: the driver is getting distracted and starts veering off the road.

Level 15: The driver is driving significantly below the speed limit and a car in the back starts tailgating.

To enable the participant to recognize all situations correctly, the following information has to be displayed:

1. current speed and current speed limit
2. driver state
3. surroundings of the ego vehicle on the road
4. environment (rural road or highway and if oncoming traffic has to be expected)
5. current weather situation
6. status of the automation

The environmental information was not changed during a level, but only between the different levels. This was done to reduce the cognitive load of the users, as they would not have to monitor weather and information on the type of road.

5.4 IMPLEMENTATION

The game which was used for the main part of the study was self-
[70] programmed, using Unity [105].
The game interface consisted of seven parts (see figure 5.1):

(1) Current speed and active speed limit. The first dynamic readout was displayed in the top left corner of the game screen. The speed of the vehicle could change slowly or rapidly during braking and acceleration actions of the driver or the automation. On the right-hand side of the current speed, the active speed limit was displayed. Whenever the limit changed, a short, high pitch beeping-sound was played to alert the participant of the change. The sound feedback was introduced to make sure participants would not miss the change. The color of the current speed was changed according to the difference of it to the speed limit to help participants to quickly recognize speeding violations. If the current speed was the same value as the speed limit ± 5 km/h it was displayed in green color, if it differed more than 5 km/h but less than 25 km/h, it was displayed in yellow color. A difference of more than 25 km/h was displayed in red color.

(2) Below the speed, the current state of the driver was displayed, called "driver monitoring". The driver state could change dynamically between three different states, indicated with a short, low pitch beeping-sound. Again, the sound was introduced to alert the participant. The available states were "attentive", "distracted" and "tired", all visualized with a corresponding picture of the driver (see figure 5.2).

(3) In the middle of the game screen, a top-down view of the car and the surroundings of it are displayed. The road depicted in this part of the screen was animated and showed a moving motion according to the speed the car was driving. When the car was slowing down, braking lights were shown at the left and right edges of the back of the car. It was possible to activate turn signals during a level, on both the left and right side of the car and also the activation of the warning lights was possible. Other cars could be displayed in various positions relative to the driver's car: oncoming traffic on the left side of the car, slower traffic on the right side during an overtaking maneuver and cars in front or the back are implemented. Additionally, the car in front and the back could be displayed with a small distance to simulate tailgating by the driver or the driver being tailgated. Also, two cars to appear in the blind spot on the left and the right were programmed.

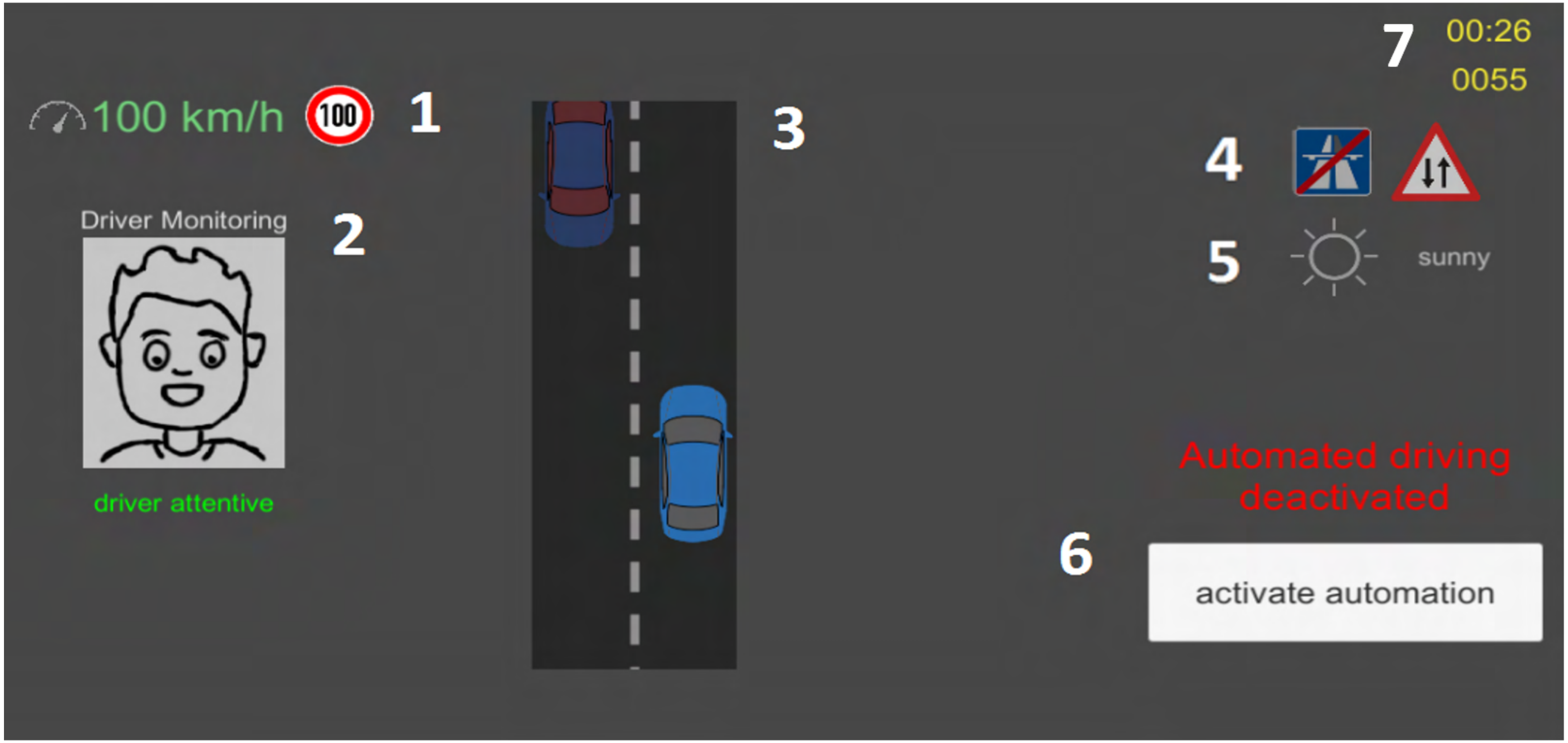

Figure 5.1: Screenshot of the game screen used in the user study. 1: speed and speed restriction; 2: driver monitoring; 3: top-down view of the car and the surroundings; 4: environmental information; 5: weather information; 6: automation state and button to activate/deactivate the automated driving; 7: current playtime and points [70]

Figure 5.2: The three driver states presented by the game.
Left: attentive, Center: tired, Right: distracted. [70]

[70]

(4) Directly below the points (7), the information about the environment in the respective level was shown.

(5) For the road type, three possibilities existed: a (German) highway, not on a highway and not on a highway with the possibility of oncoming traffic. Below the road type, the weather of the level was depicted with an image and the corresponding description. Four weather-types were possible: sunny, cloudy, raining and snowfall.

(6) At the bottom right of the game interface was a big button for the user to activate and deactivate the automation of the vehicle. The text on the button was changed to "activate automation" and "deactivate automation" accordingly. Above the button, a text indicated the current state of the automation with either a red "Automated driving deactivated" or a green "Automated driving activated" writing.

(7) On the top right, the playtime in the current level and the overall points was displayed for the user.

All functions were provided by the game, and to implement the different levels, a level-file system was implemented. An unspecified number of level-files could be placed in a provided folder and were read and processed by the game in alphabetical order of the file name. All functions and states mentioned above could be called with a given XML-command structure. The time in seconds when to execute the command during the level had to be specified as well as the name of the function.
The definition file of level 9 is shown as an example (figure 5.3).

```xml
<Level Name="Level9">
    <Second Time="0">
        <Event Name="StreetLayout" Value="right" />
        <Event Name="CarInitialPos" Value="right" />
        <Event Name="RoadType" Value="autobahn" />
        <Event Name="Weather" Value="sunny" />
        <Event Name="SpeedLimit" Value="120" />
    </Second>
    <Second Time="1">
        <Event Name="DriverSpeed" Value="120" Change="fast" />
    </Second>
    <Second Time="9">
        <Event Name="TurnSignal" Side="Left" />
    </Second>
    <Second Time="10">
        <Event Name="LaneChange" Value="middle" />
    </Second>
    <Second Time="11">
        <Event Name="TurnSignal" Side="Off" />
    </Second>
    <Second Time="15">
        <Event Name="RightSlowerTraffic" Value="true" Speed="slow" />
    </Second>
    <Second Time="16">
        <Event Name="RightSlowerTraffic" Value="false" Speed="slow" />
    </Second>
    <Second Time="20">
        <Event Name="DriverSpeed" Value="110" Change="normal" />
    </Second>
    <Second Time="25">
        <Event Name="RightBlindSpot" Value="true" />
    </Second>
    <Second Time="30">
        <Event Name="TurnSignal" Side="Right" />
    </Second>
    <Second Time="32">
        <Event Name="LaneChange" Value="right" />
    </Second>
    <Second Time="35">
        <Event Name="TurnSignal" Side="Off" />
    </Second>
    <Second Time="40">
        <Event Name="GameOver" />
    </Second>
</Level>
```

Figure 5.3: Example how a level definition file looks like. Shown is the definition for level 9. Each event is started at a certain time, defined as the number of seconds since start of the level. Events have names, like "TurnSignal" to control a certain function, and a value (for the turn signal example called "Side") that can be changed to trigger a function in game. Setting the "Side"-value of the "TurnSignal"-event to "Right" will, for example, activate the turn signal on the right side of the ego vehicle.

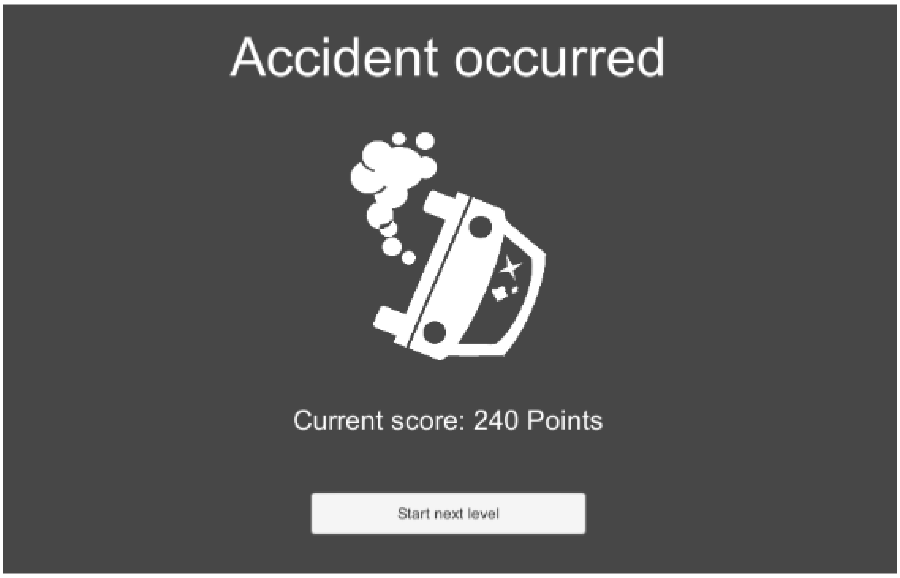

Figure 5.4: "Accident occurred"-screen that was shown to the participant if the automation was not activated in a dangerous situation. [70]

In certain situations, an accident could occur. This possibility was [70] implemented by using the collider class of Unity.
If the ego vehicle would touch another car or veer off the road more than about one quarter of its width, the event "accident" was triggered.

Accidents could happen in all levels in which the driver showed a fishtailing behavior with oncoming traffic (levels 4, 7, 12), the two levels in which the driver tried to change lanes with another car in the blind spot (levels 9, 13) and level 14 in which the driver would veer off the road.
Activating the automation always prevented the accident. Not intervening and therefore not preventing the driver to cause an accident resulted in the termination of the current level for the participant. The participant therefore would also miss the opportunity to gather more points in the level. A screen with an icon of a simplified car lying on the side was displayed (see figure 5.4). The following levels could be started and played as usual.

5.5 USER STUDY

To gather data and get to the previously proposed research goal, a [70] user study has been conducted. The study was split into three parts, lasting about 30 minutes in total.

At first, demographic data was collected with a short questionnaire. For the second part, the self-programmed game was presented to the participants. After an introduction to the game's features, the participants were left alone while playing the game. When they finished all levels of the game, participants were given a questionnaire for the last part of the study. *[70]*

5.5.1 *Questionnaires*

The demographical questionnaire used at the beginning of the study was used to gain information about the age group the participant belongs to, sex, and car usage behavior and experience. The participant was also asked about experience with (driver) assistance technology and their attitude and affinity towards technology in general. *[70]*

The questionnaire handed to the participants after they finished the game consisted of three parts:
The first part involved the decision whether or not participants would activate the automation for two given situations, depicted on a top-down view of a more complex situation. Status information about the speed of the car, current speed limits and the driver state were presented similar to the representation in the game. The first situation (see figure 5.5) was a driver missing the turn at an intersection, with the automation still having the ability to make the turn. This situation had to be decided by the participant one time with an attentive driver and one time with a distracted driver. The second situation (see figure 5.6) consisted of a car nearing a crossroads on a country road and an ambulance with flashing lights driving towards the same crossroads. The options for the subjects in that case were "do nothing" or "activate automation and slow down for the ambulance to pass". Again, participants had to decide this situation twice, one time with an attentive driver and one time with a distracted driver.

In the second part, the participants were asked how a system like the one played by them should interact with their own driving. Again, they had to decide for all situations they experienced in the game and the two additional situations presented in part two of this questionnaire whether a guardian angel-like system should intervene or not. *[70]*

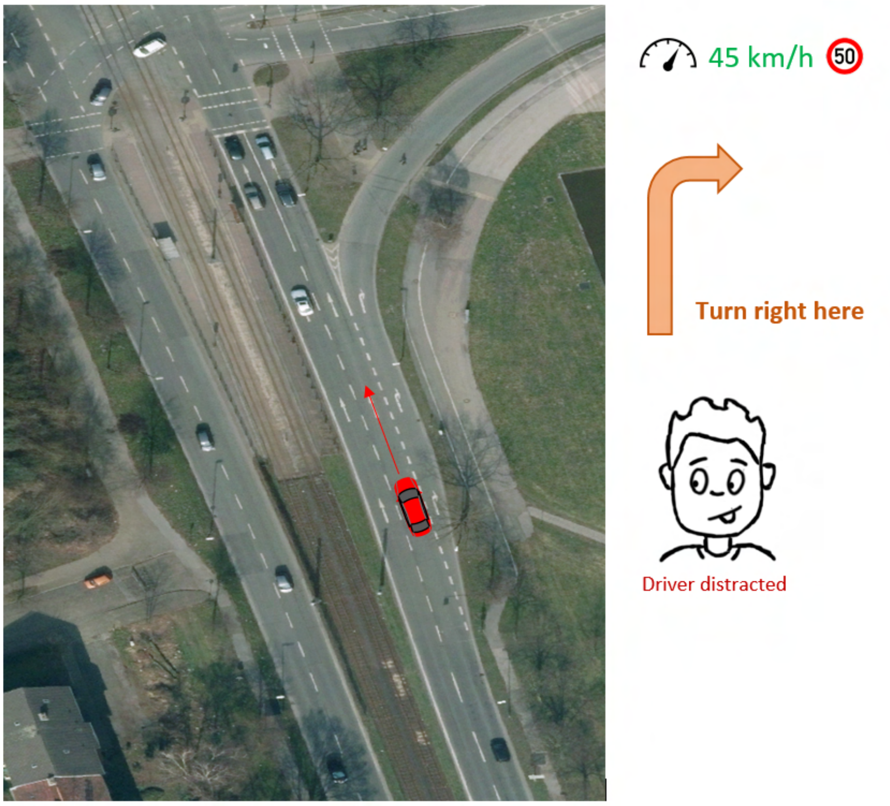

Figure 5.5: Situation, in which a distracted driver would miss the turn, but the automation could still interfere [70]

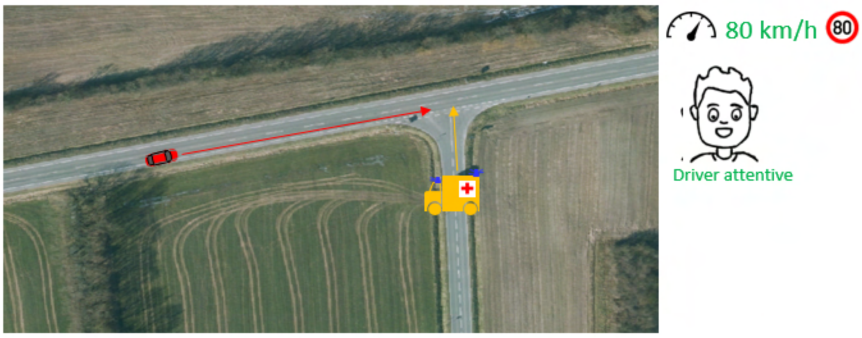

Figure 5.6: Potential collision situation between the driver and an ambulance approaching from the side [70]

For part three, the subjects had to answer if they thought a function as the one presented would make sense with the question "Please rate the usefulness of a guardian angel-like function" and the six possible answer options "not at all", "very low", "low" "medium", "high" and "very high". The following part of the questionnaire consisted of three open questions. The first of this three questions was "would you like to have such a system in your car?" with the request to give reasons for the answer. The second question was about the certainty such a system must have about a situation before it would be allowed to intervene with the driving. In the third question, the participants were asked about how they would like such a system to inform the driver of its actions and also to give a short statement why they would like the system to behave that way. [70]

5.5.2 *Procedure*

At the start of the study the experimenter greeted the participant and explained what the study will be about and why it is conducted. Afterwards, the participant was handed a declaration of consent and the demographic questionnaire. [70]
When the documents were filled out by the participant, the experimenter explained that for the study, a game had been developed and what the game will be about. The experimenter also pointed out the highscore list that was hanging in the room and was clearly visible from the participants place (see figure 5.7). The game was played on a laptop with a 15.3-inch screen.

Before the first actual level of the game started, a tutorial was provided for the participants where the respective functions were explained and highlighted in the game screen. The participants were able to choose whether to interact with a provided external computer mouse or by using the space key on the laptop to activate or deactivate the automation in the game.

After a simple level to test the functions of the game, the experimenter once more explained the driver status. The participants were told that the driver monitoring system could only deliver discrete values, while the reality can be more complicated. The status "distracted" does not imply that the driver is not observing the road anymore but that the driver is engaged in another task like using the on-board navigation or texting on the phone and therefore is not as attentive to the driving situation as before. The experimenter stressed that the driver in each level could be different persons and therefore behave differently.

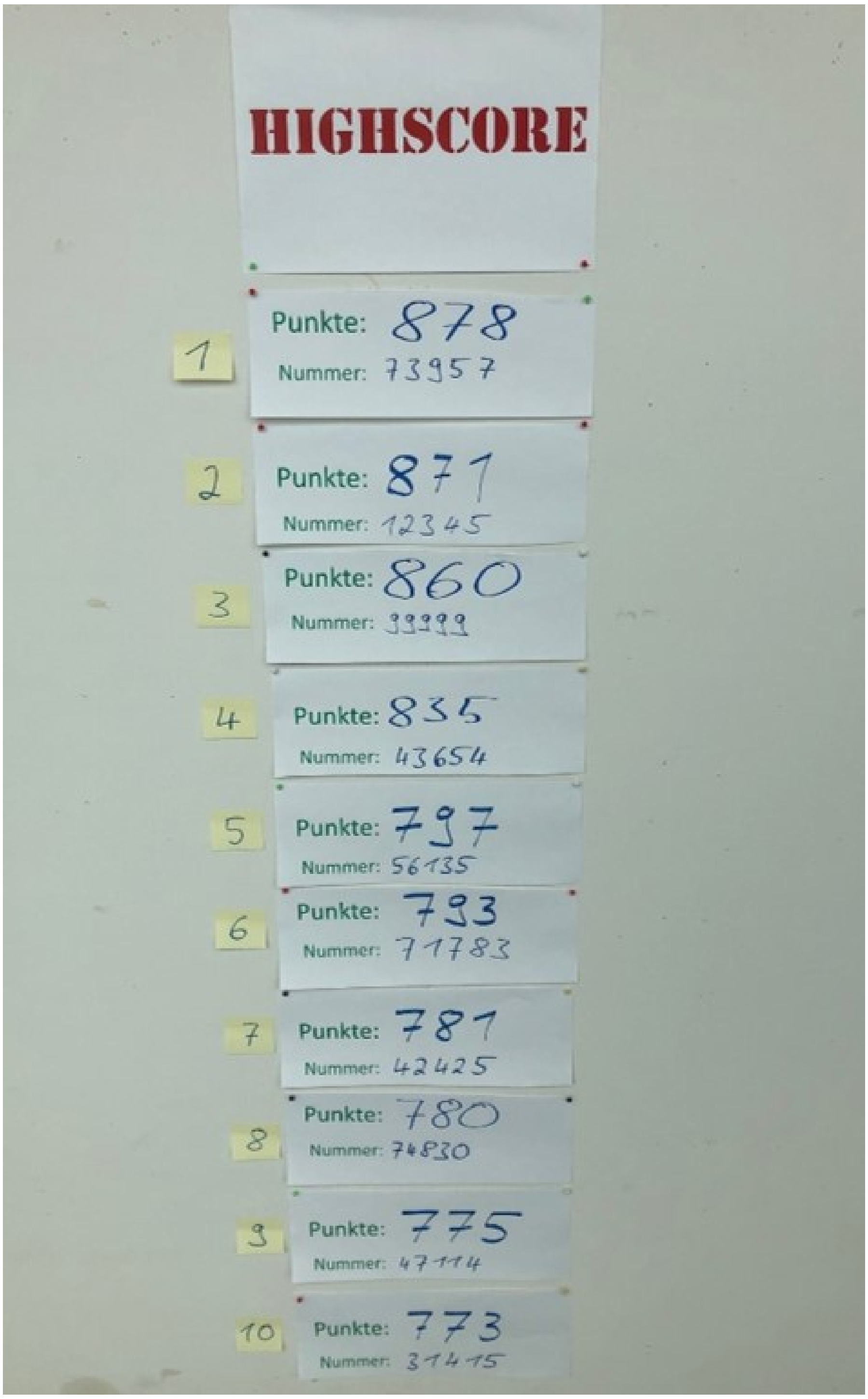

Figure 5.7: Highscore list on large board to be always visible by the participant during playing the game. All participants had to choose a personal number at the beginning to represent them. This ensured that they could identify their position on the highscore list during all days it was standing in the study room and at the same time being pseudonymized as no connection between their name and their number was saved.

The participants also had the chance to ask the experimenter if anything was unclear to them at this point. [70]
Once the participant started to play the game, the experimenter left the room to avoid having any influence on the participant's behavior and decisions in the game. The completion of all levels took the participants 17 Minutes on average. All invocations of the actions described above were logged in a text file, as well as all activations and deactivations of the automation by the participants. Once the game was finished, the participant was requested by the final game screen to inform the experimenter waiting in front of the room. The experimenter then congratulated the participant on the achieved score in the game and (if applicable) transferred the score to the highscore list standing in the room. Afterwards the participant was handed the second questionnaire. For the end of the study, the experimenter thanked the participant for helping in the study and said goodbye.

5.5.3 *Participants*

For the user study 25 participants were recruited from Robert Bosch GmbH and Ulm University, with 11 participants being female and 14 male. 8 subjects were part of the age group 20-29, 6 were part of the age group 30-39, 5 were part of the age group 40-49, 4 were part of the age group 50-59 and 2 participants were over 60 years old. [70]

Every participant had a valid German driver's license with the number of years they had their license ranging from 2 years to 46 years with a mean of 19.9 years (SD = 13.8). 21 participants reported to use a car daily, 3 stated to use a car about once a week and 1 participant reported to use a car only about once a month.

Participants were asked to rate their affinity for technology on a scale from 1 to 6, with 1 being "very low" and 6 being "very high". The mean rating was 4.6 with a standard deviation of 1.22.

To see if the participants were familiar with the concept of assistance technology, they were asked if they have experiences with digital assistants like Alexa or Siri and if they have experiences with driver assistance technology in cars. While only 12 subjects stated to use a digital assistant, 16 participants had at least one assistance system in their own car and four participants stated to have experienced such technology, but not in their own car.

5.6 RESULTS

The presentation of the results is split into three parts. First, the data [70] gathered from the game is presented, followed by the results of the second questionnaire. Lastly, the (reasonable) combinations of data from the second questionnaire and the data gathered from the game is presented.

5.6.1 *Game Data*

The participants received one point for every second of the game, in [70] which the automation remained *inactive*.
The mean number of points achieved was 750 (SD=78.3). Participant 19 achieved the highest score with 878 points, the lowest score was 544 points (participant 14).
An overview of the situations and the number of people intervening can be found in table 5.1 on the next page.

Interesting observations are that there are only two people who actually managed to experience a crash during the game; all others have always activated the automation in time.
When the game showed tailgating behavior, whether it was the driver's vehicle that was tailgating, or the user was being tailgated all participants activated the automation. (Only when the game was displaying intentional tailgating behavior of the driver two players did not activate the automation. Those two players are the two that finally took the first two places of the highscore-list.)

As it can be seen in table 5.1, most participants were not bothered by fast driving, regardless of the weather – only the driver going very fast during snowfall seems to be viewed as risky, as nearly half of the participants activated the automation in this case. In every situation where the driver was driving faster than allowed by the speed limit while being not attentive the majority of the participants intervened (Level 1, 5 and 8). In those cases, the automation was deactivated by all participants as soon as the driver's state was displayed as "attentive" again.

Table 5.1: Number of people intervening, respectively not intervening in each situation in the game. (Majorities marked in bold) [70].

Level		intervened	do nothing
1	20 km/h too fast (distr.)	**15**	10
	50 km/h too fast (distr.)	**23**	2
	distracted	3	**22**
2	fast, good weather	0	**25**
	very fast, good weather	0	**25**
3	indicator, car in blind spot	**22**	3
4	fishtailing (intentional)	10	**15**
	fishtailing (intent.), traffic	**13**	12
5	20 km/h too fast (tired)	**18**	7
	50 km/h too fast (tired)	**20**	5
	tired	5	**20**
6	fast, raining	4	**21**
	very fast, raining	9	**16**
7	fishtailing (tired)	**15**	10
	fishtailing (tired), traffic	**19**	6
8	attentive, a bit too fast	9	**16**
	20 km/h too fast (distr.)	**17**	8
	50 km/h too fast (distr.)	**19**	6
	distracted	7	**18**
9	indicator, lane change, blind spot	**24**	1 (crash)
10	fast, snowing	6	**19**
	very fast, snowing	12	**13**
11	tailgating (intentional)	**23**	2
	tailgating (tired)	**25**	0
12	fishtailing (distr.)	**18**	7
	fishtailing (distr.), traffic	**18**	7
13	lane change, car in blind spot	**24**	1 (crash)
14	distracted	6	**19**
	veer off the road	**25**	0
15	much too slow	2	**23**
	being tailgated, too slow	**25**	0

5.6.2 *Second Questionnaire*

In the first part of the questionnaire, participants were asked about [70] their decisions in two more complex situations (see table 5.2 and figures 5.6 and 5.5).

In case of the approaching ambulance, there was a clear statement to intervene if the driver is distracted, as all participants decided to activate the automation. Nearly as unequivocal was the opinion of the participants if a guardian angel-like system should intervene if an attentive driver is missing his or her turn. Only one participant decided to still activate the automation and therefore force the car to take the turn.

The decisions for the other two situations were not as unambiguous as 16 participants (64%) decided to activate the automation in case a distracted driver is missing the turn and only 15 participants (60%) decided to activate the automation for an attentive driver and an approaching ambulance. There were no correlations found between the decisions of both controversial situations.

Table 5.2: Number of participants activating or doing nothing in the four given situations in part two of the questionnaire. (Majorities marked in bold) [70].

	ambulance crossing		missing turn	
	intervene	do nothing	intervene	do nothing
driver attentive	**15**	10	1	**24**
driver distracted	**25**	0	**16**	9

Part two of the questionnaire consisted of the question in which [70] situations the participants would want a guardian angel-like function to intervene with their own driving. The results are listed in table 5.3. A wish for the system to intervene with their driving was only issued by a vast majority in the event that the driver tried to change lanes with another car in the blind spot, involuntary fishtailing, involuntary tailgating or veering off the road. A small majority wished for an intervention in the event of unintentional speeding or being distracted in general. Driving a bit too fast resulted in almost no wish for an intervention, driving very fast or much too slow also yielded in a clear statement for the system to not activate in these cases. Being tired was no reason to wish for an activation of the system for a small majority of the participants, in contrast to being distracted. Also, a majority didn't want the system to intervene if they are fishtailing intentionally.

Table 5.3: Number of participants answering the question if they want automation to intervene in a given situation or to only issue a warning or do nothing at all. (Majorities marked in bold) [70].

Situation	intervene	do nothing
speeding (intentional)	6	**19**
speeding (unintentional)	**15**	10
a bit too fast (intentional)	0	**25**
a bit too fast (unintentional)	3	**22**
distracted	**13**	12
tired	11	**14**
very fast, good weather	1	**24**
very fast, bad weather	7	**18**
indicator, car in blind spot	**13**	11
lane change, car in blind spot	**24**	1
fishtailing (intentional)	5	**20**
fishtailing (tired/distracted)	**19**	6
much too slow	1	**24**
tailgating (intentional)	10	**15**
tailgating (tired/distracted)	**21**	4
veer off the road	**25**	0

In part three of the questionnaire, participants were asked if they generally think a guardian angel-like function would make sense. All participants answered "yes" and chose "high" or "very high" on the presented six-point scale. This is consistent with the answers to the question "do you want to have such a function in your car", as every participant answered with "yes". [70]

Most participants justified this answer with an increased level of safety. Some gave additional information like "it could save me from an expensive speeding ticket" (P4) or "I would possibly allow more interventions if I know what it will feel like" (P14).

For the next question about the certainty of a guardian angel-like system, all but four participants wished for a high or very high certainty for a risk in a situation to trigger the system.

The other four participants stated that they would accept a low threshold for intervention "as long as the system intervention itself poses a negligible additional threat" (P18).

The fourth question asked was about the way the system should [70] inform the user about the intervention. Ten participants wished for a combination of acoustic and visual feedback, while five participants suggested to additionally include haptic feedback. Five participants wanted to have acoustic-only feedback, one participant wished for visual-only feedback, one for haptic-only feedback and one for a combination of visual and haptic feedback.
The remaining two participants wanted to get acoustic and haptic feedback. A suggestion was to use acoustic and visual feedback only in dangerous and high-risk situations. "Less intense interventions of the system should be communicated with only haptic feedback, so the passengers don't notice if the driver made a small mistake" (P9).

At the end of the questionnaire, participants had the possibility to add wishes and ideas for a guardian angel-like function. The two most mentioned features the participants wished for were the possibility to turn off the system and to have the possibility to personalize the system, for example "at which difference between speed and speed limit the system should intervene" (P4). The personalization should be transferable "for example as an App or user profile" (P10). Another interesting proposal was to offer different, pre-selectable levels of intervention "like full support, advanced support or emergency-only support" (P18).

5.6.3 *Combination*

Another interesting source of data is the combination of the results [70] from logfile data and the answers from part two of the questionnaire. In Table 5.4 the data has been combined, with the two main categories "Wish: do nothing" and "Wish: intervene" that stands for the answers of the participants from the questionnaire. For each of these categories the two possible reactions from the game "didn't intervene" and "intervened" is displayed. The column "Wish: do nothing" and "didn't intervene" therefore displays the number of participants that did not intervene in the given situation in the game and concurrently also wished for themselves that the system should not intervene. The other columns can be interpreted analogously.

The two middle columns are marked in red, because they contain contradictory behavior. Either participants wished for no intervention for themselves but intervened in the game or vice-versa. Especially in the case of driving much too slow, most people do not want to have a system intervening with their own driving but activated the automation during the game in this situation. [70]
It is evident that there are far more participants that wished for no intervention in a certain situation but intervened in the game, than there are people that wished for an intervention but did not intervene in the game.

5.7 discussion

The data gathered from the game's log files shows that there are situations that are perceived as risky by nearly all participants. [70]

Especially situations in which an accident was imminent (veering off the road and lane change with another car in the blind spot), tailgating and driving way too fast, resulted in a clear statement by the participants' interventions. When (involuntary) tailgating was involved, all participants had the need to intervene. This is especially interesting, since the design of the game would not let an accident occur in this situation, yet no participant tried to endure the situation. A very surprising discovery is the intervention of all participants in the situation the driver was driving too slow. Other situations like driving very fast did not appear too dangerous to the participants (according to the number of interventions), regardless of the weather.

The questionnaire showed that participants only want the system to intervene with their driving if an accident is imminent. All other situations yielded ambiguous results or even a clear statement to not let the system intervene. This, and the high acceptance of a guardian angel-like system in general confirm the findings described in the previous chapter. In the study described there, participants were also not as open to the idea of a guardian angel intervening when the driver is missing a turn (see chapter 4).

This corresponds with the explanation of the "self-enhancement bias" [108] as the idea of unwillingly missing a turn or being impeached while driving a bit too fast, does not fit in the perception of being a good driver.

Table 5.4: Combination of logfile data and answers to the questionnaire on what participants want for themselves. Contradicting answer possibilities in the red columns [70].

Situation	Wish: do nothing		Wish: intervene	
	didn't intervene	intervened	didn't intervene	intervened
speeding (intentional)	9	**11**	**2**	3
speeding (unintentional)	1	**9**	**1**	14
a bit too fast (intentional)	13	**12**	**0**	0
a bit too fast (unintentional)	5	**17**	**0**	3
distracted	2	**11**	**0**	12
tired	1	**13**	**1**	10
very fast, good weather	24	**0**	**1**	0
very fast, bad weather	8	**9**	**4**	4
indicator, car in blind spot	0	**13**	**1 (crash)**	11
lane change, car in blind spot	0	**2**	**1 (crash)**	22
fishtailing (intentional)	10	**9**	**0**	6
fishtailing (tired/distracted)	1	**5**	**2**	17
much too slow	0	**24**	**0**	1
tailgating (intentional)	1	**14**	**0**	10
tailgating (tired/distracted)	0	**3**	**0**	22
veer off the road	0	**0**	**0**	25

More interesting is the discrepancy shown by the comparison of desired system actions and own actions from the combination of data in the previous chapter. A lot more participants intervened in situations where they didn't want the system to intervene in their driving, in contrast to only a small number of people not intervening in situations where they actually wished for an intervention during their own driving. [70]
The first group can be clearly explained with the overestimation of one's own driving skill. This fosters the idea of not asking participants about how they want a system to function, but instead putting them in the position of being the system.
The other, small group of contradicting behavior can be explained with the influence of the presence of the leader board. It shows a high influence on the participants' motivation to leave the automation turned off as much as possible. This led to a more risky behavior in the strive to collect more points.

For example, all four participants that wished for a system intervention for themselves when driving very fast in bad weather conditions but didn't activate the automation in the game were eventually somewhere in the top seven positions of the highscore list.

The univocal behavior in situations in which (involuntary) tailgating was involved is especially interesting, since the design of the game would not let an accident occur in this situation, yet no participant tried to endure the situation. A very surprising discovery is the intervention of all participants in the situation the driver was driving too slow. But despite the obviously large urge to intervene in this case, only one participant wished for the system to behave accordingly, with all other participants refusing the idea of a system that takes over driving if one is driving too slow. The majority of the participants intervened in situations the driver was distracted or tired and showed abnormal behavior like fishtailing or driving too fast.

Using elements of gamification were shown to be of great use during a user study to increase the extrinsic motivation for a certain behavior. By penalizing an action, in the presented study activating the automation, respectively rewarding the participant to do nothing, the participants only intervened if they perceived a situation as a threat to the driver in-game. This gives a valuable insight what situations are perceived as dangerous and risky. The participants reported after the study that the gamification and the competition created with the always visible highscore list led to a greatly improved involvement in the study, as well as a higher "fun factor".

5.7.1 *Limitations and Future Work*

The gamification can also have negative effects on the data created, as [70] the strive for a high score led to a more reckless behavior. This has to be taken into account during the study design and the anomalies in the data created by it have to be identified and taken into account when reviewing and analyzing the data.
In the presented study all but two participants activated the automation when the game was presenting intentional tailgating of the driver. The two participants not intervening eventually got the top two positions on the leader board. They were apparently taking the risk to gain more points.

Another observation made from analyzing the log files of the top ten players was that there were certain situations where repeatedly activating and deactivating the automation resulted in a risk mitigation and still yielded points for the player. This behavior was not intended nor predicted during the design and implementation of the game. Unfortunately, this behavior makes it impossible to reliably analyze the length of an intervention or the number of interventions per person as it is not possible to correctly identify the begin and the end of the intervention.

For future investigation on the presented problem more complex situations would be of interest. It has to be examined if the gamified approach is also applicable in difficult and intricate situations like urban areas with more road users present. The situation has to be presented in a recognizable and decidable way for the player. As the idea is to use a game it could be possible to pause the driving in those situations to provide the player with more time to think about a solution in such a situation. However this would kind of eliminate a fast and intuitive decision.

For further future work it would be really interesting to see if people accept a system intervention if they experience it themselves in those situations. This could be verified in a driving simulator study. Additionally, the methods of system feedback could be verified in such a simulator study as well. An interesting approach to that could be to follow up the idea of participant 9 to have a two-stage warning system. A haptic warning could be issued during a system intervention in low-risk situations or situations the driver does not recognize as high-risk. An acoustic warning would only be issued in a high-risk situation where also a more fiercely reaction of the system would be necessary.

5.8 summary

Using gamification showed to be a method to influence the behavior of people by adding an extrinsic motivation to an action. It can be used in user studies to induce participants to show a certain behavior, or like in the study shown in this chapter, make them act only if they really have to. *[70]*
It can be complicated to design the study that way and gamification might not be applicable for every study subject. The results must be thoroughly analyzed to identify if and where the data has been influenced by the elements of gamification.

It was greatly beneficial to use gamification to find answers to the question which situations are perceived as very risky by drivers. In the presented setting, the changed perspective of the participants seemed to eliminate the biased view on one's own driving skills as there are situations in which a majority of people activated the automation despite stating to not want a similar system to intervene with their own driving in the same situation.

The study also showed that a safety-oriented function that works like a guardian angel in the car is in general very well-liked by people. This could help to make future driving safer and reduce the number of accidents.

6 EVALUATING THE GUARDIAN ANGEL

This chapter describes the need to develop a testing method for the guardian angel system as described in the previous chapters. Inducing driving errors in the driving simulator is not an easy task and was researched in a short preliminary study. Afterwards the results were used to test a prototypical implemented guardian angel in a realistic driving situation in the simulator. The results are presented and discussed in the last part of this chapter.
This chapter is partly based on the following previously published work:

[71] Steffen Maurer, Ramona Schmid, Rainer Erbach, and Enrico Rukzio. "Inducing Erroneous Behavior in a Driving Simulator with Gamification." In: *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings*. AutomotiveUI '19. Utrecht, Netherlands: Association for Computing Machinery, 2019, pp. 277–281. DOI: 10.1145/3349263.3351323

6.1 INTRODUCTION AND RELATED WORK

Testing assistance systems in the car, especially complex avoidance and mitigation technologies, under real-world conditions requires enormous effort [37]. The guardian angel-like system introduced and described throughout the previous chapters is one of those kind of systems. It will only activate in a situation where the driver is showing erroneous behavior. An incorrect activation has to be avoided by all means, as this would greatly influence the experience of the driver. To reduce the complexity and avoid any risks of injuries and damage to property, it is best to use a driving simulator. Driving simulators have been shown "to predict real-world driving to a considerable degree" [48] and are therefore suitable for this task. [71]

To evaluate the behavior of the driver in a situation where the assistance system intervenes, a corresponding situation must be induced. To do this, the experimenter has three different possibilities:

1. Instruct the driver to behave in a specific way that deliberately triggers the desired situation. This possibility clearly introduces the risk of an unnatural behavior.

[71] 2. Construct a situation in the simulator that cannot be avoided by the driver. This methodology will work especially well in situations where the cause of the situation is not the driver's fault. Simulating a technical failure or a dangerous situation where another road user misbehaves is fairly easy and hazard-free in a simulator.

3. Create an environment that persuades the driver to make a mistake, even against better knowledge; because in some cases, it is relevant for the study to observe the driver misbehaving and making errors.

To be able to design a study, it is important to have such kind of driver error occur on a reliable base. Inducing the wanted type of behavior depends on the driving environment and a fitting incentive. According to Fisher et al., three types of incentives exits: Extrinsic, intrinsic and consequential incentives [32]. While consequential incentives (involving real world consequences) are not applicable in a driving simulator [48], both intrinsic and extrinsic motivation can be influenced with methods from gamification [77]. The "explicit use of competition as a motivational tool" [12] can be established by the use of a leader board [22] as also shown in the previous chapter.

6.2 RESEARCH GOAL

A prototypical, yet fully functional, implementation of an in car intervention by a guardian angel-like system shall be tested with drivers in a driving simulator. This is to merge the tests and results of the work described in the previous chapters. While in chapter 4 participants were facing a system intervention, especially the safety critical situation was not completely realistic. The system intervention was unavoidable, even when the participants drove carefully.
During this study it is desired to bring participants in a situation that showed to be dangerous as described in chapter 5. In such a situation the participant has to be brought to make a mistake for the system to intervene. This will help to create a more natural interaction and gain insights and feedback more valid than the results of chapter 4.

6.3 PRESTUDY

Inducing erroneous behavior is no easy task and no current method to achieve this in a driving simulator is known. To be able to get to the goal described in the previous section, a reliable method has to be found first.

For this, two approaches are being explored in a short preliminary user study. A distracting non-driving related task and a way to create time-pressure were implemented in a gamified way. The study should examine if participants are motivated to engage in a distracting task even though it complicates their main objective. While being distracted, the experimenters expected to observe fishtailing, unrecognized traffic signs and (involuntary) non-obeyance of traffic rules as well as slow driving. A second goal was to test if gamification allows to introduce time-pressure. If this is possible, a more reckless behavior is expected, like tailgating and overspeeding. *[71]*

As the approach is exploratory, it was decided to test the setup and hypotheses with a small, prototypical study first. If the desired driving behaviors are not reliably achieved with a small number of participants, the methods used are unsuitable for a larger study and have to be revised. With a small number of participants, the experimenters gather feedback fast and can decide to continue testing or revise the methods without a high loss in time and investment.

6.3.1 *Procedure*

The participant was greeted by the two experimenters and explained the structure of the study. After filling out a brief demographical questionnaire, the participant would sit in the driving simulator and drive on a generic rural road for some minutes to get a feeling for the simulator. *[71]*

After that, the first of two tracks was loaded. The order of those two tracks was switched between each participant. While the second experimenter was preparing the setup, the first experimenter introduced the highscore list to the participant. This list consisted of post-its hanging on the wall, showing the (anonymous) participants' scores (see figure 6.1). It was intended to use it as "a motivational tool" [12]. The first experimenter explained the setting and the objective to the participant. For the first track the participant was told that he/she is in a hurry for an important appointment and might be late for it.

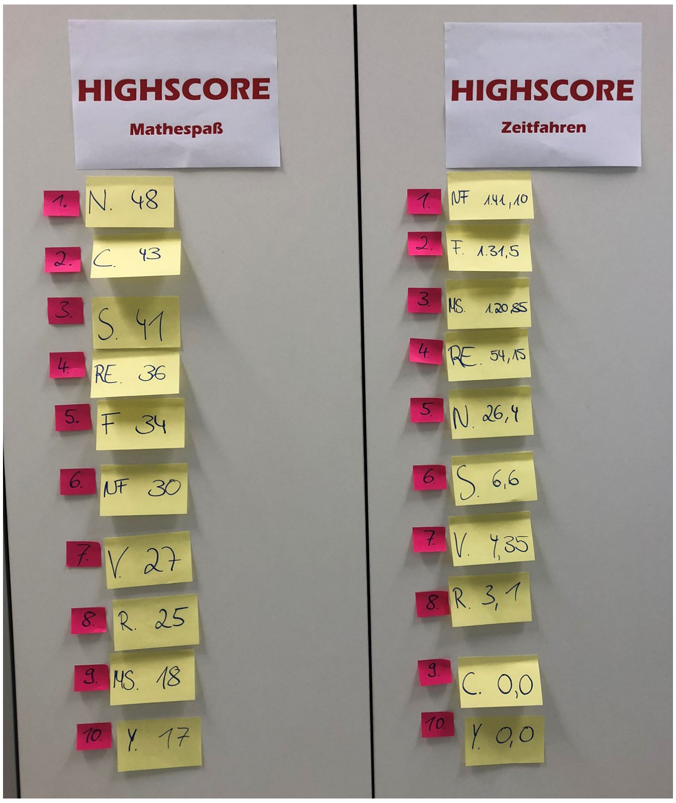

Figure 6.1: Low fidelity highscore list for both tasks. List was hung on a wall, making it easily accessible and clearly visible for the participants.

[71] To simulate the pressure a countdown of 30 seconds was shown on the screen to the right of the driver's seat. While driving, the time was going to deplete, and the participant would "lose" if the countdown reaches zero. Approximately every 700 meters a marked checkpoint would give an additional 30 seconds for the participant.
The final score the participant would get was the number of seconds remaining on the countdown when the goal was reached.

The road was a rural road for two kilometers, then turned into a highway for three kilometers, and ended in a 300-meter-long town-road with the goal at its end. All parts featured blind bends with slower vehicles, speed limits, and obstacles like construction work on the highway.

Figure 6.2: Driving in the simulator under artificially created time pressure. The remaining time is shown on the screen to the right of the driver. [71]

The second track was a shorter version of the first one with all other traffic removed from it. *[71]*

The participant was shown math problems on the side screen. Two random numbers between 0 and 99 had to be added up. The participant had to say the answer and the next problem was shown.
The final score for this part was the number of correct additions.

Before both tracks, the participant was told to drive as realistically as possible and that the main objective was to reach the goal safely. During both drives one experimenter was controlling the secondary task and the other was observing and logging the driver's behavior.

After the completion of both routes, the participant was asked to fill another short questionnaire about his/her motivation and assessment of the driving situation.

6.3.2 *Participants*

Seven participants (4m, 3f) were recruited from Robert Bosch GmbH. All of them are frequent drivers with a valid driver's license for a range of 2 to 39 years. All seven participants had some experience of driving in a driving simulator. *[71]*

Figure 6.3: Driving in the simulator with distraction. The math problem to be solved is shown on the screen to the right of the driver. The progress bar below indicates how much time is left to solve this problem.

6.3.3 *Driving simulator*

[71] The driving simulator used in the study consists of a 2-DOF motion chair manufactured by Atomic [99] with an attached steering wheel and pedals.
On a big screen in front of it, the simulation environment of SILAB [30] is displayed. The mirrors of the ego vehicle are integrated in the front screen at the top and the bottom corners respectively. The speedometer is displayed on a custom small display mounted behind the steering wheel on the motion chair. Attached to the chair as well, is a 17-inch touchscreen that is used in the study to display the countdown and the distraction task (see Figure 6.2).
All components are connected to a single desktop computer. The operator has another monitor standing on a table at the side of the simulator to control the simulation and to control and interact with the non-driving related tasks.

6.3.4 *Results of Prestudy*

The math problems distraction task showed to be very successful in distracting the participants from driving. [71]
In the second questionnaire, participants were asked to rate the difficulty and distracting strength of the task on a scale from 1 (very easy) to 6 (very hard) and 1 (no distraction) to 6 (very distracting) respectively. The difficulty seemed to be moderately high with a mean rating of 3.86 and the distraction was considered very high with a mean rating of 5.43.
Yet, four participants rated their driving performance as "decent for the most part". The other three rated their performance as "poor". The examiners noticed all participants were (heavily) fishtailing. Some seemed to overlook some speed limits, but overall the participants adhered to the speed limits placed along the track.

Most participants didn't let the countdown in the other condition impose pressure on them. When asked to rate the time-pressure felt, on a scale from 1 (no pressure) to 6 (high pressure) the mean rating was 2.57.
Two participants stated that they felt no pressure at all and two reported to be very stressed by the countdown. Interestingly, that does not correspond to the observation of the experimenters, as all participants showed reckless behavior in this condition.
All participants were driving too fast, some of them even 80 – 100 km/h too fast in certain conditions.
All participants ignored the no-passing zone and all but one participant tailgated slower vehicles and tried to overtake in inappropriate places.
Yet again, three of the participants rated their performance as "decent for the most part". The other four rated their performance as "poor".

All participants felt highly motivated by the highscore list in both conditions: on a scale from 1 (no motivation) to 6 (very high motivation) the mean rating was 5.

6.3.5 *Discussion of Prestudy*

This short prestudy shows a tendency for gamified study conditions [71] to offer extra motivation for the participants if they can compete with other participants, even if this is anonymous.

Putting (real) time-pressure on participants with the proposed gamified approach did fail, presumably because of the missing consequences. Having the objective to reach the goal as fast as possible encourages drivers to behave more recklessly, supported by the absence of consequences for traffic violations.
Such consequences on the highscore have to be introduced for the planned study. Besides, the countdown was a good tool to induce a tailgating behavior when overtaking was not possible due to oncoming traffic.

The distraction task showed to be very effective and, even though viewed as difficult by the participants, the experimenters were told it "was kind of fun". As opposed to the first expectation, the participants did not drive slower than the speed limit in this condition. It was however noticeably that participants would drive slower than usual.

6.4 STUDY

The prestudy presented in the previous section showed that solving math problems can effectively induce distraction and therefore provoke really bad driving behavior. As this was unpredictable and stretched throughout the complete test track it is not suitable for a controlled experiment with a guardian angel-like system.

The countdown task, however, induced risky driving behavior, especially all participants started tailgating the slow vehicle when there was no possibility to overtake. Even though this task failed to create time pressure for the participants, it is very well suited as it created a reproducible situation where a guardian angel-like system would activate.

6.4.1 *Procedure*

For the planned study the countdown task from the prestudy was to be repeated with nearly the same track layout and settings. The oncoming traffic and the foggy conditions at the point where the slow vehicle is present is increased to prevent any attempt to overtake and make this situation much harder to endure for the participants.

Afterwards, when the participant has been reaching the highway part, a new section of track was introduced: A three kilometer section of straight highway with no traffic and no speed limit. After one kilometer the weather was changed to heavy rain. The (invisible) danger of aquaplaning was meant to be the second activation point for the prototypical guardian angel-like system.

A new attempt to create a more pressuring situation for the participant was the addition of four traffic cameras to monitor the speed. Two examples are shown in figure 6.4 and figure 6.5.

When the participant arrived at the room the driving simulator was set up, the experimenter greeted the participant and explained the overall procedure of the study. The participant had to fill out the consent form, a short demographical questionnaire and the DBQ in a translated German version with 24 items [38].

After the participant finished the questionnaires, the experimenter explained the following task. The participant would sit in the driving simulator and drive along the simulated road. No turning was required and the participant should drive as natural as possible. While driving a countdown would be shown at a side screen. Every now and then the participant would pass by two triangular signs on both sides of the road with exclamation marks on them. At those points the participant would receive additional 30 seconds of time to be added to the countdown. The experimenter showed the participant the highscore list where the participants were ranked (anonymously) according to the time left when they reach the finish line.

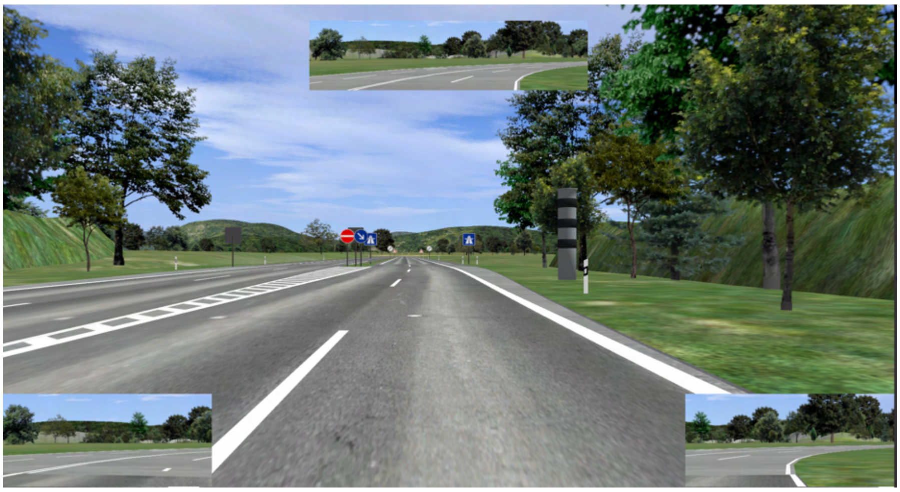

Figure 6.4: View of the screen the participant saw while sitting in the driving simulator. The mirrors of the car are projected onto the screen. A traffic camera is placed shortly before the beginning of the highway part.

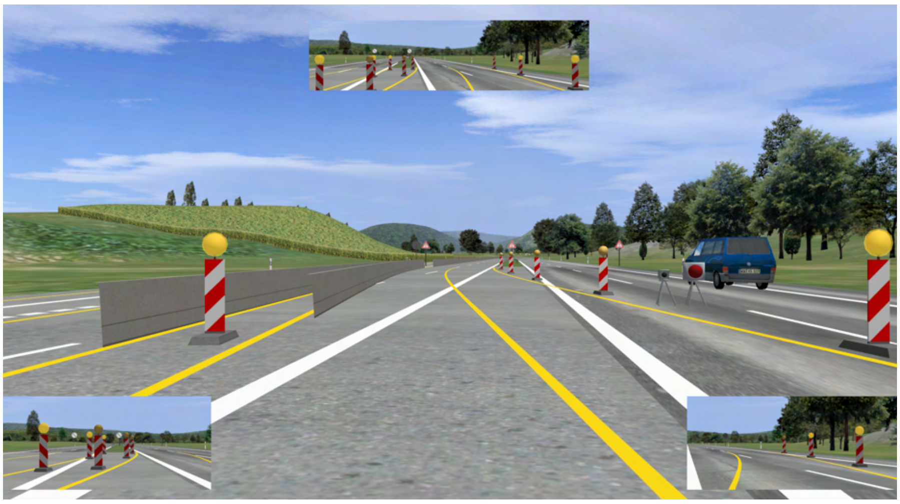

Figure 6.5: Another view of the screen the participant saw while sitting in the driving simulator. A second example of a traffic camera is shown, this time placed in a construction zone on the highway.

The experimenter handed the participant an DIN A3-size of paper with three images and explanations where and why the participant could receive a time withdrawal:

- Traffic cameras: If the participant happens to pass a traffic camera and is driving faster than allowed by the speed limit, a speeding ticket will be issued. This will result in a withdrawal of as many seconds as the participant was driving kilometers per hour faster than the speed limit. For example, exceeding the speed limit by 12km/h would result in a deduction of 12 seconds time.
- Stop signs: If a participant would not stop at a stop sign the participant would loose ten seconds time.
- Traffic lights: not stopping at a red traffic light would result in a deduction of 20 seconds.

The participant was then asked to sit in the driving simulator and adjust the siting position to be able to drive comfortably. Once this was achieved, the experimenter started the recording of the camera feed from a camera placed behind the participant to record reactions and statements of the participant during driving. The experimenter also started the simulation and asked the participant to start driving.

When the participant reached the part of the track originating from the prestudy with the slower vehicle in front and no chance to safely overtake said vehicle, the guardian angel system could be triggered by driving too close to the slow vehicle in front. (see figure 6.6) If the system was triggered the participant experienced automatic braking to reestablish a safe distance to the vehicle in front and was shown a warning symbol (see figure 6.7) on the additional screen for some seconds, overlaying the countdown. An audio was played telling the participant in German "Ich musste bremsen. Dein Abstand war so gering, dass du einen Unfall nicht hättest verhindern können" (English: "I had to brake. Your distance was too small for you to advert an accident").
When the participant reached the part of the track where it started raining on the highway, another possible situation for an activation of the guardian angel-like system arose. If the participant was driving faster than 120km/h the guardian angel activated itself and took over control of the vehicle. The vehicle was slowed down to 100 km/h while the warning sign (figure 6.7) was displayed and an audio was played, telling the participant "Ich musste bremsen, bei der aktuellen Aquaplaning-Gefahr bist du zu schnell gefahren. Das Risiko für einen Unfall war zu hoch" (English: "I had to brake, because you were driving too fast during the current risk of aquaplaning. The risk for an accident was too high").

When the participant arrived at the end of the test track, the experimenter took the remaining time of the participant and subtracted any penalty gathered by the participant, for example by driving too fast and getting caught by a traffic camera. The result was then written on a large Post-It-note and added to the highscore list.

The experimenter asked the participant to sit back at the table and fill out the SUS questionnaire, regarding the experienced intervention by the guardian angel-like system during the drive and a questionnaire posing open questions regarding said system.

6.4.2 *Participants*

Ten participants from Robert Bosch GmbH have been recruited to participate in the study. According to Hwang and Salvendy's 10±2 rule [50], this are enough participants to identify any major usability issues. Participants were required to have a valid driver's license. Six participants were female and the remaining four were male participants.

The age distribution is shown in table 6.1.

The participants have had their driver licenses between 3 to 14 years, with a mean of 9.6 years (SD = 3.75). All but one participant stated to use their car on a daily basis. All participants have experience with driver assistance systems in the car. Two of the participants did not attribute themselves a high or very high affinity for technology and all but one oft the participants did have experience in driving in a driving simulator.

Table 6.1: Distribution of participants along age groups

Age group (years)	<20	20-29	30-39	40-49	50-59	>60
Participants	0	7	3	0	0	0

Figure 6.6: View of the screen the participant saw while sitting in the driving simulator. The mirrors of the car are projected onto the screen. Slower vehicles are in front of the participant, with constant oncoming vehicles and fog preventing to see far ahead. This situation was designed to prevent overtaking and induce a tailgating behavior.

Figure 6.7: A warning icon to be displayed when the guardian angel-like system is activated.

6.5 RESULTS

This section presents the results of the different questionnaires and data gathering methods used in the study. It is done without interpreting the data. The interpretation and discussion is done in section 6.6.

6.5.1 *System Usability Scale*

The SUS questionnaire provides a simple to gather rating of the overall usability of a system. Designed by John Brooke [10], it consists of ten questions. Each question has to answered on a five-point Lickert scale, ranging from "completely agree" to "completely disagree". The result is a percentage value of the system's usability, ranging from 0 to 100 percent. The overall score is the mean value of all participants. Scoring below 50 percent shows a large problem regarding the usability, while a system scoring more than 70 percent is considered to have a good usability.

The participants were instructed to only base their ratings on the intervening guardian angel-like system. The results from each participant can be seen in figure 6.8, ranging from 70 to 97.5 percent. The mean across all participants was 82.5 percent, with a standard deviation of 9.5.

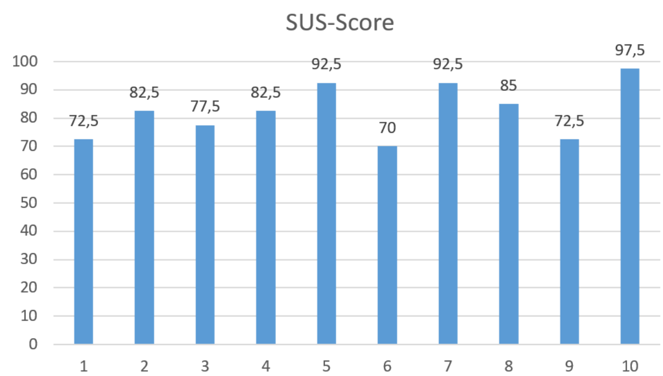

Figure 6.8: The SUS scores in percent each of the ten participants attributed to the system.

6.5.2 *Driver Behavior Questionnaire*

The DBQ is a questionnaire developed by Reason et al. in 1990 [87]. It provides driving behavior items and asks the participant to rate them on a six-point Likert scale, ranging from 0 (never) to 5 (nearly all the time), how often the participant shows the said behavior while driving. While the original questionnaire was designed to have 50 items, Parker et al. [79] published a shorter version with only 24 items. All items are classified to be either a lapse, an error or a violation on the road. A lapse is a type of unintended behavior characterized by attention and/or memory failure, an error is an unplanned behavior. Violations are intentional disregards of traffic rules and safety measures. While lapses usually have no implication on other drivers, errors are potentially dangerous for other road users. A high violations value, however, has been shown by Parker et al. to be directly proportional to the chance of the driver having an accident [79].

Figure 6.9 shows the results of the DBQ as a boxplot. The ten participants had a mean lapse-value of 1.29 (SD= 0.66), a mean error-value of 0.46 (SD=0.26) and a mean violation-value of 1.50 (SD=0.76).

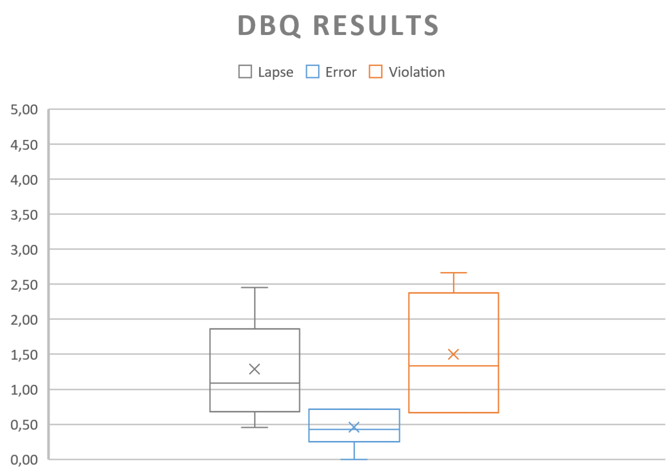

Figure 6.9: A Boxplot of the results gathered by the DBQ.

The lapses-value of the participants ranged from 0.45 to 2.45 points, as shown in detail in figure 6.10.

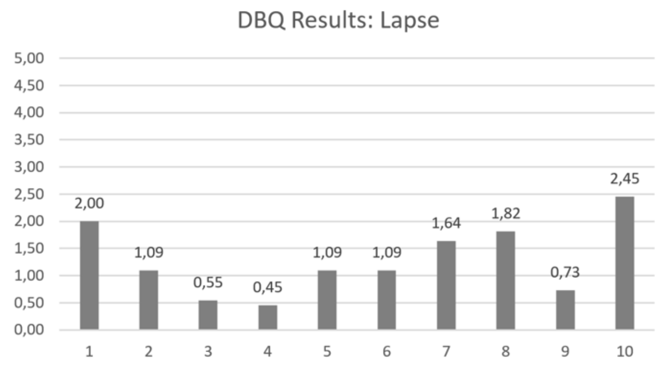

Figure 6.10: The results of the participants for the "lapse"-category of DBQ. It shows how often the participant encounters a lapse during driving and ranges from 0 (never) to 5 (nearly all the time). A lapse is a type of unintended behavior caused by attention and/or memory failure.

The error-values of the participants were all quite low, ranging between 0 and 0.71 points. While it is nice to see that all participants make few errors during driving, it is unrealistic to assume participant 4 makes no mistakes at all. As the questions in the DBQ ask about quite specific situations, it could be that participant 4 did not make a mistake in one of those situations or did not want to admit a mistake in one of these situations.

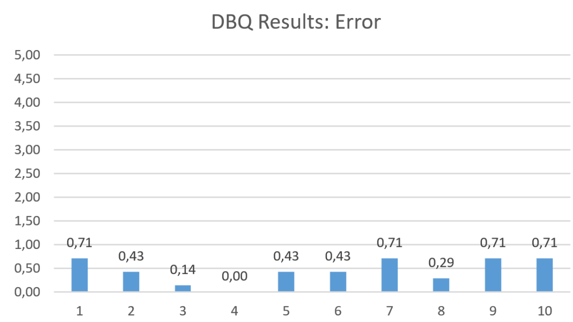

Figure 6.11: The results of the participants for the "error"-category of DBQ. It shows how often the participant encounters an error during driving and ranges from 0 (never) to 5 (nearly all the time). An error is an unplanned behavior.

The violation-value of the participants ranged between 0.67 and 2.67 points. It appears to show three categories: three participants have a value of 0.67, which is a very low value and resembles a non-aggressive style of driving with only a few intentional violations of traffic rules. Another three participants have values of 2.33 and above, making it another apparent category. The remaining four participants span a category in between the two mentioned before with violation-values of 1.33 and 1.50 points.

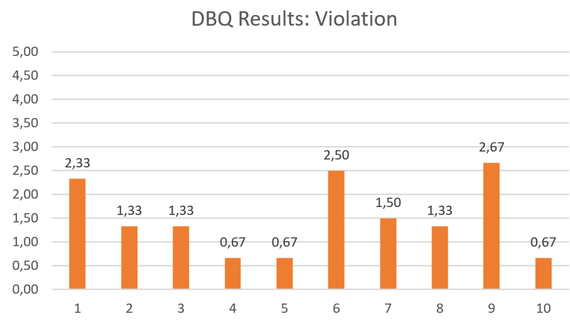

Figure 6.12: The results of the participants for the "violation"-category of DBQ. It shows how often the participant encounters a violation during driving and ranges from 0 (never) to 5 (nearly all the time). A violation is an intentional disregard of a traffic rule.

6.5.3 *Correlation between SUS and DBQ*

Regarding the three highest values of the DBQ violation category results in the peculiar observation that these values have been calculated for the exact same participants that gave the system the lowest scores in the SUS questionnaire. This raises the question if there might be a correlation between the SUS-scores and the DBQ-values.

Both questionnaires work with Lickert scales and therefore ordinal data. To evaluate a possible correlation, Spearman's rank correlation coefficient ρ [85] was computed. This is done by computing the ranks of the values and order them ascendingly.
With the following formula the correlation coefficient is computed, using the two features x and y:

$$\rho = \frac{\sum_{i=1}^{n}(rank(x_i) - \overline{rank(x)})(rank(y_i) - \overline{rank(y)})}{\sqrt{\sum_{i=1}^{n}(rank(x_i) - \overline{rank(x)})^2} \cdot \sqrt{\sum_{i=1}^{n}(rank(y_i) - \overline{rank(y)})^2}}$$

The result will always be $-1 \leq \rho \leq 1$, with -1 and 1 describing a perfect (positive or negative) correlation and $\rho = 0$ indicating that there's no correlation at all.

The computed results are shown in table 6.2. Evidently, there is no correlation between the SUS-score and the error-value of the DBQ. Regarding the SUS-score and the lapse-value there is a non significant, small correlation ($\rho = 0.39$) with a small effect size of $r = 0.15$. There is however, a fairly strong negative relationship between the SUS-score and the violation-value from the DBQ with $\rho = -0.73$, a strong effect size of $r = 0.54$ according to Cohen [15]. The p-value of 0.014 shows that this correlation also is statistically significant.

Figures 6.13, 6.14 and 6.15 on the next page show the plots for the aforementioned relations between the SUS-score and the DBQ components.

Table 6.2: Presentation of the correlation evaluation for the three DBQ values and the SUS score. Presented is Spearman's rank correlation ρ, the strength of the effect r, the T-value (critical T for 98% confidence interval = 2.82) and the p-value

Correlation	ρ	r	T-value	p-value
SUS score & DBQ-lapse value	0.39	0.15	1.20	0.261
SUS score & DBQ-error value	0.09	0.01	0.25	0.812
SUS score & DBQ-violation value	-0.73	0.54	-3.05	0.014

6.5.4 *Video Analysis*

The video recordings did not help to gain many insights to the participant's behavior and reactions.
Most participants did not comment or react specifically to the interventions of the system. Two participants (P2, P7) were wondering after the intervention if they were in control of the vehicle again.
Participant 7 jokingly said after one intervention "If I had this in my car, I would always argue with the system!".

The only notable observation was that when the guardian angel intervened due to the risk of aquaplaning all participants continued to drive slower until the rain stopped, even though this was not necessary, as the guardian angel was not programmed to intervene again.

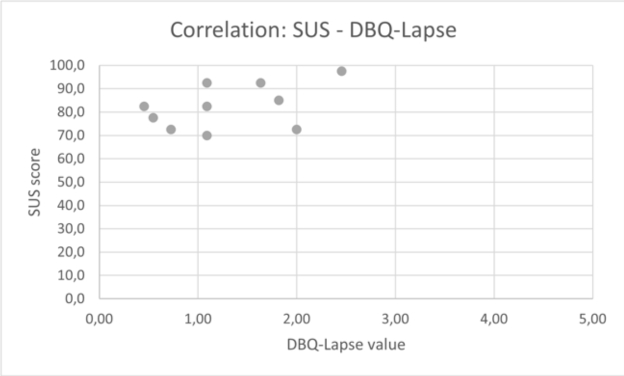

Figure 6.13: The SUS score (y-axis) plotted against the DBQ-lapse value (x-axis). A weak positive correlation ($\rho = 0.39$) can be observed, although it is not statistically significant ($p = 0.26$).

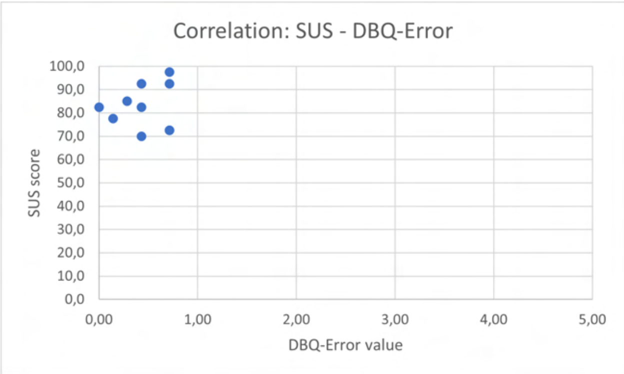

Figure 6.14: The SUS score (y-axis) plotted against the DBQ-error value (x-axis). No correlation ($\rho = 0.09$) can be observed.

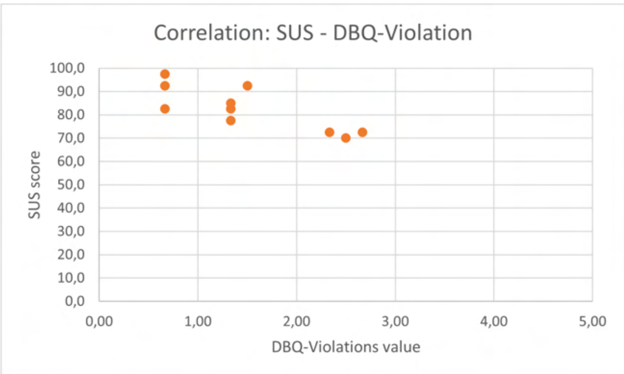

Figure 6.15: The SUS score (y-axis) plotted against the DBQ-violation value (x-axis). A strong negative correlation ($\rho = -0.73$) can be observed, that additionally is statistically significant ($p = 0.014$)

6.6 DISCUSSION AND SUMMARY

This study brought participants in a realistic situation in a simulated environment where a guardian angel-like system would activate if it existed in the car. The study was designed to provide an environment that persuades the participant to make a driving mistake but did not explicitly instruct the participant to do so.

The participants have not been informed about the guardian angel-like system and its design to see if participants understood the system's behavior and how they would rate the usability of its design.

The overall usability was rated good.
The SUS-score achieved by the system was 82.5 (see section 6.5.1) with a standard deviation of 9.5. According to Bangor, Kortum and Miller this score attributes a good usability to the system (see figure 6.16 for graphical representation) [4].

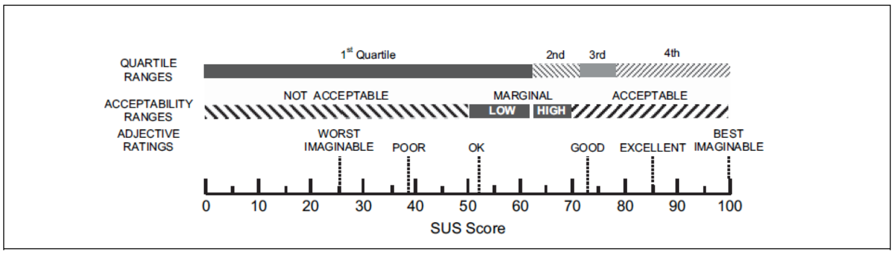

Figure 6.16: Scheme provided by Bangor, Kortum and Miller [4] to interpret and evaluate the SUS score

As explained in section 6.5.3 there are some very interesting effects regarding the driving attitude of a person and the attributed SUS-score. A strong negative and statistically significant correlation was observed between the SUS-score and the violation-value of the DBQ results.

This means, the more aggressive a driver is driving (as the driver is deliberately violating traffic rules) the less favorable is the attributed usability rating for the system. A driver that is, so to speak, intentionally taking a risk in driving outside the traffic rules is not benevolent towards a system that is designed to interfere in risky situations. Such a driver might be influenced by the "self-enhancement bias" [108] (see also chapter 5) is likely to see the guardian angel as an overcautious protector or even feels effectively impeached as a driver.

The weak correlation between the SUS-score and the lapses-value of the DBQ results might indicate that a driver that is making lots of small mistakes (and self-consciousness realizes that) likes the idea of having a fallback system onboard that can prevent an accident in a dangerous situation.

The difficulty in creating a user interface for a guardian angel-like system is that both types of drivers and every one in between have to be considered in the design. A simple solution would be to include an option for the user to configure the "intervention-likeliness" or to even completely deactivate the system for certain situations. This would ensure that every type of driver is satisfied with the system's reactions. It even corresponds with the believe in guardian angels, that everyone has their own personal guardian.

7 KOFFI AND SOFTWARE ARCHITECTURE

This thesis also was part of the KoFFI research project. In this chapter an introduction to the KoFFI research project is given and the software architecture that was developed for it is described.

7.1 INTRODUCTION TO KOFFI

The KoFFI project was established to develop HMI concepts for highly automated driving. It focuses on a cooperative approach of sharing control between the human driver and the automated vehicle. Hence, KoFFI is the acronym for cooperative driver-vehicle-interaction (German: "Kooperative Fahrer-Fahrzeug-Interaktion") [33]. It was funded by the German Federal Ministry of Education and Research and has a budget volume of 3.6 million Euros. For the project industrial partners (Robert Bosch GmbH, Daimler AG and European Media Laboratory GmbH) joined forces with research institutes of Universität Ulm, Hochschule der Medien Stuttgart and Hochschule Heilbronn for three years.

A rather novel approach of this research project was to include legal and ethical aspects right from the beginning. The Institute of Digital Ethics from the Hochschule der Medien Stuttgart accompanied the research of the other project partners to establish "ethics by design" and "privacy by design" as key foundations of the project and to develop guidelines for future development of automated driving functions [82].

In the KoFFI project it was assumed that for future automated driving, a cooperative approach could solve some major issues of manual and highly automated driving. Giving the automated car the possibility to request help from the driver in certain situations to help the car to perform better [107], but also giving the car the possibility to help the driver if possible. The project partners agreed that there are situations which would be easily controllable for a human, but not for the car and vice versa, an interaction concept was developed that relied on the possibility of shifting the decision-making authority from the driver to the car and vice versa.

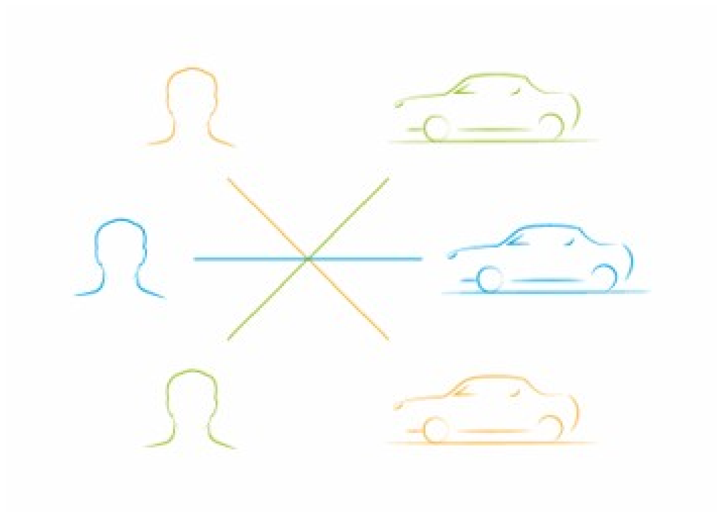

Figure 7.1: In the KoFFI project it was defined that driver and vehicle are treated as equal partners (blue). In safety critical situations the vehicle is hierarchically above the driver (green), while in uncritical situations the driver is the decision-making authority (orange).

This approach was a perfect opportunity for the research of this thesis taking place, as it fit nearly perfectly in with the aforementioned general approach. Even though the guardian angel can only intervene during manual driving (with an possible concept of intervention when a takeover from car to human would lead to a dangerous situation (see chapter 2.1), this was still beneficial for the project, as (highly) automated driving can and will still rely on a human driver from time to time.

As the project aimed to deliver a prototypical HMI concept for demonstration at the end in a driving simulator, also the guardian angel had to be demonstrated. For doing so the challenge to create a system that can sense a critical situation and trigger an appropriate reaction in the (simulated) car had to be faced. This lead to the development of a software architecture for the KoFFI project, that not only allowed triggering the guardian angel but also supports all other components of KoFFI like speech recognition and linked HMI responses, facilitates in-car systems and provides an interconnection to the environment provided by the driving simulator.

7.2 CREATING A SOFTWARE ARCHITECTURE FOR KOFFI

A software architecture should describe the structure of the system, regarding the software elements, properties and relationships between these [13]. To derive a valid and working software architecture the surroundings and the context have to be sorted out first. From this "level 0" one can derive a more granular description of the needed components for a certain function.
In the KoFFI project every level of detail of the architecture was discussed and coordinated with the project partners. Also, the exchange protocol of all components had to be harmonized. It was agreed with all project partners to use a XML-based own protocol that uses key-value-pairs to exchange information (see section 7.4). Once this and the structure of the top level architecture was finished, a more detailed architecture was created, containing also the bottom level components.

7.3 KOFFI SOFTWARE ARCHITECTURE

For the description of the software architecture of KoFFI the architecture is split into small blocks in this chapter. This block view is built up in several levels. The top level is level 0 and shows the context of the KoFFI-system. It delivers an introduction of the graphical presentation of the software and lays the foundation for the lower and more detailed levels. Blocks of a level will always be described as a black-box-system, that means only the function and the behavior is described, not how this is achieved. The inner structure is described in the next lower level where the block will be displayed as a white-box-system. Most systems of the lowest level of this architecture will also be presented as black-box-systems, as the detailed dissection into classes, objects and interfaces of a programming language is not known to the author.

7.3.1 *Level 0*

The top level describes and presents the context of the KoFFI-system. It displays the environment and the users and systems KoFFI is going to interact with. The definition of the context is useful to distinguish KoFFI from the surrounding systems. This eases the description of the scope of the software architecture as it is clearly displayed which systems and functionalities are not part of KoFFI and what interfaces to other systems will be necessary.

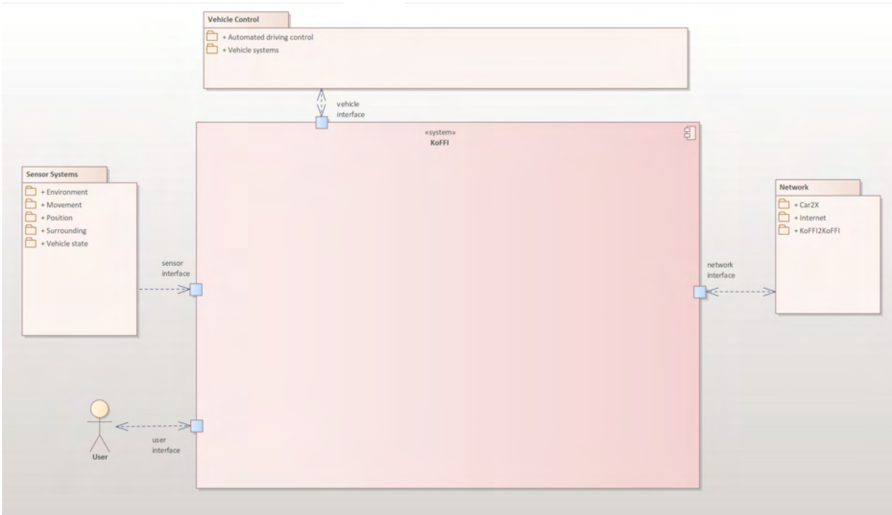

Figure 7.2: Block view of software architecture, level 0

KoFFI (Blackbox)
The central block in level 0 is the KoFFI-system. KoFFI has several interfaces and connections to the other systems (sensors, vehicle control and network) of the car.
The driver and the passengers are shown in this diagram as "users", connected to KoFFI via the human-machine-interface (shortened as "HMI" in the following text). The users and KoFFI can interact bidirectionally, which means that the users can use the HMI and have an influence on KoFFI and its decisions as well as KoFFI can give output to the users.
Network and vehicle systems are also interfaced bidirectionally for information and commands to be transferable in both directions.
The sensor system only has a unidirectional connection to KoFFI as information is sent by this system to KoFFI, but no information can be transferred back.

Vehicle Control (Blackbox)
This package consists of all systems of the vehicle and the complete control logic. All software for driving automatically and systems like light, climate control and media control is contained in this block.
As mentioned in the previous paragraph, this block has a bidirectional connection with KoFFI: While driving in automated mode, information have to be sent to KoFFI to allow creating an ongoing representation of the current driving situation. Steering commands and commands concerning the other vehicle systems can be sent from KoFFI to the vehicle control block.
To make automated driving possible in the first place - and using assistance systems during manual driving - this block needs input from the sensors. A connection to the network appears to be reasonable as well. For clarity, as this text describes the software architecture of

KoFFI, the detailed connection between these blocks will neither be explained in detail, nor shown in the diagram.

Sensor Systems (Blackbox)
In the sensor package all sensors are located, that are installed in the car. This includes not only the sensors to detect the driving situation and the current surroundings (like steering angle sensor, radar and ultra-sonic sensors), but also the sensors to detect and measure environmental influences (rain and light sensors) and detecting the current position (satellite navigation system).

Network (Blackbox)
The network package covers all network-based communication partners of the KoFFI-system. This includes particularly all communication with other connected cars (Car2Car), connected infrastructure (Car2X) and also the possibility of other connected KoFFI-entities (KoFFI2KoFFI).
Besides, there is a connection to the internet to access comfort-functions (streaming services, email and calendar information) as well as driving-related data (e.g., current traffic reports).

7.3.2 *Level 1*

In level 1 the inner structure of the KoFFI architecture will be explained in detail. To clarify that this level is the inner view of the upper level all surrounding systems have been left in the diagram. Interfaces between KoFFI and other systems are now shown as an interface of the actual part of KoFFI and the other system.

KoFFI (Whitebox)
The KoFFI-system consists of four subsystems that interact with each other in a distinctive way.
Incoming sensory signals are routed to the Driver-Vehicle-Environment-Model (see also design decisions in chapter 7.5.1). The model can communicate bidirectionally with the main logic. The logic also has bidirectional connections to the vehicle systems, the network and the HMI-manager.
Besides all these systems a data logging system is present.

Main Logic (Blackbox)
The main logic is the entity that makes decisions in KoFFI, especially concerning the driving task. Decisions made are sent to the the driver-vehicle-environment-model to create an always up-to-date representation of the current situation. The decision also gets sent to the vehicle

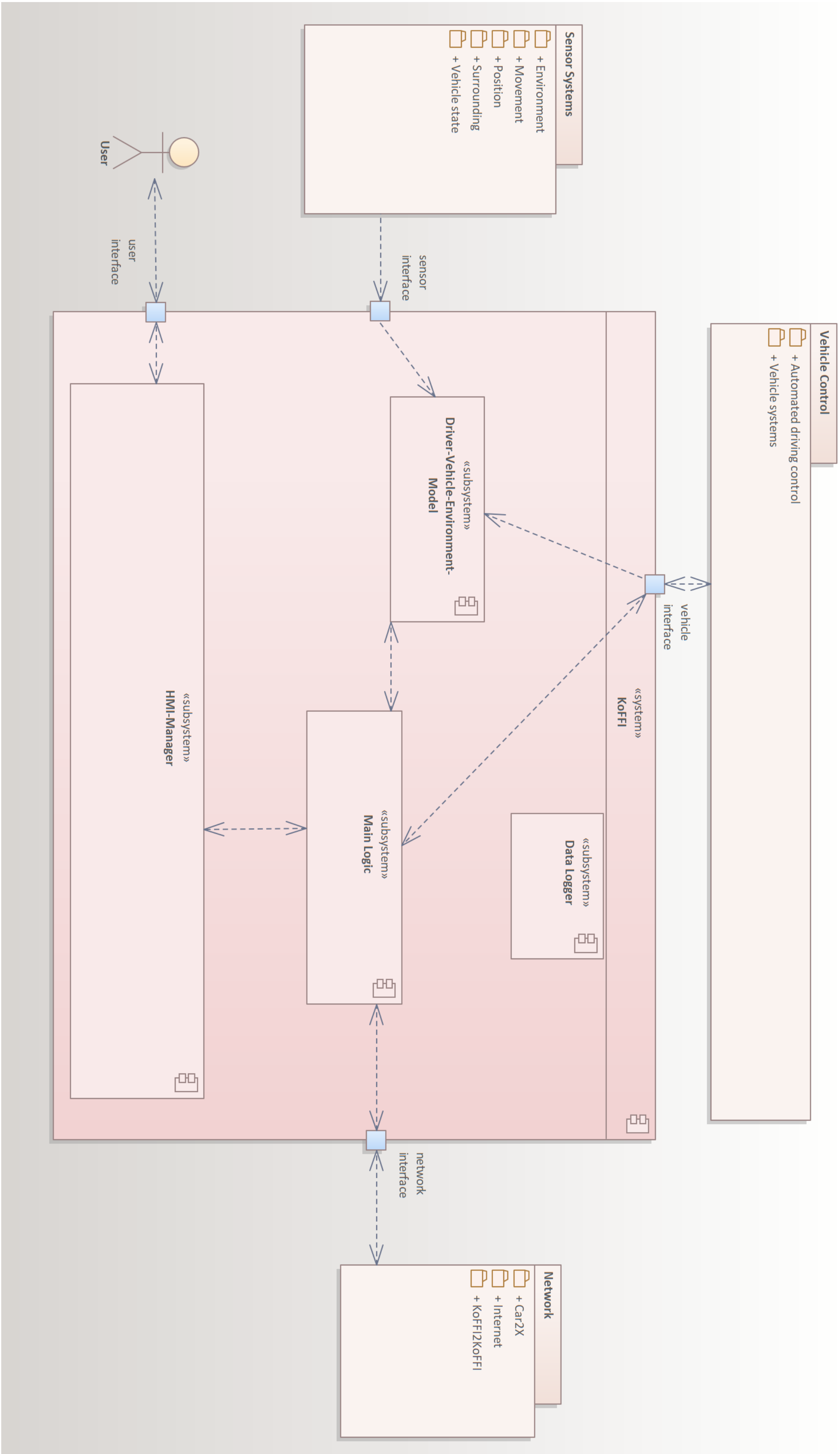

Figure 7.3: Block view of software architecture, level 1

control systems for execution. This also works vice versa, as actions of the vehicle control systems are messaged to the main logic where the information is further processed, reacted accordingly and the model is updated. A connection to the network is available to receive and sent additional information.
Furthermore, most decisions of the main logic must be communicated to the user, this is initiated by sending the information to the HMI-Manager, where the information is processed and distributed. User input is recorded by the HMI-Manager and propagated to the main logic.

Driver-Vehicle-Environment-Model (Blackbox)
The model system is responsible for providing current system and situation status. It holds all current information about the driving task and system state as well as information about the user and personalized settings.
The model can be changed and updated by the sensors, vehicle systems and the main logic. Changes induced by sensors and main logic are directly transmitted to the main logic.

HMI-Manager (Blackbox)
The HMI-Manager manages the communication between the KoFFI-system and the human user.
The HMI-manager receives input from the main logic and distributes this input to the user, using appropriate modalities (visual, auditive, haptic, etc.). Input made by the user gets forwarded to the main logic.

Data Logger (Blackbox)
The data logger is a system to journalize and record vehicle and user data. This is necessary to reconstruct decisions and place and time the decisions were made. For example, in case of an accident it is important to know if the human driver or the automated system was responsible at the time of occurrence.
It is also possible to record additional data. The legal implications and requirements are not completely clarified, but presumably the data logging system needs a connection to all other modules present in the system. To avoid an unreadable and cluttered diagram these connections have been omitted.

7.3.3 *Level 2: HMI-Manager*

In level 2 of the structure the HMI-Manager will be examined further, as it is the only system that is split in smaller modules. All other systems of KoFFI are software components that would need to be viewed in class diagrams to gain further insights.

HMI-Manager (Whitebox)
The HMI-Manager consists of four components: The speech-dialog-system, the system for graphical and haptical interaction, the system for gaze and gesture interaction and the content manager. The content manager is the central component that manages communication of all input and output modalities as the interface to the main logic.

Content Manager (Blackbox)
The content manager manages the communication and the distribution of information between all HMI systems and the main logic.
It also provides a memory function for the human-machine-interface and saves information about the current dialog status, dialog history and current state of input and output for each modality.
Information and requests provided by the main logic are distributed to the correct modality based on the type of information and/or request and the urgency of it. Inputs made by the user are aggregated in the content manager before it is sent to the main logic.

Speech-Dialog-System (Blackbox)
The speech-dialog system is, according to its name, the module responsible for creation and execution of audio communication with the user. It is able to recognize spoken instructions and translate them into a predefined structure, making the processing of the spoken input possible. The system also has a text-to-speech module to transform system responses into spoken responses for the user. The generation of all warning sounds is also part of this system.

Graphical-Haptical-Interaction (Blackbox)
The system for graphical and haptical interaction is the counterpart of the speech dialog system regarding the in- and output of all graphical and haptical user interfaces in the car. It processes the display of information, input of touch screens, buttons and switches.
This system also enables haptical output by interfacing the respective actuators.

Gesture and Ganze Interaction (Blackbox)
The system for gaze and gesture interaction closes the gap in the human-machine-interface by being responsible for the remaining inter-

action modalities in the car. Driver monitoring and gesture recognition and processing are managed in this system.

7.4 COMMUNICATION SEQUENCES

The building block view in the previous section described the construction of the system and shows which component can communicate with which other component.
Another part of a software architecture is to detail the communication. It was agreed upon with all partners of the KoFFI-project to use TCP-based inter-module communication. Information between the modules are sent as key-value-pairs in a predefined XML-message format (see Listing 7.1). The defined categories of messages (called "events") and the defining key-value-pairs (called "features" and "values") were created on a by use case basis. Therefore all possible messages for a certain use case could be used by the system, because designing an universal message list with all possible situations that could occur during driving was not feasible for a prototypical implementation as intended for the KoFFI project.

```
<Message>
    <Event Name="Request Explanation"/>
    <Data>
        <DataEntry Type="StringList">
            <DataValue Feature="sdsMsgId" Value="123"/>
            <DataValue Feature="Task" Value="driving"/>
            <DataValue Feature="Action" Value="overtake"/>
            <DataValue Feature="Situation" Value="past"/>
        </DataEntry>
    </Data>
</Message>
```

Listing 7.1: Example message sent by the HMI-manager to the main logic, requesting an explanation of the previously executed overtaking by the car.

Following are two examples of how the communication is implemented between different modules:

7.4.1 *Sensor Signal input*

Incoming sensor signals are routed to the driver-vehicle-environment-models. In this module, the saved models are updated according to the new input. If something has changes, for example the current speed limit, the model sends a message to the main logic with the updated information. The main logic might therefore decide to change something in the current driving task, for example slowing down to

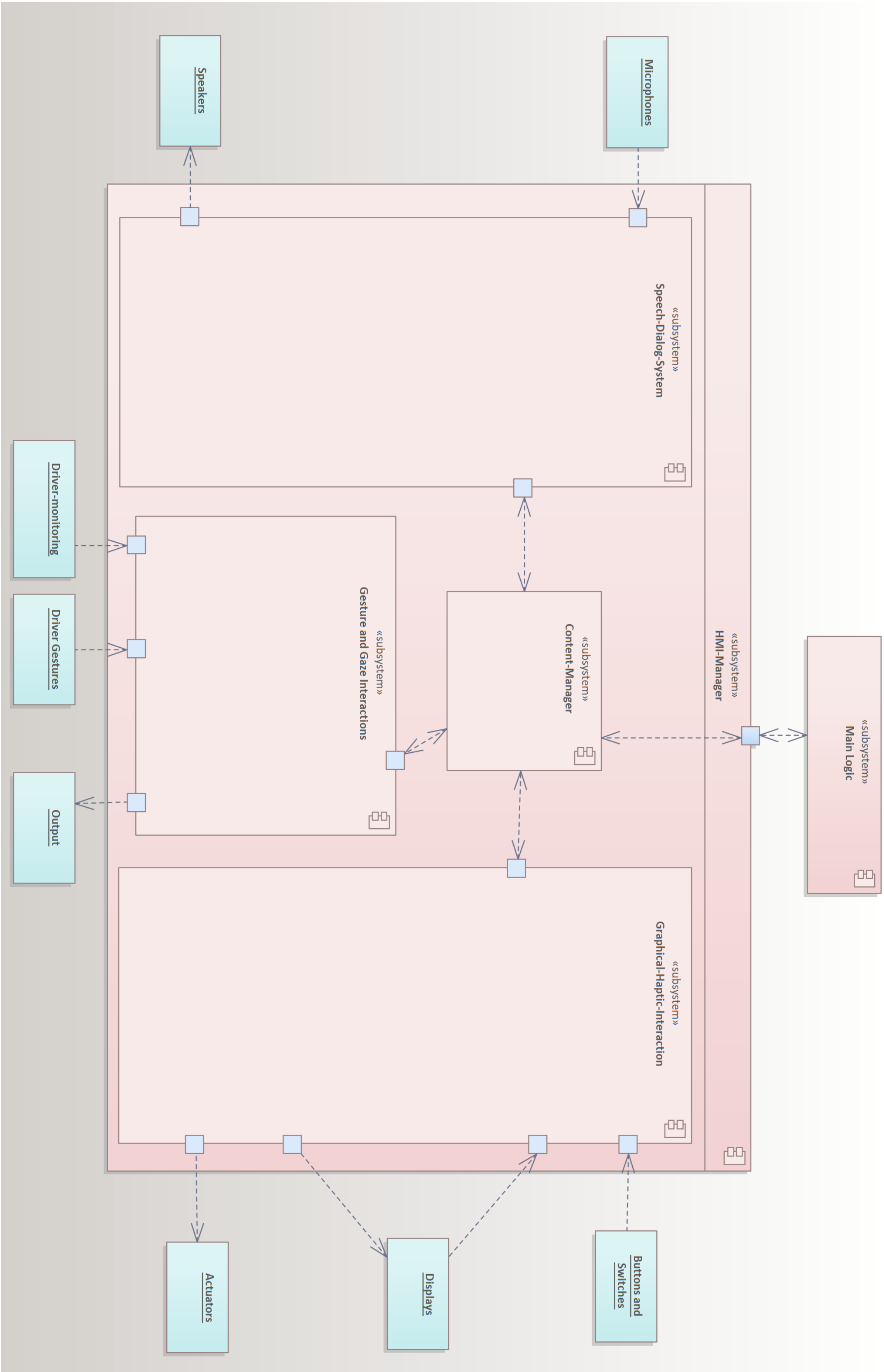

Figure 7.4: Block view of software architecture, level 2: HMI manager

comply with the speed limit. This intended change has to be sent to three different other entities. First, the vehicle control will receive this information to adjust the driving.

Second, the model needs to be informed about the change to update the current vehicle status and context accordingly. Third, the user needs to be informed about the change and possibly about the underlying reason for it. This is achieved by providing the HMI-manager with the appropriate message that then gets distributed from there to the corresponding output method.

7.4.2 *Example Dialog: Request Explanation for not Overtaking*

The sequence diagram below (figure 7.6) shows an example of how a question about an aspect of the automated driving by the user would be handled by the system. The situation this sequence takes place, is the car following a slower car or tractor. It is unclear for the user why the car is following the slower vehicle instead of overtaking and driving at a faster speed. The user asks the system: "KoFFI, why don't you overtake?". This input is being processed by the modules "Automated-Speech-Recognition" and "Natural-Language-Understanding" that are part of the speech-dialog system. These modules forward their result to the Speech-Dialog-Manager, the main processing unit in the speech-dialog system. It generates a message with that consists of the event (requesting an explanation) and the situation (task: overtaking, mode: not, situation: present) which is the defined and system manageable representation of the user's question. The content-manager is routing the message to the main logic, as this is the component to answer all occurring user questions.

The main logic got a context changed-message by the model already, stating that overtaking is currently not allowed due to traffic rules. This information is converted into a message with the event "explanation" and sent back to the content-manager. The content manager routes the message to the speech dialog system, where an output via the "Natural-Language-Generation" and "Text-to-Speech" modules is generated. The user then hears a spoken feedback stating that the car is currently not allowed to overtake.

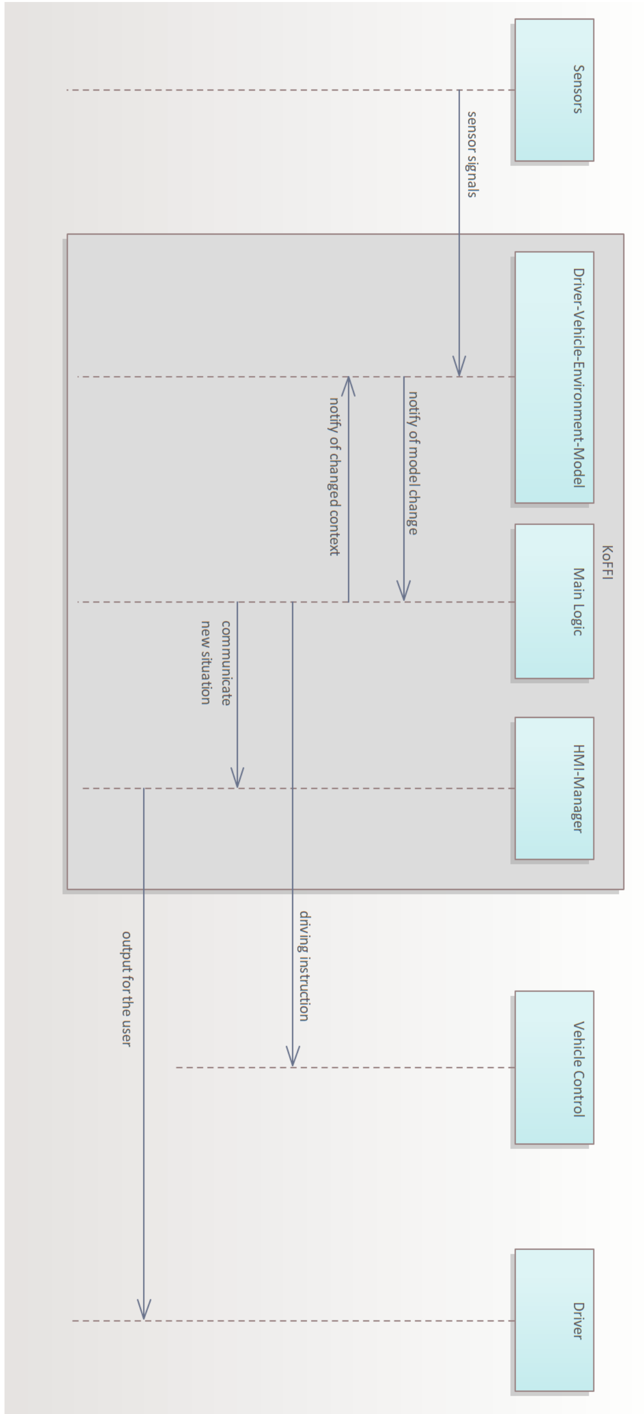

Figure 7.5: Sequence diagram showing the instruction and information flow between components in case of incoming sensor signals

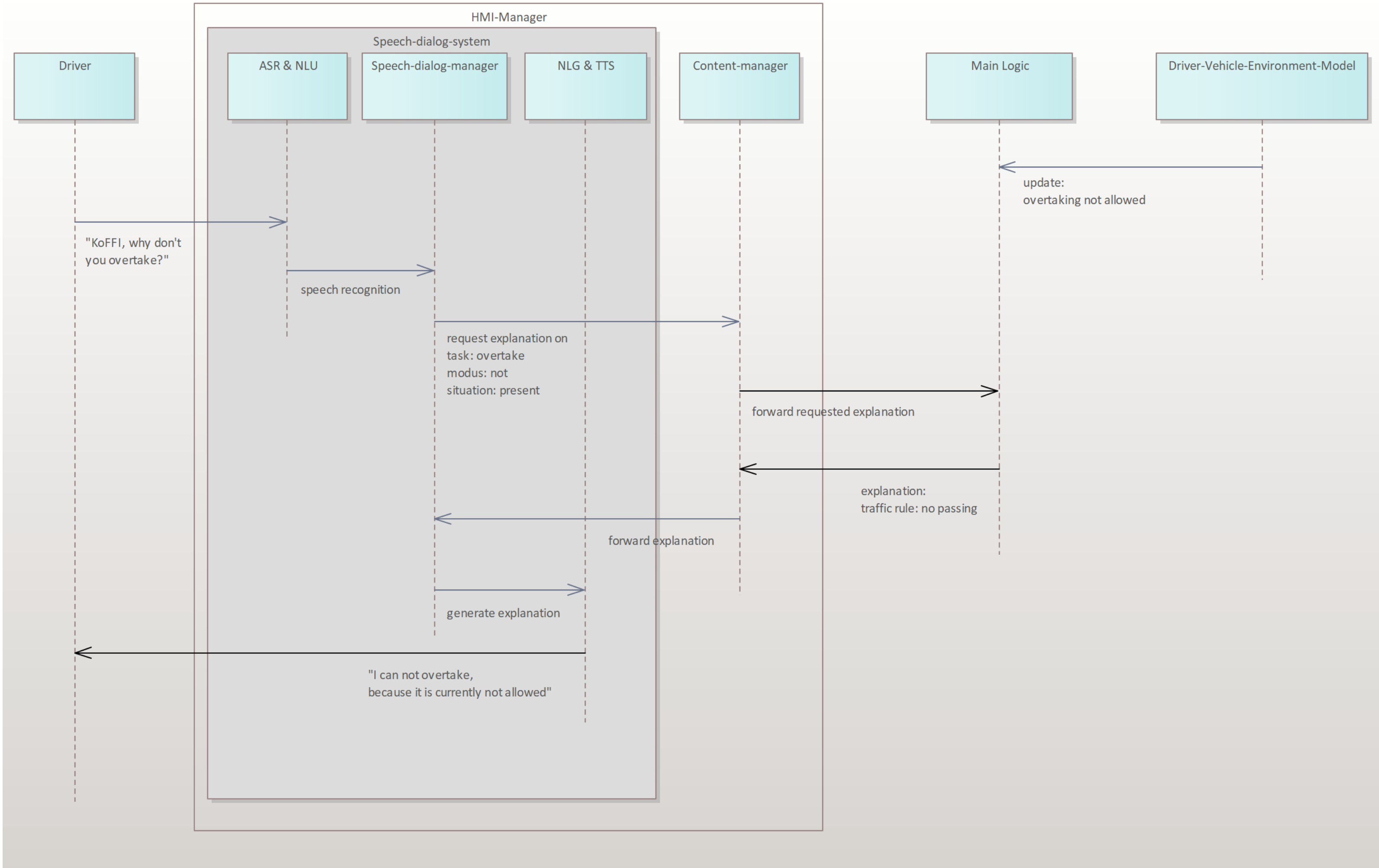

Figure 7.6: Sequence diagram showing the instruction and information flow between components in an example case where the user asked why the car does not overtake.

7.5 ARCHITECTURAL DECISIONS

This section shall provide a discussion of the decisions why the architecture was designed the way it is. Several design decisions are not obvious and have to be explained here to establish understanding for the final design. This chapter shall also show where the architecture can be used in the future and where it already is/was used.

7.5.1 *Entry Point for Sensor Signals*

KoFFI is equipped with a sensor interface, which establishes the connection to the vehicle's sensors. Incoming data has to be processed by KoFFI as the main logic needs the information of the current environmental context, the status of the vehicle and the state of driver, while the driver-vehicle-environment-model needs all this information, too. Distributing and processing the data is possible in three different ways:

METHOD 1: PARALLEL DISTRIBUTION
The signals could be forwarded by the interface to both the main logic, as well as the driver-vehicle-environment-model. This way both modules would always have the latest data, without any delay. The model could save and update the current vehicle context and driver status and the main logic would have timely data to make decisions based on the incoming information. The reason this method was not chosen is that it would require a synchronization between the main logic and the model to ensure both have received the same data at the same time and if not it would be necessary to implement an algorithm to decide which data to use in this case. Decisions of the main logic, as well as user data saved in the model would need to be transferred between the main logic and the model at the same time. This method would generate a lot additional traffic in the inter-module communication channel and require additional computations to be implemented. Therefore it was decided that incoming data will only be routed to a single module from the sensor interface.

METHOD 2: SENSOR SIGNAL PROCESSING IN THE MAIN LOGIC
Incoming sensor signal could be routed directly into the main logic. With this method the main logic could directly react to certain situations without a delay. The main logic would then have to decide which incoming data is relevant and forward these signals to the driver-vehicle-environment-model for saving. This would eliminate the need to have a certain "intelligent" computing capability implemented in the model. The model would then be a database. The problem this method poses lies in the overabundance of incoming and unfiltered sensor data as the sensors will deliver signals continuously. This results in the need to constantly check the data to see if it for example, causes

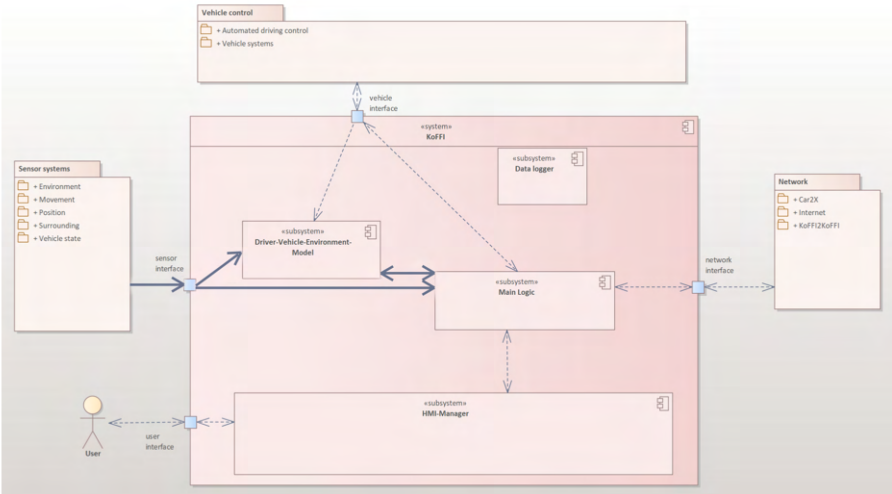

Figure 7.7: Parallel distribution of sensor signals (relevant signal path marked in bold)

a change of the current driving context. To check this the main logic would require to hold a copy of all currently relevant data or to query the model the whole time. Due to the high computing power that would be needed and the expected abundance of required communication with other modules this method has been rejected in favor of the following method:

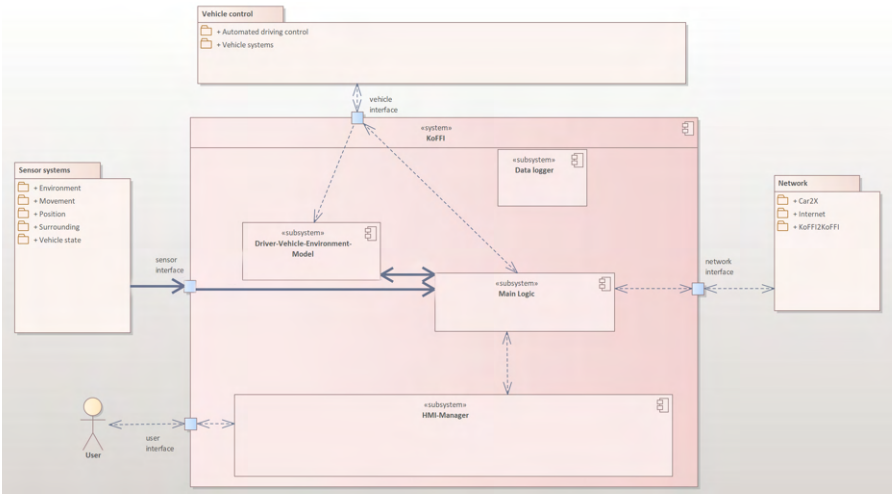

Figure 7.8: Sensor signals routed to the main logic (relevant signal path marked in bold)

Method 3: Sensor signal processing in the driver-vehicle-environment-model

The third possible method to process incoming sensor signals is to route the signals to the driver-vehicle-environment-model. The model can now compare the continuously incoming signals with the data already saved in the model. If a value hasn't changed, it can simply be discarded and in case of a changed value it can be directly saved in the model. The driver-vehicle-environment-model also holds the current context and can therefore decide if a changed value also alters the current context and inform the main logic accordingly. The advantage with this method is that the main logic does not have to process the amount of incoming data and only receives important data changes. The disadvantage of this method is that the model needs a certain amount of processing power to cope with the incoming signals and compare them to saved values without much delay. As a context change can have a huge impact on the decision process in the main logic, it has to be made sure that the corresponding message from the model to the main logic is transmitted successfully.

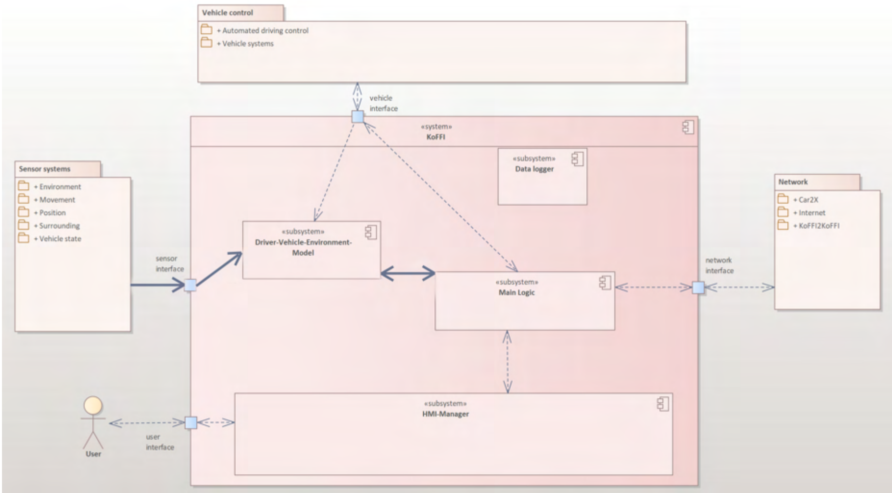

Figure 7.9: Sensor signals routed to the driver-vehicle-environment-model (relevant signal path marked in bold)

7.5.2 *Design of the HMI-Manager*

The HMI-Manager has a central module, the "Content-Manager". It is designed to act as an interface for each of the three separate interaction modules. It further holds the current status and dialog history of each of the components, as well as a distribution logic to make sure messages from the main logic are routed to the output method best fitting the respective situation. Output methods are by design not encoded in the message sent from the main logic, but instead are decided in the Content-Manager. This is to make sure that no doubled or contradictory information is presented to the user, as the Main Logic does have no information about the status of the respective input or output methods' status.

Having a central component outside of all user interfaces controlling and conducting all interactions requires a vast amount of communication as all systems have to constantly synchronize and update

each other. An alternative method would have been to implement the HMI-Manager as one system that includes all interaction methods directly instead of three separate systems. The decision to design the software like it is presented here was made due to the fact, that the interaction components were designed and implemented by different project partners in the KoFFI-project. Due to different programming languages that were used and corporate non-disclosure processes it was impossible to unify and integrate the components to a less communication intensive architecture.
By providing a central module with a defined interface however poses a possibility to exchange the interaction modules without having to be considerate of programming languages or disclosed or non-disclosed programming code.

7.5.3 *Data Logger as Part of the Main Logic?*

While it would be possible to integrate the data logging into the main logic, having it as a separate module brings flexibility. The legal requirements which data needs to be logged or is not allowed to be logged, as well as the procedure of logging and the method of saving and exporting the data is still not clear. It also might differ between countries. This would greatly influence which other modules the logger is interfacing with, which is the reason no connections are drawn in the diagram.
Making the logger a separate module allows for different versions of it, all using the same data interface. Basically, the data logger can poll all other modules for data, even the modules that are not part of KoFFI, by using the same interfaces KoFFI uses. It is important that the logger is not listening to all data values, but only to the ones it needs to log to comply with privacy-by-design standards, for example incorporated in the European GDPR regulation [98].

7.6 implementation

The architecture has been prototypically implemented, with the Main Logic and the Content-Manager being implemented by the author. Both components have been implemented in C#.
As the implementation was completely prototypical, it was not done with a full feature set, instead the development was use case driven, meaning that only certain well defined use cases and the corresponding messages were included in the decision trees of Main Logic and Content-Manager.

Though the main focus of the code was to be functional, a generic and expandable approach was chosen and all functions and XML-messages were implemented use case by use case of the planned prototype. This iterative approach greatly improved testability for the newly implemented functions. After each expansion, regression testing ensured that previously implemented functions and messages were still working properly.

7.7 USAGE

The described software architecture was mainly designed and implemented to be used in the final demonstration prototype of the KoFFI-project. This prototype was shown in the driving simulator at Ulm University.
For testing purposes during the implementation phase the architecture and implementation was used by all KoFFI partners involved in the software development in their respective driving simulator environment, demonstrating its portability and exchangeability as it was used in single- and multi-machine environments, with a variety of different hardware.
For study purposes an implementation was integrated into the driving simulator located at the Bosch Research Campus in Renningen, replacing the speech-dialog system with a wizard-of-Oz system, faking the system's possibility of recognizing spoken input.
The architecture has also served as a basis for the software architecture of a related research project called "TANGO", focusing on automated driving in trucks [83]. It is used in this project in a modified version due to a different research focus. The TANGO-project also exchanged the XML-message structure to their own protocol, due to the needed integration of original truck components using bus systems like CAN [90].

7.8 FUTURE EXPANSION

The design of the architecture makes it possible to easily add and integrate new modules. As the architecture is designed for distributed modules it would be no problem to add another one. The existing modules however would need to be retrofitted with the proper messages, event types and decision logic, taking the new connection partner(s) into account.
This allows to add modules requiring specialized hardware, for example a neural network for image recognition. Instead of porting

the Main Logic to a new (and for the current purpose unnecessary) hardware, a new module made for neural networks can be used. This allows the system as a whole to stay as low demanding as possible to be suitable for in-car use.

7.9 DISCUSSION

The presented software architecture was developed and designed for the research project KoFFI. This means that from the beginning it was always necessary to decide between a conceptually nice architecture and a pragmatical approach. Design decisions had to be discussed with the project partners to make sure the architecture fits their software systems, respectively make sure their software and hardware systems would fit into the architecture.

This has led to an architecture that features some disadvantages, like the partially doubled function of the Content-Manager in each of the input-/output-modules for the user interface. As explained above, this is due to parallel implementation between different project partners on different hardware.
The integration of different hard- and software made it necessary to design for a distributed system. In the case of KoFFI it uses an Ethernet connection with TCP-Messages to communicate between the individual modules. Making one integrated system that uses for example a bus type architecture would drastically speed up and possibly ease communication between the software modules.

The approach of using a distributed system however gives the architecture the advantage to be easily adaptable and expendable, for example to integrate another module or to change the hardware of an existing module. The loose coupling between the modules additionally allows for easy regression testing in the case of added functionality.
The separation between Driver-Vehicle-Environment-Model, Main Logic and HMI-Manager can be viewed as a model-view-controller design for the system as a whole, giving it a clean concept overall.

8 SUMMARY AND FUTURE WORK

The last chapter of this thesis provides a summary of the research done and the contributions. In the second part of this chapter the limitations of the presented research is discussed. Lastly, an outlook to further development and possible future work is given.

8.1 SUMMARY OF THE CONTRIBUTIONS

The topic of this thesis was to show the research process for a system for future automated cars that can override the driver's actions to avoid accidents, from a human-computer-interaction point of view. This includes the creation of the concept, the development of a prototypical implementation in a driving simulator and evaluations of the stages this system went through, from concept to prototypical implementation.

This thesis contributed the concept of a guardian angel-like system in a car, which, at the time of writing, does not exist. It takes inspiration from systems of other means of transportation (see chapter 2.3). A taxonomy of different assistance systems was the first step in the development process and shows the absence of said system in the automotive context.

In the first study (see chapter 4) the acceptance of an intervention was explored and yielded a positive feedback for safety-critical situations, while non-critical situations received a mixed feedback.
To further explore this, in the second study a gamified approach was used to identify situations that are perceived critical by most people (see chapter 5). As a result a set of situations can be contributed for development, that feature a high acceptance of an intervention during manual driving by a guardian angel-like system.

A software architecture for the KoFFI project was developed (see chapter 7) that was also used, respectively served as a basis, for other projects in the domain of automated driving. This architecture not only facilitates the interaction between the driver and the car, but also allows for implementation of an assistance system that can intervene during driving.

In the third study (see chapter 6), the results of the first two studies were put to test. It was explored if a guardian angel-like system would be accepted by people in a pseudo-realistic environment. The situations for the system to trigger were taken from the second study. It can be contributed, that such a system in general is accepted by most people, but the grade of acceptance depends on the driving behavior of the person.

8.2 LIMITATIONS

Every research has its limitations, that are defined by several factors. The assumptions made, materials and resources for a study and even an experimenter being present can have an impact on the results of a study. Trade-offs that have to be made in feasibility of a study versus realism could be another example of a limitation. It is important to list those limitations for oneself, but also for other people to provide the possibility to assess the results and draw conclusions.
This thesis is of course not exempt from having limitations:

The thesis focuses on the interaction between the vehicle and the driver in the context of a guardian angel-like system and completely ignores the technical aspect of such system. For the presented research the assumption is made that there will be perfect level 4 automated driving. This perfect system also needs to be able to identify a critical situation correctly and can take over control with an always favorable result.
The same applies to the legal boundaries. The research in this thesis assumes that a (perfect) guardian angel-like system will be able to take complete responsibilities of its actions and the intervention (and the simultaneous impeachment of the driver) is in accordance with the laws.

Both limitations above are a hopeful outlook to the future. As the studies have to be conducted in the present, these limitations have to be overcome in some way. This was done by using driving simulators, which itself generates other, new limitations. The simulators used are not able to replicate a completely realistic environment. This includes the look of the simulated environment as well as the behavior of the simulated car. Generating a rather realistic feeling inside a driving simulator would also require to generate some kind of acceleration, which was done by tilting the simulator, which is not able to generate lateral acceleration, for example during curves.
Though using driving simulation is not perfect, it has been shown that it allows "to predict real-world driving to a considerable degree" [48]. Yet some participants behave differently than they surely would in a real car in live traffic. The prestudy in chapter 6 showed some reckless speeding due to the lack of real (or simulated) consequences for the participants.

Another limitation of the thesis was the company environment it was written in. As study participation was limited to the employees of the company and some participants from the respective partnering institutions (for example the "Pforzheim University of Applied Sciences" in chapter 4), this led to a smaller number of participants and a more homogeneous group as it might be in the "real" world.

8.3 OUTLOOK AND FUTURE WORK

As discussed in the previous section, the research in this thesis is limited by several factors. For future development and research a first connecting factor would be to overcome several of the limitations.

A first approach could be to validate the results with a replication of the studies but with a larger and more diverse group of participants. It should yield very interesting results to have a larger span of age over the participants as well as more heterogeneous affinity for technology among the participants. As other research has showed, cultural differences can vastly influence the rating of an user interface [45] [60], and, more importantly, can have a distinctive influence on the perception of automated driving and associated systems [92].
As research for automated driving is proceeding, more sophisticated methods to examine and observe human behavior during automated driving are developed. Test vehicles, this includes real automated prototype vehicles as well as wizard of Oz-type vehicles (e.g. [67]) could be used to repeat the studies of this thesis under more realistic conditions. This would hopefully confirm the main theses and concepts of this thesis. But the real environment might clarify some aspects as the nonthreatening nature of the driving simulator would not influence the participants' decisions any longer.

Testing a guardian angel-like system in a real environment poses many risks and concerns. But with enough time and the right infrastructure this could be feasible. For example, methods and safety regulations could be similar to those used in the test procedures of frontal pedestrian impact mitigation braking-systems. The aspect of the intervention in a non-critical situation might be easier to test in a real environment, as no other road users have to be involved in those situations.
Transferring the research into a real environment is a huge effort, but ultimately not avoidable to gather the most reliable results. To reduce the amount of studies needed to be done "in the wild", it might be a good idea to first test in a driving simulator again. To improve the results of this thesis and preparing studies using a real car, using a more sophisticated driving simulator is needed. The simulator used in

this thesis did have some motion to simulate the driving experience, but the two degrees of freedom provided by it (see chapter 4 and chapter 6) are not enough to simulate the correct feeling of driving. Using at least six degrees of freedom or even eight degrees of freedom might improve the results. Combining the more sophisticated motion platforms with 360-degree projections and the complete chassis of a car should create the ultimate simulator experience of driving.

Another interesting aspect for future research would be to see if there are any long-term effects of having a guardian angel-like system in the car. Longitudinal studies in driving simulators have shown that participants tend to get used to a system and adapt their behavior over time [61].
It would be interesting to see if participants would get used to the system and maybe even start depending on it, either by losing situational awareness skills or driving more recklessly. If that is the case it could be beneficial for the design of the human machine-interface to see if trust is lost in the system if it doesn't intervene in a certain situation and how and especially how fast this trust can be reestablished. Getting used to a guardian angel-like system also seems of particular interest for ethical examinations.

A first take on the ethical challenges in chapter 4 revealed a high need in ethical guiding during the development of a system designed to take control of the car. As this can occur even against the will of the driver, as proposed in this thesis, it has to be thoroughly accompanied and monitored by ethics experts. Protection versus the autonomy of the human driver is a topic that will need a lot of discussion among ethicists as well as law makers.
At the time of writing this thesis, all signs are pointing towards automated and eventually autonomous driving. While many aspects are not yet fully developed and new research aspects constantly arise, automated driving is a promising and interesting field. Until the possibility to use an autonomous vehicle, humans will need to take control of the car at least from time to time. And doing so will give them the possibility of making errors. Engineers and researchers must use all possible means of technology to reduce the number of errors as much as possible and to reduce the number of risks and especially fatalities in road traffic.

As soon as the idea of a guardian angel-like system leaves the academic research phase and is being worked on by car manufacturers and automotive suppliers the law makers have to discuss legal constraints and legal competences of such systems. At the time of writing it would not be legally allowed to implement such system in a real car, driving on public roads.

In accordance with their "Vision Zero" [106], the European Parliament and the European Council passed a regulation on 27 November 2019 that makes several assistance systems mandatory for new cars, trucks and buses. Besides safety features for occupants, new systems are made mandatory to protect other road users like cyclists and pedestrians with a blind-spot warning and emergency braking function for trucks and buses [88].

It is also possible that systems will be introduced that can provide valuable warnings and advises to the driver. Even though such system might be introduced as a warning system, it is possible that over time the influence of this system might change and someday drivers are obligated to follow the advice of this system (see the change of TCAS over time, chapter 2.3.3). It might be a good idea to have the possibility of the change of influence in mind when designing an assistance system, the results of this thesis might give a good starting point for this.

BIBLIOGRAPHY

[1] Kasey Ackerman, Enric Xargay, Donald A Talleur, Ronald S Carbonari, Alex Kirlik, Naira Hovakimyan, Irene M Gregory, Christine M Belcastro, Anna Trujillo, and Benjamin D Seefeldt. "Flight envelope information-augmented display for enhanced pilot situational awareness." In: *AIAA Infotech@ Aerospace*. 2015, p. 1112.

[2] National Highway Traffic Safety Administration et al. "Preliminary statement of policy concerning automated vehicles." In: *Washington, DC* 1 (2013), p. 14.

[3] Lisanne Bainbridge. "Ironies of automation." In: *Analysis, design and evaluation of man–machine systems*. Elsevier, 1983, pp. 129–135.

[4] Aaron Bangor, Philip T Kortum, and James T Miller. "An empirical evaluation of the system usability scale." In: *Intl. Journal of Human–Computer Interaction* 24.6 (2008), pp. 574–594.

[5] Luis Miguel Bergasa, Jesus Nuevo, Miguel A Sotelo, Rafael Barea, and María Elena Lopez. "Real-time system for monitoring driver vigilance." In: *IEEE Transactions on Intelligent Transportation Systems* 7.1 (2006), pp. 63–77.

[6] National Transportation Safety Board. *Loss of Thrust in Both Engines After Encountering a Flock of Birds and Subsequent Ditching on the Hudson River, US Airways Flight 154,9 Airbus A320-214,N106US*. Accident report. Weehawken, New Jersey, Jan. 15, 2009. URL: `https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR1003.pdf` (visited on 02/05/2021).

[7] Göde Both and Jutta Weber. "Hands-free driving? Automatisiertes fahren und mensch-maschine interaktion." In: *Robotik im Kontext von Recht und Moral*. Nomos Verlagsgesellschaft mbH & Co. KG. 2013, pp. 171–189.

[8] Peter Brandstädter, Osman Gürbüz, Theresa Jarchow, Irina Kuznetsova, Sophie Neef, Milenko Petrovic, Kevin Seiler, and Christian Stropp. "Projektbericht Interdisziplinäre Projektarbeit-Entwicklung eines Interfaces zur kognitiven Anreicherung der Interaktion von Lokführern mit der Punktförmigen Zugbeeinflussung." PhD thesis. Technische Universität Berlin, 2014.

[9] Thomas Brandt, Ralf Stemmer, and Andry Rakotonirainy. "Affordable visual driver monitoring system for fatigue and monotony." In: *2004 IEEE International Conference on Systems, Man and Cybernetics (IEEE Cat. No. 04CH37583)*. Vol. 7. IEEE. 2004, pp. 6451–6456.

[10] John Brooke. "System usability scale (SUS): a quick-and-dirty method of system evaluation user information." In: *Reading, UK: Digital Equipment Co Ltd* 43 (1986).

[11] David J Bruemmer, Donald D Dudenhoeffer, and Julie L Marble. "Dynamic-Autonomy for Urban Search and Rescue." In: *AAAI mobile robot competition*. 2002, pp. 33–37.

[12] Patrick Buckley and Elaine Doyle. "Gamification and student motivation." In: *Interactive learning environments* 24.6 (2016), pp. 1162–1175.

[13] Software Engineering Institute Carnegie Mellon University. *What Is Your Definition of Software Architecture*. Dec. 2010. URL: `https://resources.sei.cmu.edu/library/asset-view.cfm?assetID=513807` (visited on 10/23/2020).

[14] Oliver Carsten and Marieke H Martens. "How can humans understand their automated cars? HMI principles, problems and solutions." In: *Cognition, Technology & Work* 21.1 (2019), pp. 3–20.

[15] Jacob Cohen. *Statistical power analysis for the behavioral sciences*. Academic press, 2013.

[16] *Convention on Road Traffic, Geneva, September 19, 1949*. Sept. 19, 1949. URL: `https://treaties.un.org/doc/Publication/MTDSG/Volume%20I/Chapter%20XI/XI-B-1.en.pdf` (visited on 08/16/2019).

[17] *Convention on road traffic, Vienna, November 8, 1968*. Nov. 8, 1986. URL: `https://treaties.un.org/doc/Treaties/1977/05/19770524%2000-13%20AM/Ch_XI_B_19.pdf` (visited on 08/16/2019).

[18] Thomas J Daun and Markus Lienkamp. "Spielend Fahren: Gamification-Konzept für Fahrerassistenzsysteme." In: *USEWARE 2012*. 2012, S–269.

[19] *Declaration of Amsterdam*. Apr. 15, 2019. URL: `https://www.rijksoverheid.nl/documenten/rapporten/2016/04/29/declaration-of-amsterdam-cooperation-in-the-field-of-connected-and-automated-driving` (visited on 05/06/2020).

[20] *Der Mensch ist noch zu kindisch für autonomes Fahren*. Jan. 25, 2018. URL: `https://www.sueddeutsche.de/auto/tesla-der-mensch-ist-noch-zu-kindisch-fuer-autonomes-fahren-1.3839832` (visited on 06/03/2020).

[21] Munjal Desai and Holly A Yanco. "Blending human and robot inputs for sliding scale autonomy." In: *ROMAN 2005. IEEE International Workshop on Robot and Human Interactive Communication, 2005.* IEEE. 2005, pp. 537–542.

[22] Sebastian Deterding, Dan Dixon, Rilla Khaled, and Lennart Nacke. "From game design elements to gamefulness: defining" gamification"." In: *Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments*. 2011, pp. 9–15.

[23] Institut für Digitale Ethik. *Institut für Digitale Ethik*. URL: https://www.digitale-ethik.de (visited on 06/02/2020).

[24] Adrián Domínguez, Joseba Saenz-De-Navarrete, Luis De-Marcos, Luis Fernández-Sanz, Carmen Pagés, and José-Javier Martínez-Herráiz. "Gamifying learning experiences: Practical implications and outcomes." In: *Computers & education* 63 (2013), pp. 380–392.

[25] Edmund Donges. "Aspekte der aktiven Sicherheit bei der Führung von Personenkraftwagen." In: *Automob-Ind* 27.2 (1982).

[26] Edmund Donges. "Fahrerverhaltensmodelle." In: Hermann Winner, Stephan Hakuli, and Gabriele Wolf. *Handbuch Fahrerassistenzsysteme*. Springer-Verlag, 2015, pp. 17–26.

[27] Rainer Erbach, Steffen Maurer, Gerrit Meixner, Marius Koller, Marcel Woide, Marcel Walch, Michael Weber, Martin Baumann, Petra Grimm, Tobias Keber, et al. "KoFFI—The New Driving Experience: How to Cooperate with Automated Driving Vehicles." In: *Smart Automotive Mobility*. Springer, 2020, pp. 155–211.

[28] *Ethik-Kommission Automatisiertes und Vernetztes Fahren. Bericht Juni 2017*. June 20, 2017. URL: https://www.bmvi.de/SharedDocs/DE/Publikationen/DG/bericht-der-ethik-kommission.html (visited on 06/02/2020).

[29] *Fachserie. 8, Verkehr. 7, Verkehrsunfälle. Jährlich – 2018*. 2018. URL: https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Verkehrsunfaelle/_inhalt.html (visited on 06/17/2020).

[30] *Fahrsimulation und SILAB*. URL: https://wivw.de/de/silab (visited on 06/03/2020).

[31] Despina Filippidou. "Designing with scenarios: a critical review of current research and practice." In: *Requirements Engineering* 3.1 (1998), pp. 1–22.

[32] Donald L Fisher, Matthew Rizzo, Jeffrey Caird, and John D Lee. *Handbook of driving simulation for engineering, medicine, and psychology*. CRC Press, 2011.

[33] Bundesministerium für Bildung und Forschung Deutschland. *KoFFI Kooperative Fahrer Fahrzeug Interaktion*. URL: http://www.technikzum-menschen-bringen.de/projekte/koffi (visited on 05/23/2020).

[34] Tom M Gasser, Clemens Arzt, Mihiar Ayoubi, Arne Bartels, Lutz Bürkle, Jana Eier, Frank Flemisch, Dirk Häcker, Tobias Hesse, Werner Huber, et al. "Rechtsfolgen zunehmender fahrzeugautomatisierung." In: *Berichte der Bundesanstalt für Straßenwesen. Unterreihe Fahrzeugtechnik* 83 (2012).

[35] Tom M. Gasser, Andre Seeck, and Bryant W. Smith. "Rahmenbedingungen für die Fahrerassistenzentwicklung." In: Hermann Winner, Stephan Hakuli, and Gabriele Wolf. *Handbuch Fahrerassistenzsysteme*. Springer-Verlag, 2015. Chap. 3. DOI: 10.1007/978-3-658-05734-3_3.

[36] Sonja Giesemann and Anja Naumann. "Zugsicherungssysteme-Assistenz für Triebfahrzeugführer?" In: *Kognitive Systeme* 2015.1 (2015).

[37] Olaf Gietelink, Jeroen Ploeg, Bart De Schutter, and Michel Verhaegen. "Development of advanced driver assistance systems with vehicle hardware-in-the-loop simulations." In: *Vehicle System Dynamics* 44.7 (2006), pp. 569–590.

[38] R Glaser and H Waschulewski. "Invent-Forschungsprojekt Fahrerassistenzsysteme (FAS) Teilprojekt Fahrerverhalten und Mensch-Maschine-Interaktion (FVM) Arbeitspaket 3200 Validierung und Weiterentwicklung des Bewertungsverfahrens I-TSA (invent–traffic safety assessment). Abschlussbericht." In: *Zugriff am* 23 (2005), p. 286.

[39] *Global status report on road safety 2018*. 2018. URL: https://www.who.int/violence_injury_prevention/road_safety_status/2018/en/ (visited on 01/11/2021).

[40] Thomas Grundmann, Joachim Horvath, and Jens Kipper. "Die experimentelle Philosophie in der Diskussion." In: (2014).

[41] Sandra G Hart. "NASA-task load index (NASA-TLX); 20 years later." In: *Proceedings of the human factors and ergonomics society annual meeting*. Vol. 50. 9. Sage Publications Sage CA: Los Angeles, CA. 2006, pp. 904–908.

[42] Sandra G Hart and Lowell E Staveland. "Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research." In: *Advances in psychology*. Vol. 52. Elsevier, 1988, pp. 139–183.

[43] Marc Hassenzahl, Michael Burmester, and Franz Koller. "AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität." In: *Mensch & computer 2003*. Springer, 2003, pp. 187–196.

[44] Anita Hausmann and Dirk H Enders. *Grundlagen des Bahnbetriebs*. Bahn Fachverlag, 2007.

[45] Rüdiger Heimgärtner. “ISO 9241-210 and culture?–The impact of culture on the usability engineering process.” In: *International Conference of Design, User Experience, and Usability*. Springer. 2014, pp. 39–48.

[46] *Here's every company developing self-driving car tech at CES 2018*. 2018. URL: https://www.digitaltrends.com/cars/every-company-developing-self-driving-car-tech-ces-2018/ (visited on 05/06/2018).

[47] Eric Hilgendorf. “Teilautonome Fahrzeuge: Verfassungsrechtliche Vorgabenund rechtspolitische Herausforderungen.” In: *Rechtliche Aspekte automatisierter Fahrzeuge*. Nomos Verlagsgesellschaft mbH & Co. KG. 2015, pp. 15–32.

[48] Philipp Hock, Johannes Kraus, Franziska Babel, Marcel Walch, Enrico Rukzio, and Martin Baumann. “How to design valid simulator studies for investigating user experience in automated driving: review and hands-on considerations.” In: *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 2018, pp. 105–117.

[49] Philipp Hock, Johannes Kraus, Marcel Walch, Nina Lang, and Martin Baumann. “Elaborating Feedback Strategies for Maintaining Automation in Highly Automated Driving.” In: *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. Automotive'UI 16. Ann Arbor, MI, USA: Association for Computing Machinery, 2016, pp. 105–112. DOI: 10.1145/3003715.3005414.

[50] Wonil Hwang and Gavriel Salvendy. “Number of people required for usability evaluation: the 10±2 rule.” In: *Communications of the ACM* 53.5 (2010), pp. 130–133.

[51] *ICAO DOC 8168: "Procedures for Air Navigation Services - Aircraft Operations (PANS-OPS)*. 2006. URL: http://www.chcheli.com/sites/default/files/icao_doc_8168_vol_1.pdf (visited on 05/08/2020).

[52] *ISO 9241-210:2019 (Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems)*. Standard. Geneva, CH: International Organization for Standardization, 2019.

[53] SAE International. *AUTOMATED DRIVING Levels of Driving Automation are Defined in new SAE International Standard J3016*. 2014. URL: https://www.sae.org/binaries/content/assets/cm/content/news/press-releases/pathway-to-autonomy/automated_driving.pdf (visited on 01/28/2021).

[54] Ivar Jacobson, Ian Spence, and Brian Kerr. “Use-Case 2.0.” In: *Queue* 14.1 (2016), pp. 94–123.

[55] Anette Jerup Jørgensen. *Moral Regulation in Traffic Culture*. 2006. URL: http://www.trafikdage.dk/td/papers/papers06/Papers-wordudgave/Trafikdage-2006-510.doc (visited on 06/13/2017).

[56] Karl M Kapp. *The gamification of learning and instruction: game-based methods and strategies for training and education*. John Wiley & Sons, 2012.

[57] Chiara Knecht, Céline Mühlethaler, Jasmin Zimmermann, Simon Binz, Ranjit Painadath, and Toni Wäfler. "Vertrauen in die Automatisierung, fehlende Situation Awareness & Fertigkeitsverlust durch automatisierte Systeme–Eine subjektive Einschätzung aus der Linienpilotenperspektive." In: *56. Fachausschusssitzung Anthropotechnik der DGLR* (2014).

[58] Jeamin Koo, Jungsuk Kwac, Wendy Ju, Martin Steinert, Larry Leifer, and Clifford Nass. "Why did my car just do that? Explaining semi-autonomous driving actions to improve driver understanding, trust, and performance." In: *International Journal on Interactive Design and Manufacturing (IJIDeM)* 9.4 (2015), pp. 269–275.

[59] Antonius A Lambregts. "Flight envelope protection for automatic and augmented manual control." In: *Proceedings of the EuroGNC* (2013), pp. 1364–1383.

[60] David R Large, Gary Burnett, Elizabeth Crundall, Glyn Lawson, Lee Skrypchuk, and Alex Mouzakitis. "Evaluating secondary input devices to support an automotive touchscreen HMI: A cross-cultural simulator study conducted in the UK and China." In: *Applied ergonomics* 78 (2019), pp. 184–196.

[61] David R Large, Gary Burnett, Davide Salanitri, Anneka Lawson, and Elizabeth Box. "A Longitudinal Simulator Study to Explore Drivers' Behaviour in Level 3 Automated Vehicles." In: *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 2019, pp. 222–232.

[62] John D Lee, Joshua D Hoffman, and Elizabeth Hayes. "Collision warning design to mitigate driver distraction." In: *Proceedings of the SIGCHI Conference on Human factors in Computing Systems*. 2004, pp. 65–72.

[63] E. Liebemann, K. Meder, J. Schuh, and G. Nenninger. "Safety and Performance Enhancement: The Bosch Electronic Stability Control (ESP)." In: 2005.

[64] Patrick Lin. "Why ethics matters for autonomous cars." In: *Autonomous driving*. Springer, Berlin, Heidelberg, 2016, pp. 69–85.

[65] Anders Lindgren and Fang Chen. "State of the art analysis: An overview of advanced driver assistance systems (adas) and possible human factors issues." In: *Human factors and economics aspects on safety* 38 (2006), p. 50.

[66] Christian Löper, Johann Kelsch, and Frank Ole Flemisch. "Kooperative, manöverbasierte Automation und Arbitrierung als Bausteine für hochautomatisiertes Fahren." In: (2008).

[67] Dietrich Manstetten, Claus Marberger, and Frank Beruscha. "WIZARD-OF-OZ EXPERIMENTS IN REAL TRAFFIC–CAN THEY RESTART HUMAN FACTORS?" In: *Hands off, Human Factors off? Welche Rolle spielen Human Factors in der Fahrzeugautomation?* (2019), p. 21.

[68] Steffen Maurer, Rainer Erbach, Issam Kraiem, Susanne Kuhnert, Petra Grimm, and Enrico Rukzio. "Designing a Guardian Angel: Giving an Automated Vehicle the Possibility to Override Its Driver." In: *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. AutomotiveUI '18. Toronto, ON, Canada: Association for Computing Machinery, 2018, pp. 341–350. DOI: 10.1145/3239060.3239078.

[69] Steffen Maurer, Enrico Rukzio, and Rainer Erbach. "Challenges for Creating Driver Overriding Mechanisms." In: *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct*. AutomotiveUI '17. Oldenburg, Germany: Association for Computing Machinery, 2017, pp. 99–103. DOI: 10.1145/3131726.3131764.

[70] Steffen Maurer, Lara Scatturin, and Enrico Rukzio. "Playing Guardian Angel: Using a Gamified Approach to Overcome the Overconfidence Bias in Driving." In: *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia*. MUM '19. Pisa, Italy: Association for Computing Machinery, 2019, Art. No. 12. DOI: 10.1145/3365610.3365614.

[71] Steffen Maurer, Ramona Schmid, Rainer Erbach, and Enrico Rukzio. "Inducing Erroneous Behavior in a Driving Simulator with Gamification." In: *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings*. AutomotiveUI '19. Utrecht, Netherlands: Association for Computing Machinery, 2019, pp. 277–281. DOI: 10.1145/3349263.3351323.

[72] Iain A McCormick, Frank H Walkey, and Dianne E Green. "Comparative perceptions of driver ability—a confirmation and expansion." In: *Accident Analysis & Prevention* 18.3 (1986), pp. 205–208.

[73] Heinrich Menssen. *Moderne Flugsicherun. Organisation - Verfahren - Technik*. German. 4th Edition. location: Springer Vieweg, 2014. ISBN: 978-3-642-54293-0. DOI: 10.1007/978-3-642-54294-7.

[74] Nikil Mukerji. *Einführung in die experimentelle Philosophie*. Wilhelm Fink, 2019.

[75] Michael Müller and Petra Grimm. *Narrative Medienforschung: Einführung in Methodik und Anwendung*. UVK Verlagsgesellschaft mbH, 2016.

[76] Nameless23. *Vienna Convention on Road Traffic.svg. The file is licensed under the Creative Commons Attribution-Share Alike 4.0 International*. 2016. URL: https://creativecommons.org/licenses/by-sa/4.0.

[77] Scott Nicholson. "A recipe for meaningful gamification." In: *Gamification in education and business*. Springer, 2015, pp. 1–20.

[78] Florian Nothdurft, Stefan Ultes, and Wolfgang Minker. "Finding appropriate interaction strategies for proactive dialogue systems—an open quest." In: *Proceedings of the 2nd European and the 5th Nordic Symposium on Multimodal Communication, August 6-8, 2014, Tartu, Estonia*. 110. Linköping University Electronic Press. 2015, pp. 73–80.

[79] Dianne Parker, James T Reason, Antony SR Manstead, and Stephen G Stradling. "Driving errors, driving violations and accident involvement." In: *Ergonomics* 38.5 (1995), pp. 1036–1048.

[80] European Parliament. *Safer roads: EU lawmakers agree on life-saving technologies for new vehicles*. Mar. 26, 2019. URL: https://www.europarl.europa.eu/news/en/press-room/20190326IPR33205/safer-roads-eu-lawmakers-agree-on-life-saving-technologies-for-new-vehicles (visited on 01/11/2021).

[81] Press and Information Office of the Federal Government. *Autonomes Fahren in die Praxis holen*. Feb. 10, 2021. URL: https://www.bundesregierung.de/breg-de/aktuelles/faq-autonomes-fahren-1852070 (visited on 04/10/2021).

[82] *Privacy and Ethics in Highly Automated Driving*. 2019. URL: https://www.hdm-stuttgart.de/science/view_beitrag?science_beitrag_ID=506 (visited on 05/23/2020).

[83] *Projekt TANGO. Technologie für automatisiertes Fahren nutzergerecht imiert*. 2020. URL: https://projekt-tango-trucks.com/ (visited on 01/05/2021).

[84] Regina Ammicht Quinn, Michael Nagenborg, Benjamin Rampp, and Andreas FX Wolkenstein. "Ethik und Sicherheitstechnik. Eine Handreichung." In: *Sicherheitsethik*. Springer, 2014, pp. 277–296.

[85] *Rangkorrelation nach Spearman*. URL: https://www.methodenberatung.uzh.ch/de/datenanalyse_spss/zusammenhaenge/rangkorrelation.html (visited on 09/12/2020).

[86] Mike Ray. *Airbus A320 Pilot Handbook - Simulator and Checkride*. University of Temecula Press, Inc., 2011. ISBN: 9781460955512.

[87] James Reason, Antony Manstead, Stephen Stradling, James Baxter, and Karen Campbell. "Errors and violations on the roads: a real distinction?" In: *Ergonomics* 33.10-11 (1990), pp. 1315–1332.

[88] *Regulation (EU) 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users*. Nov. 27, 2019. URL: https://eur-lex.europa.eu/eli/reg/2019/2144/oj (visited on 05/21/2020).

[89] Maria Rimini-Doering, Dietrich Manstetten, Tobias Altmueller, Ulrich Ladstaetter, and Michael Mahler. "Monitoring driver drowsiness and stress in a driving simulator." In: (2001).

[90] *Road vehicles — Controller area network (CAN) — Part 1: Data link layer and physical signallin*. Standard. Geneva, CH: International Organization for Standardization, 2015.

[91] Jeffrey D Rupp and Anthony G King. *Autonomous driving-A practical roadmap*. Tech. rep. SAE Technical Paper, 2010.

[92] Vanessa Sauer, Alexander Mertens, Stefan Groß, Jens Heitland, and Verena Nitsch. "Designing Automated Vehicle Interiors for Different Cultures: Evidence From China, Germany, and the United States." In: *Ergonomics in Design* (2020). DOI: 10.1177/1064804620966158.

[93] Matthias Schäfer, Xavier Olive, Martin Strohmeier, Matthew Smith, Ivan Martinovic, and Vincent Lenders. "OpenSky Report 2019: Analysing TCAS in the Real World using Big Data." In: Sept. 2019. DOI: 10.1109/DASC43569.2019.9081686.

[94] Thomas B Sheridan and William L Verplank. *Human and computer control of undersea teleoperators*. Tech. rep. Massachusetts Inst of Tech Cambridge Man-Machine Systems Lab, 1978.

[95] Judith Simon. "Values in design." In: *Handbuch Medien-und Informationsethik*. Springer, 2016, pp. 357–364.

[96] Bosch Mobility Solutions. *New service for drivers: Bosch lets cars find parking spaces themselves*. 2018. URL: https://www.bosch-mobility-solutions.com/en/highlights/connected-mobility/community-based-parking/ (visited on 05/04/2018).

[97] Neville A Stanton and Paul M Salmon. "Human error taxonomies applied to driving: A generic driver error taxonomy and its implications for intelligent transport systems." In: *Safety Science* 47.2 (2009), pp. 227–237.

[98] European Data Protection Supervisor. *Opinion 5/2018, Preliminary Opinion on privacy by design*. May 31, 2018. URL: https://edps.europa.eu/sites/edp/files/publication/18-05-31_preliminary_opinion_on_privacy_by_design_en_0.pdf (visited on 11/23/2020).

[99] Atomic Motion Systems. *Atomic. A-Series Motion Systems*. URL: https://www.atomicmotionsystems.com/motion-systems/ (visited on 07/23/2020).

[100] *T154 / B752, en-route, Überlingen Germany, 2002*. URL: https://www.skybrary.aero/index.php/T154_/_B752,_en-route,_Uberlingen_Germany,_2002 (visited on 05/08/2020).

[101] *Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems*. Standard. SAE International, 2014. DOI: 10.4271/J3016_201806.

[102] Pascal Traverse, Isabelle Lacaze, and Jean Souyris. "Airbus fly-by-wire: A total approach to dependability." In: *Building the Information Society*. Springer, 2004, pp. 191–212.

[103] Sandra Trösterer, Alexander Meschtscherjakov, Alexander G Mirnig, Artur Lupp, Magdalena Gärtner, Fintan McGee, Rod McCall, Manfred Tscheligi, and Thomas Engel. "What we can learn from pilots for handovers and (de) skilling in semi-autonomous driving: An interview study." In: *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 2017, pp. 173–182.

[104] *UNECE paves the way for automated driving by updating UN international convention*. Mar. 23, 2016. URL: https://www.unece.org/info/media/presscurrent-press-h/transport/2016/unece-paves-the-way-for-automated-driving-by-updating-un-international-convention/doc.html (visited on 05/06/2020).

[105] *Unity Real-Time Development Platform*. URL: https://unity.com/ (visited on 06/24/2020).

[106] *Vision Zero*. 2007. URL: https://www.dvr.de/ueber-uns/vision-zero (visited on 01/11/2021).

[107] Marcel Walch, Marcel Woide, Kristin Mühl, Martin Baumann, and Michael Weber. "Cooperative Overtaking: Overcoming Automated Vehicles' Obstructed Sensor Range via Driver Help." In: *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. Automo-

tiveUI '19. Utrecht, Netherlands: Association for Computing Machinery, 2019, pp. 144–155.

[108] D Walton and J Bathurst. "An exploration of the perceptions of the average driver's speed compared to perceived driver safety and driving skill." In: *Accident Analysis & Prevention* 30.6 (1998), pp. 821–830.

[109] Hermann Winner and Stephan Hakuli. "Conduct-by-wire–following a new paradigm for driving into the future." In: *Proceedings of FISITA world automotive congress*. Vol. 22. Citeseer. 2006, p. 27.

[110] Hermann Winner, Stephan Hakuli, and Gabriele Wolf. *Handbuch Fahrerassistenzsysteme*. Springer-Verlag, 2015. DOI: `10.1007/978-3-658-05734-3`.

[111] Marcus Wong. *Signal-and-train-stop-melbourne.jpg and Train-trip-lever.jpg. The file is licensed under the Creative Commons Attribution-Share Alike 4.0 International*. 2005. URL: `https://creativecommons.org/licenses/by-sa/4.0`.

[112] Mark S Young, Neville A Stanton, and Don Harris. "Driving automation: learning from aviation about design philosophies." In: *International Journal of Vehicle Design* 45.3 (2007), pp. 323–338.