Approaches of User-Centered Interaction Development for Highly Automated Vehicles in Traffic-Jam Scenarios

Felix Wulf, Maria Rimini-Doering, Marc Arnon and Frank Gauterin

Abstract In the recent years one of the goals of driver assistance systems has been to disburden the driver of parts of the driving task. Current developments are able to take over full control of the vehicle in specific use cases. One of the main challenges is to maintain the driver's ability to take back the responsibility while being driven by the car. As it is assumed that the driver's main benefit of such systems is the possibility to perform secondary tasks, a target conflict comes up. This paper describes a systematic approach to derive new ways of interaction between the driver and the automated vehicle. Traffic jam situations are chosen as the example situational context for this paper since they are one of the first expected use cases for automated driver assistance systems. By incorporating knowledge of experts of interdisciplinary fields in an innovation workshop, multiple points of view towards the given problem are enabled. For good rated ideas the generalized functional principle is formulated which describes how the user is kept aware of his supervision task. The resulting functional examples are decoupled from the initial ideas by deriving them only from these principles.

Keywords Driver assistance · Automation · Traffic jam · Human–machine interaction · Driver attentiveness

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1 Introduction

Due to the increasing mobility, there is a growing demand for comfort and safety in traffic. Current developments in the sector of driver assistance systems (DAS) concentrate on the lateral guidance of vehicles (e.g. [4] or [13]). The resulting automatic steering control (ASC) is able to take over lateral control of the vehicle. The next step will be the combination of ASC with existing systems like adaptive cruise control (ACC), which is capable of taking over longitudinal control of the vehicle [14]. The emerging integrated cruise assistance systems (ICA) will therefore be able to take over longitudinal and lateral control of the vehicle in specific environments and hence disburden the driver of parts of his driving task. Stanton and Marsden [12] have identified significant potential benefits of automated driving functions:

- Improved well-being of the driver,
- Reduction of driving error and therefore enhancement of safety,
- Greater attractiveness and desirability of such driver assistance systems and therefore increased sales.

One of the first expected use cases for automated DAS is driving in traffic jams. This is due to the fact that the driver is usually underloaded in traffic jams because of the tiresome and monotonous driving situation. Hence, this is one of the scenarios where good advantages can accrue from automation.

The following chapters describe the human role in an automated vehicle. This motivates a need for new interactions schemes for automated DAS. Afterwards an overview on an innovation process is given. It is designed to generate new interaction schemes for automated driver assistance systems. Subsequently, the process is conducted using the example of automated driving in traffic jams.

2 The Human in Automated Vehicles

Recent research [5] has identified several degrees of automation to characterize driver assistance systems that can take over both longitudinal and lateral control of the vehicle. The main distinctive features for the characterization of such systems are the necessity for permanent observation of the automation and the necessity for the driver's constant ability of controlling the vehicle. If both needs are given, the corresponding level of automation is called "partly automated". In the higher levels of automation permanent attention of the driver is not necessary which leads to legal issues covering product liability and the question of responsibility in case of an accident. Since these issues are not yet solved, partly automatic DAS are seen as the next step towards autonomous driving. The current paper deals only with partly automatic DAS.

As mentioned above, in partly automatic DAS the driver needs permanent attention. The attention level can be represented by the concept of situation awareness. Endsley [3] defines situation awareness as the “perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”. Consequently, one can speak of three levels of situation awareness (perception, comprehension and projection). A sufficient global level of situation awareness is needed in order to react adequately to external stimuli. Rauch [11] states that automation can have a negative effect on situation awareness. In case of system errors, a lack of situation awareness can lead to late, wrong or even missing counter-reactions of the operator [2, 8].

A sufficient level of situation awareness is essential. Hence, the fulfilment of this requirement is one of the main aims in the current research activity. This paper focuses on the process of discovering new interaction schemes between the driver and a partly automated DAS which can support situation awareness.

The term “interaction” denominates in this case the collaboration of the driver and the automated system in order to perform the task of driving the vehicle. This can mean both the allocation of drive-related tasks between human and automation and the communication between them e.g. through displays or operational controls.

Any new interaction element has an influence on the characteristics of the DAS. This can potentially also change the acceptance and the perceived benefit of the end user. Both are among the main criteria for the success of DAS. Therefore, these aspects are also taken into account in the evaluation of the interaction schemes.

3 Overview on the Process of Deriving Interaction Schemes to Support Situation Awareness

In order to find new interaction elements, a specific innovation process was conducted. The development was based on the process to find new products, described by Pahl and Beitz [9]. Two steps were added in order to enhance the quality of the results. Thus, it consists of four main stages which are visualized in Fig. 1.

In the first step, new ideas are generated. It is therefore called the Generation step. According to the basic process [9], new thoughts can be found through various methods. One of them is the innovation workshop using intuitive methods such as a brainstorming or other creativity techniques. The aim of this step is to generate the highest possible number of ideas.

After the generation of new ideas, they must be evaluated and filtered in the second step of the process (Filtering). Therefore, similar ideas are identified and merged. Afterwards the effectiveness of every idea towards the given criteria of

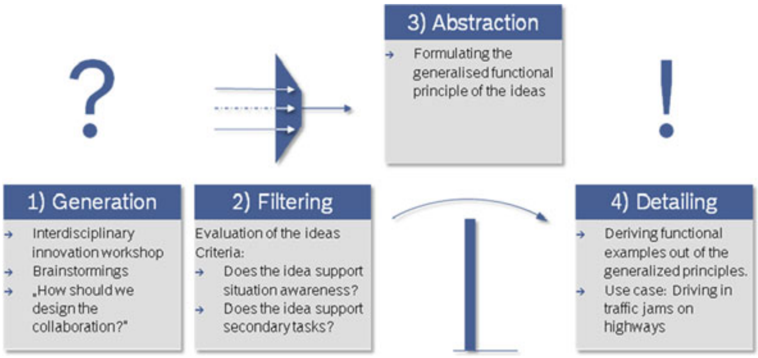

Fig. 1 Overview on the approach of generating generalized functional principles and examples

the innovation process is rated. The objective of this step is to reduce the quantity and to raise the quality of the resulting items.

It is supposed that many of the resulting ideas are designed according to few functional principles. This stands in analogy to the TRIZ-method, which states that many technical conflicts can be solved using only a few abstract principles of invention [6]. Thus, in order to get a better overview on the resulting ideas, the Abstraction step is added to the standard process described by Pahl and Beitz [9]. Every good rated element is generalized and its underlying functional principle is formulated. This principle describes how the given goals shall be reached. This is a further step in order to reduce the quantity and to raise the quality of the resulting items.

In the subsequent Detailing step, the resulting elements of the process are derived only from these generalized principles. The advantage of this procedure is that the results are decoupled from the conceived ideas in the first step and that new perspectives on the same principles can be allowed. Thus, the results become more holistic.

In the following chapters, the process is conducted using the example of automated driving in traffic jams.

4 The Generation Step

In the generation phase, a workshop with 14 experts was conducted. In order to ensure multiple points of view towards the given problem, the participants were recruited from three different groups:

- Experts in the field of driver assistance systems,
- Experts in the field of Human–Machine Interaction,
- Various other technical experts.

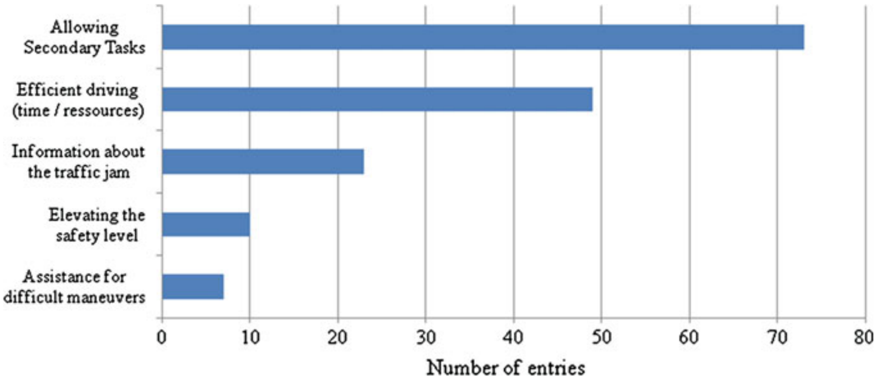

Fig. 2 End-user benefits of DAS in traffic jams

The workshop was conducted by a team of two facilitators. It was divided into two parts, in each of which a brainstorming with a different focus was carried out.

The first brainstorming concentrated on the end user benefit of driver assistance systems in traffic jams in general. Therefore the participants were asked how they would wish to be assisted while driving in congested traffic. On the one hand, the resulting ideas contained general categories of end user benefit. On the other hand, specific interaction schemes were mentioned, which were sorted into the general benefit categories according to their specific scopes. Figure 2 shows the distribution of entries to the resulting benefit categories.

The results show that the end user benefit expected by most participants is the ability to perform secondary tasks while being driven by the system. The tasks mentioned by the participants cover a wide range of activities e.g. reading news or playing games. Hence, the ability to perform secondary tasks shall be the second requirement which adds to the first requirement, keeping a sufficient level of situation awareness. Secondary tasks can have negative effects on situation awareness [10]. Thus the two requirements can possibly be in conflict with each other. Hence, there is need for interaction schemes that on the one hand enable the driver to perform secondary tasks but on the other hand ensure that he has a sufficient level of situation awareness. This underlines the need for the present research activities.

The second important end user benefit of such a DAS in traffic jams is efficient driving. By reduction of driving errors concerning the choice of speed and distance, the automation is able to smooth the traffic flow in jams raising the average speed and thus reducing time losses and fuel consumption. This is a requirement towards the application of the DAS. It is therefore not specifically related to the driver's attentional state. The remaining mentioned benefits are either part of other systems like navigation devices ("Information about the traffic jam") or do neither have specific relations to the driver's attention ("Elevating the safety level through reduction of driver errors" and "Assistance for difficult maneuvers"). Therefore these requirements are not in this paper's focus.

Before the start of the second brainstorming the participants were informed about technical details of future partly automatic driver assistance systems and about the constant need for the driver to supervise the system and to intervene in case of danger. The brainstorming was focused on the question how driver and system have to cooperate in order to keep the driver in charge of the driving process while he or she is at the same time being driven completely by the system. This was the basic idea generation part in which new interaction schemes should be generated. The participants were divided into five groups. Each of these groups concentrated on certain situations that can occur using an automated DAS in traffic jams, e.g. “turning the system on and off” or “behavior in case of special infrastructure”.

5 The Filter Step

The second step of the innovation process is the filter. In general its goal is to reduce the number of different ideas that have to be considered. Hence, similar ideas have to be merged and the resulting items have to be evaluated. Those ideas which do not contribute to the given goals have to be identified and eliminated. As stated above, there are two main requirements which potentially oppose each other. On the one hand, the driver has to maintain a sufficient level of situation awareness. But on the other hand, the driver’s benefit of the automation shall be raised by enabling him to perform secondary tasks during the drive in traffic jams.

As some of the ideas emerging from the first brainstorming also contain specific interaction schemes, both conducted brainstormings are seen as input for this step. First, similar ideas coming from both brainstormings are merged. The subsequent evaluation is performed by a team of experts in the two fields of “Human–Machine Interaction design” and “development of DAS”. Each item emerging from the innovation workshop is reviewed considering the two given goals. There are three categories of evaluation for each element and goal:

- The item has a negative effect on the given goal,
- The item has a neutral effect on or is irrelevant for the given goal,
- The item has a positive effect on the given goal.

Items that do not have any positive effect on any of the goals are neglected. By performing the filter step, the amount of items could be further narrowed.

6 The Abstraction Step

For each item resulting from the previous filter step, a generalized functional principle is formulated. As related ideas can have the same underlying principle, this is a further step reducing the amount of different items to be considered.

The functional principle should comprise how the given goal shall be reached. The following explanations give a brief introduction to the found principles. They can be on the one hand grouped into principles concerning the allocation of the driving task between the driver and the automation and on the other hand into principles concerning the communication schemes between the driver and the automation. In the following, the resulting four principles are described shortly.

1. Artificial degradation of the systems performance (limiting the quality of control)

This principle is based on the fact that the underlying DAS either does not take over the driving task completely or that the quality of its vehicle control is artificially reduced compared to a fully functional system. For example some special driving situations may be intentionally executed badly. This system behaviour must be clearly shown to the driver through frequent appearance. By doing that, the driver will become well aware of the system's limits and does not rely too much on it. Hence, the driver will stay involved in the task of driving and a sufficient level of situation awareness is kept. Too high frequencies can have negative effects on the driver's trust to the system [2] and therefore affect the user acceptance. This principle follows.

2. Artificial degradation of the system's availability (limiting the quantity of control)

By reducing the availability of the DAS, the ratio of automated driving is reduced. As the driver has to take over control in a relatively high number of situations, he is always prepared for doing so. Hence the level of situation awareness stays high.

3. Guidance of driver's attention towards the surrounding environment

According to Endsley's model of situation awareness [3], the logical first step in order to enhance the global level of the driver's situation awareness is to support him in the perception of his environment. To do so, his attention must be guided geometrically into the directions that are important at the moment. As the perception during the driving task is performed up to 90 % using the optical channel [1], special importance must be given to the direction of view.

4. Monitoring the driver's attention towards the surrounding environment

The attentional state of the driver can be seen as an additional system boundary. As soon as the driver looses the needed level of situation awareness, he can be warned and the automation can be shut down with an adequate intervention strategy. One of the main issues is the detection of the driver's state. Rauch et al. presented an approach to identify the driver's state using a camera based system [10]. As there is still an intensive demand for development of such driver state assessment systems, this generalized mechanism is not in focus of this work.

Functionality \ Interaction	Basic Interaction (only status displays)	Status displays in Head-Up-Display	Secondary Task in Head-Up-Display	Environment-Representation in Infotainment-Display
ACC only				
ASC only				
Manipulating the ideal trajectory				
Limiting the time				
Limiting the speed range				
ICA				

Fig. 3 Matrix of alternatives emerging from the innovation process

7 The Detailing Step

The last step in the given process is the derivation of specific realizations. Consequently, another brainstorming was conducted with four experts in the field of driver assistance. The given task was to find solutions, which are designed according to the given generalized principles from the preceding step. Thus, the results are independent from the output of steps one and two and the amount of point of views to the problem can be further raised.

Due to the additional step conducted around the generalized functional principles, the resulting list contains several new items (20 %). This states that the developed process helped to gain additional views onto the given problem. Thus, the results become more holistic.

Every driver assistance system consists of a functionality scheme and a communication scheme. Consequently, the resulting functional examples must comprise at least one element from each group. The resulting functional examples can thus be arranged in form of a matrix (Fig. 3). As mentioned above, principle 4 is not in focus of the current work and therefore not represented in the matrix.

Functionalities which are designed according to principle 1 reduce the system's performance in relation to an ICA. Trivial elements are therefore the existing systems ACC or ASC in a stand-alone package. Either the lateral or the longitudinal control is not taken over by the system which can be seen as a reduction of performance in relation to an integrated system. Another way to reduce the

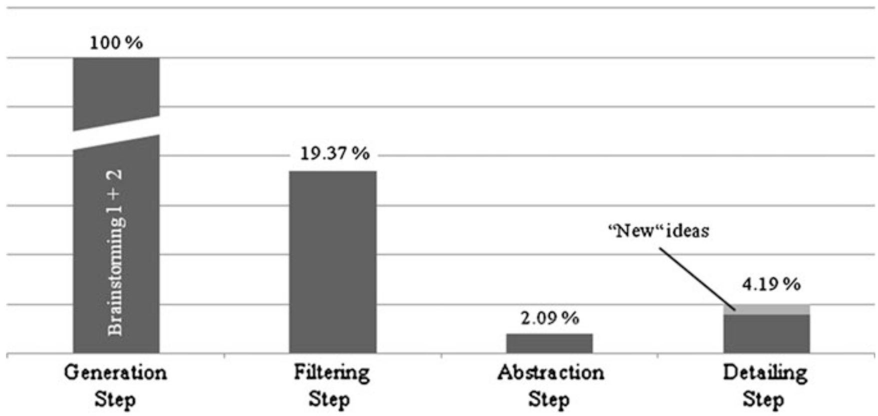

Fig. 4 Amount of items resulting from the various process steps

performance of the system is to manipulate the lateral and/or longitudinal trajectory in relation to the ideal trajectory. By doing that, mistakes are built in. It must be ensured that these mistakes do not lead to dangerous situations. One example of this is a system that constantly drives a little bit slower than necessary to follow the preceding vehicle. By doing that, the gap between the vehicles will be growing steadily and the driver has to intervene occasionally.

Functionalities designed according to principle 2 reduce the systems availability. This can be done by limiting either the time chunk the automation may be turned on without driver interaction, the speed range or by a combination of both.

The resulting communication elements are all based on principle 3, the guidance of the driver's attention towards the surrounding environment. This is done by arranging visual elements the driver needs or wants to watch (e.g. system status indicators or secondary tasks) together with the surrounding environment. A trivial solution for this is placing them in a head-up-display. A possible realization of this is described in [7]. Another way is to place visual elements that represent the environment (e.g. video) in infotainment displays.

All mentioned principles and elements do have effects on the resulting levels of situation awareness, end user benefit and acceptance and there is definitely need for research to assess the effect's quality and quantity. This will be done in future work.

8 Summary and Outlook

The current paper describes a systematic analysis to derive new ways of interaction between the driver and a partly automatic vehicle. Traffic jam situations are chosen as the example situational context for this paper since they are one of the first expected use cases for automated driver assistance systems.

In a partly automated driver assistance system, it is necessary that the driver is attentive and able to intervene at all times. On the other hand, it is supposed that one of the main benefits arising from automated driving, especially in traffic jams, is the ability to perform secondary tasks while being driven by the car. Hence, the aim of the activity is to find interaction schemes that are able to meet both requirements.

Two additional steps are included into the standard innovation process described by Pahl and Beitz [9]. In an Abstraction step the generalized functional principle is formulated for each good rated item found in the classic process. By doing that, an overview on the different ideas is gained. Four functional principles could be identified in the current analysis:

1. Artificial degradation of the systems performance (limiting the quality of control),
2. Artificial degradation of the system's availability (limiting the quantity of control),
3. Guidance of driver's attention towards the surrounding environment,
4. Monitoring the driver's attention towards the surrounding environment.

By formulating these generalized principles, a good overview on the resulting items can be given. In the subsequent Detailing step, the final results of the innovation process are derived only from these principles. Thus, the final results are decoupled from the previous results and new points of view are encouraged. Additional items that have not been thought of before arise. Figure 4 shows the quantity of items resulting from each step of the process. 20 % of the final results have not been mentioned before. This shows the efficiency of the given process.

A possible next step is to evaluate the resulting assistance systems. Further investigations of their effect onto the driver's level of situation awareness and to the driver's benefit and acceptance are necessary. Therefore the driver's interaction and response to such automated systems will be studied in future work.

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