Development and partial validation of a catalogue of action steps for a car driver

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Advanced driver assistance systems (ADAS) can help reduce accidents. In order to increase the positive effects the warnings and interventions of the systems have to be adjusted to the driver and his behavior. This paper shows details about the development and results of a catalogue of action steps of a driver. The catalogue is a summary of possible action steps (based on literature review), can help to have an overview of how the driver can react in total and therefore is a method for an analysis of driver behavior in driving manoeuvres. It can be used in order to find behavior patterns which can be applied for an adjustment of ADAS. In addition the paper shows a visualization method of the action steps and some details about a partial validation.

Practitioner Summary: The paper deals with a method to describe and visualize actions steps of a driver. The method can be used in order to find behavior patterns. The knowledge of patterns can help to adjust ADAS to the driver and his current behavior (e.g. more suitable warnings).

Keywords: Driver Behavior, Catalogue, Action Steps, Behavior Patterns, Advanced Driver Assistance Systems

1. Introduction / Motivation

The number and functionality of advanced driver assistance systems (ADAS) are increasing. But today’s systems often have the disadvantage that different kinds of information about the driver are not integrated (Bubb 2002). A consequence of this lack of integration is that the warnings of the systems are often set to an insufficient level (Blaschke et al. 2007) - the so called warning dilemma arises (Hoffmann und Gayko 2012). On the one hand the ADAS works best if warnings and interventions are set to work as early as possible (technical detection as a limit). But on the other hand early warnings or interventions can have the consequence that the driver could have reacted by himself in order to resolve the situation before an accident would have happen or even that the situation would have alleviated by itself and therefore the warning was unnecessary. Because of this the driver can feel patronized and the acceptance of the ADAS can decrease. In the worst case the driver decides to turn off the system and not use it anymore. As a consequence the positive aspects of ADAS such as reducing accidents and saving lives would be eliminated.

Blaschke et al. (2007) propose to communicate information about the actual driver condition, driver intention and type of driver to the systems. Especially the detection of the driver’s intention or the prediction of the driver’s behavior in the next few seconds can be a very important input signal for ADAS. With this additional information the ADAS activation or the timing of the warning could be adjusted in order to give the driver more time for a suitable reaction in critical situations and unnecessary warnings could be avoided. This would help to solve the warning dilemma (see above). The main challenges with the prediction of driver behavior are expectable intra- and interindividual differences (cf. chapter 3.3).

There are already several methods that can predict certain manoeuvres (e.g. Dambier (2010)) - but a method that covers all manoeuvres is still not available and improvements on the predictions are still possible. Starting point for a better understanding and an improvement of the prediction methods can be an analysis and description of the driver behavior itself. Therefore it is important to know the different possibilities of driver reaction. In addition a more precise knowledge of how typical actions for specific manoeuvres are performed can be very helpful. The first step for such a description is the identification and systematization (compiling of a catalogue) of possible action steps of a driver.
2. Method

In order to develop a catalogue of action steps different activities had to be done. At first requirements for the catalogue were collected. The most important requirements are: the catalogue should be complete in terms of the planned purpose to use it for a behavior prediction in order to improve ADAS, the detail level should be high (in order to have a full description of the steps and because differences at this level can lead to a good delimitation between the steps; reductions are possible in later stages, if the detail level is too high for automatic data processing), the details have to be measureable (again for the planned purpose to improve ADAS) and there should be a clear differentiation between different action step classes (like longitudinal or lateral guiding). Chapter 2 deals with the description of the literature research which was the foundation for the new development (see 2.1), as well as with the foundation of the catalogue (2.2) and with the development of a visualization method which was developed in order to have an easy way to visualize different actions taken in the course of a manoeuvre (2.3).

2.1 Literature Research - Action Steps of a Car Driver

One of the first development steps was reviewing literature on action steps taken by a car driver. At first the research was done in order to investigate if any other catalogues or collections of action steps were available. This showed that such collections as needed for the planned purpose (detailed description of single steps of every action step class) are not available. There was only one related catalogue which deals with “task descriptions” (McKnight und Adams 1970). But the main goal of this collection was to show an exemplary step by step proceeding of different driving manoeuvre for the driving education. Additionally the collection contains influences of the environment, aftereffects of the steps and that one single task can contain steps of different action step classes (for example in task 14-131 “Keeps eyes focused well ahead to anticipate steering corrections” (McKnight und Adams 1970) aspects of visual intake and steering (lateral guiding) are combined) and so does not suit the above mentioned requirements (see chapter 2). This collection could therefore only be used as a fundamental basis and is no direct starting point for the new catalogue of action steps. In order to set up the catalogue the research was extended to literature about general action steps of a car driver and after that to typical courses of regular driving manoeuvre in order to identify the relevant action steps and their details (like typical values and the timing of the different steps).

In this paper it is not possible to show all literature findings that are relevant for the catalogue, but the paper will show some examples of the procedure and some results in the derivation of the content of the different catalogue classes.

2.2 Development of a Catalogue of Action Steps

With the knowledge gained from the literature research (some details of the research will be shown in chapter 3.1) and in consideration of the requirements a new systemized global catalogue of action steps was developed. The action steps were logically condensed into a total of six catalogue classes, which are the framework of the catalogue:

1. Visual intake of information (I)
2. Lateral guiding (Q)
3. Longitudinal guiding (L)
4. Signaling (S)
5. Changing of gears (U)
6. Additional actions (N)

The first three classes contain important action steps which are related to the primary driving task (indispensable for driving, cf. Bubb (2002)). In the following the remaining steps were summarized to classes which are about signaling, changing of gears and additional actions (secondary and tertiary driving tasks in line with Bubb (2002)).

Every class consists of properties (named with letters, for example K for turn of head or B magnitude of turn in table 1, coding used in the visualization - see chapter 3.2) and characteristics of these properties (named with numbers, for example K1 for a non existing turn of head, 2 for a turn of head to the left side etc. in table 1, coding also used in the visualization - see chapter 3.2). The properties and characteristics are also mainly based on the literature research, but some typical values were hard to find. If no typical values were found in the literature a logical graduation was done with the use of expert knowledge. More research should
be done and the values and borders of the different characteristics should be checked with exemplary data in order to be validated (cf. chapter 4). The properties are like a second condensing level. The characteristics of the properties are very detailed in order to be used for a complex classification of the action steps. If the high level of detail is needed, it has to be analysed in later stages.

2.3 Developing a Visualization of Action Steps
After the first idea to add a coding system to the catalogue the next idea was to develop a suitable visualization method, because one goal of the catalogue was to have a method to describe the complete driver behavior in an easy and demonstrative way. The exclusive use of a coding system without an added visualization would not be enough to deliver details like the chronological relation between the tasks.

Starting with research on similar ways of visualization and on graphical possibilities to visualize complex data a new method was developed. First the visualization is only done for the steps of four catalogue classes (L, Q, I and S) but a following enlargement is possible (cf. chapter 4). Details of the visualization method can be seen in chapter 3.2.

3. Results of the development and usage
Chapter 3 shows the results of the catalogue development (3.1) with a description of all six classes and detailed tables for the first three classes, of the development of the visualization method (3.2) with figure of an excerpt of the method (figure 1) and of the first use of these two new methods (3.3)

3.1 Catalogue Classes
Catalogue Class 1 - Visual intake of information (I):
Catalogue class 1 contains action steps which are related to the perception process and the gaze behavior, respectively. As the driver behavior is often caused by changes in the driving scenario or the traffic conditions and a large portion of the informations while driving are gained by the visual channel (cf. Rockwell (1972)) the catalogue class on steps of the visual intake of information is very important. Literature shows that there are special gaze patterns for single manoeuvres making eye tracking also very important for behavior prediction.

In keeping with Hammoud und Mulligan (2008) "one of the most important types of eye movement is not really a movement at all, but rather the ability to keep the eye trained on a fixed spot in the world" - the so called fixation. This is one reason why the class focuses on glance targets and not on the movement itself. At the highest level of detail every single fixation could be described as a action step of class I - but as a relevant glance is there to collect information (for example about the current traffic situation or the current driving speed) and for a better usability of the catalogue different single glances that are directed at the same area of interest (AOI) are summed up.

For a full description of the action steps of class I the class contains the following six properties (see also table 1): turn of head, magnitude of turn, area of fixation, duration of fixation and (potential) fixated object.

While the property turn of head is quite simple to describe the magnitude of turn needs to be analysed in more detail. While glances into the left side mirror can be done with small or even without turns of the head, a glance into the right side mirror or a check of the blind spot area before a lane change needs a greater turning of the head. According to Hudelmaier (2003) the maximum for a turn of the head is about 72°.

In order to describe the target of a glance Bubb und Schweigert (2003), for example, use a mix of objects in the traffic situation and car-related AOI. On the other hand Reid et al. (1981) use dynamic areas which are related to the street. In order to have the opportunity to describe the area related to the car and in addition the fixated object in the current driving situation two properties are provided. The property area of fixation describes the car related area of the glance. Data like the front window out of this property can be devided into different parts in order to have an even higher level of detail. Next to that the property (potential) fixated object contains data of important possible glance targets.

Last but not least the property duration of fixation is important to be able to differ between the fixations. For example a longer and more frequent fixation of the side mirror could be a very good indication for an
upcoming lane change (cf. Liebner et al. (2012)). The duration is divided into a total of 8 possible values in order to make a differentiation possible and because there are typical durations for different manoeuvres and for different areas. For example during a lane change Baumann et al. (2011) report glance durations into the left window/wing mirror of about 0,5s to 1,5s next to glance durations into the speedometer of about 0,9s and glance durations into the windscreen of about 1,5s and 2,5s.

Table 1. Catalogue Class 1 - Visual intake of information (I).

<table>
<thead>
<tr>
<th>Class</th>
<th>Magnitude of turn (°)</th>
<th>Area of fixation</th>
<th>Duration of fixation (s)</th>
<th>Potential Fixated object</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: None</td>
<td>[min, max]</td>
<td>Front window</td>
<td>[0, 0.2]</td>
<td>Lane near</td>
</tr>
<tr>
<td>2: Left side</td>
<td>[min, max]</td>
<td>Upper left</td>
<td>[0.2, 0.7]</td>
<td>Lane far</td>
</tr>
<tr>
<td>3: Right side</td>
<td>[min, max]</td>
<td>Lower left</td>
<td>[0.7, 1.2]</td>
<td>Vehicle in front</td>
</tr>
<tr>
<td>4: Unknown</td>
<td>[min, max]</td>
<td>Central high</td>
<td>[1.2, 1.7]</td>
<td>Vehicle in oncoming traffic</td>
</tr>
<tr>
<td>5: Unknown</td>
<td>[min, max]</td>
<td>Central low</td>
<td>[1.7, 2.2]</td>
<td>Neighboring lane</td>
</tr>
<tr>
<td>6: Unknown</td>
<td>[min, max]</td>
<td>Upper right</td>
<td>[2.2, 2.7]</td>
<td>Crossing traffic</td>
</tr>
<tr>
<td>7: Unknown</td>
<td>[min, max]</td>
<td>Lower right</td>
<td>[2.7, max]</td>
<td>Pavement</td>
</tr>
<tr>
<td>8: Unknown</td>
<td>[min, max]</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Cyclist</td>
</tr>
</tbody>
</table>

Catalogue Class 2 - Lateral guiding (Q):

The action steps of the lateral guiding are summarized in class Q (see table 2). The first two details of the class are dealing with the choice of hand and the action with hand (for example turn steering wheel left). The next properties are about details of the steering wheel turn: the movement speed (unit °/s), the steering angle (unit °) and the starting position (unit °). Literature shows that there are typical movement speeds and steering angles for different manoeuvres. To mention an example: the range for the steering angle of normal lane changes goes from about 15° (while driving at 50km/h, van Winsum et al. (1999)) to about 40° (while driving at 100km/h, Schmidt et al. (2014)). Emergency evasions have typical movement speeds of about 200°/s (Schmidt et al. 2014) and Breuer (1998) reports even higher possible movement speeds. Consistent with Sporrer et al. (1998) emergency evasions can have a steering angle of about 80° up to 120° (or even up to more than 200° (Breuer 1998)). Based on this data taken from the literature research, the borders of the characteristics of the properties were set.

Table 2. Catalogue Class 2 - Lateral guiding (Q).
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<table>
<thead>
<tr>
<th>P:</th>
<th>A:</th>
<th>Q:</th>
<th>W:</th>
<th>P:</th>
</tr>
</thead>
<tbody>
<tr>
<td>X:</td>
<td>X:</td>
<td>X:</td>
<td>X:</td>
<td>X:</td>
</tr>
</tbody>
</table>

| X: | X: | X: | X: | X: |

Catalogue Class 3 - Longitudinal guiding (L):
In order to describe action steps of the longitudinal guiding behavior catalogue class L deals with information about the related pedal (accelerator or brake pedal), the action with foot (for example positive acuation of pedal) and details like movement speed, distance of pedal movement and starting position of the pedal (see table 3). The movement speed of the pedal is already in use in systems like brake assist and it can be important to differ between normal brakings and emergency brakings, which have a higher movement speed - as stated in Kiesewetter et al. (1997) the brake pedal movement speed for emergency stops is up to three times higher than for normal braking manoeuvres.

Table 3. Catalogue Class 3 - Longitudinal guiding (L).

<table>
<thead>
<tr>
<th>P:</th>
<th>A:</th>
<th>Q:</th>
<th>W:</th>
<th>P:</th>
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<td>X:</td>
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| X: | X: | X: | X: | X: |

Catalogue Class 4 - Signaling (S):
In class S all action steps that are related to signaling are summarized. The direction indicator can be activated, deactivated and tipped. Additionally it is important to describe the direction of the signal. Next to that the warning lights, the flasher of headlights and the horn are elements of class S.

Catalogue Class 5 - Changing of gears (U):
Another aspect of human behavior in a car is the changing of gears. Class U deals with the related action steps and is devided into steps with a car with automatic transmission and with manual transmission. The steps for automatic transmission are quite simple: they are only related to the hand movement to the gearshift lever and can include the different gears (like P, N, D, R).

The action steps in a car with manual transmission are a little bit more complex: they include actions with the left foot with details like movement speed, distance of pedal movement and the starting position (cf. catalogue class L) and hand movement to change the different gears (reverse, 1st, 2nd, 3rd and so on).
Catalogue Class 6 - Additional actions (N):
Last but not least catalogue class 6 contains additional actions of a driver, which are not directly related to the driving task. Aspects like the adjustment of the seat position, setting of air condition and the use of the windshield wiper are described in class N.

3.2 Visualization Method
As mentioned before and seen in the different tables of the catalogue, there is a coding system for the different action steps. For example a quite slow (low movement speed) and big steering turn (high steering angle) to the left with both hands out of a neutral starting position has the code Q-H4-A4-G2-W8-P6 (cf. table 2). As mentioned in chapter 2.3 such a coding system is not very demonstrative which makes it hard to use in order to analyze the driver behavior (on the other hand the coding is fine for a automated digital analysis of the steps). The full behavior and potential behavior patterns are not visible that easily and the detailed chronological relation is also not included. Because of this and due to the fact that a main goal of the research is to develop a method that describes and visualizes the action steps of a car driver, a more demonstrative visualization method was developed.

The visualization method can be described as a timeline for every class arranged in parallel (see figure 1). Via the timeline, the properties and characteristics of the action steps are visualized through special graded colors (for details like different movement speeds) and heights of the segment (for details like different angles) of the action step. With this visualization the present action steps and the chronological relation of the steps can be analyzed quite fast.

![Figure 1. Exemplary excerpt of the visualization method using a timeline (additionally the codes and a short description of the action steps are displayed; only 4 of the 6 catalogue classes are shown).](image)

In figure 1 an exemplary excerpt of the visualization of a lane change to the left lane is shown. The visualization makes it possible to analyze the driver behavior. An inicial, quite simple aspect is that the driver used the direction indicator (see line 4). Additionally you can see that the direction indicator was activated approximately 0,3s before the steering to the left (see line 2) started. If you take a closer look to the line for
the “Visual intake of information” (line 1) you can see that the driver looked into the left mirror approximately two seconds before the steering began, that the mirror glance had a duration of about 1.7s and that in the next glance the lane in front of the car was fixated.

In the next step these findings of the exemplary lane change of the subject can be compared to other lane changes of the same subject and to lane changes of other subjects in order to analyze equality and intra- and/or interindividual differences in driver behavior. The visualization helps to gain these informations in a simple way.

3.3 Use of the Catalogue and the Visualization Method

After the development, the catalogue was analyzed regarding integrity and operability and regarding patterns and differences between the different subjects. The analysis was done with data out of a field study (cf. Langer et al. (2014)) included in the UR:BAN research project (cf. Mansletten et al. (2013)). Action steps (dependent variable) were found by analyzing can-bus-data (for example, the steering wheel angle or the acceleration pedal position) and eye-tracking-data of an exemplary driving manoeuvre (one of the independent variables, free lane change left, 20 subjects, 3 lane changes per subject).

Integrity and Operability:

One of the primary results of the analysis is that the catalogue is quite easy to use and that the characteristics and properties which are relevant in the analyzed manoeuvre are defined well. The analysis also showed that the visualization method needs some further improvement as it is quite hard to understand without explicit knowledge about the details regarding the meaning of the graded colors and heights of the segments (cf. chapter 4).

Patterns and Differences:

Other findings are statements about behavior patterns of drivers and a comparison with literature results (e.g. steering patterns as mentioned by Salvucci (2006) or gaze patterns as reported by Salvucci und Liu (2002)). Furthermore, it is shown that the behavior displays intra- and interindividual differences. A global behavior pattern seems to be hard to find (for example only 30% of the analyzed lane changes are done with the use of the direction indicator). Nevertheless, the findings of the analysis can be used in order to identify partial patterns, for example of a specific group of driver, which is also very interesting regarding the involvement of drivers and their behavior in ADAS.

4. Discussion and Outlook

The use of the catalogue and the visualization method show that it is possible to describe and to visualize the action steps of a car driver in order to find possible behavior patterns. In the next iterations of the catalogue it has to be checked if other classes, action steps or even characteristics should be integrated into the catalogue - maybe action steps about the handling of ADAS could be interesting too. In order to achieve a more significant statement about the catalogue and especially about the patterns a more extensive analysis should be done. There is data collected from more subjects and also data from other maneuvers. As the analysis is ongoing, the goal of having more significant statements can be met in near future.

On the other hand, the first results show intra- and interindividual differences which have to be dissected in order to find more (partial) patterns.

In the current partial evaluation only four catalogue classes and as there was only one driving manoeuvre in the focus only some details of the catalogue were analyzed. The analysis has to be more extensive in order to check all details of the characteristics and properties. For example the analysis of emergency manoeuvres will give hints about the higher movement speeds of the steering wheel and the pedals. Even if the values and borders of the characteristics and properties are set with the use of literature, the details have to be checked more intensively (for example by using the collected data, cf. chapter 3.3).

Last but not least, there has to be further development on the visualization method of the action steps in order to make it possible to gain the information about the different steps without the need of a detailed description of the differences between the graded colors and the heights of the segment. In addition the visualization has to be widen to include action steps of the classes U (Changing of gears) and N (Additional
actions) and to have the chance to show more than one subject or manoeuvre in one figure. In addition it would be of interest to add information about a possible variation of the properties and characteristics into the visualization. For example the chance of having an action step or the variation of the chronological relation or of the duration of an action step would be interesting information.

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