A Maneuver-based Lane Change Assistance System

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Abstract—Lane change is a very demanding maneuver. Therefore, a maneuver-based lane change assistance system has been developed which, by means of a single-task-combining assistance concept, supports the driver from the driver’s first lane change intention through the final movement of the vehicle from the initial to the target lane, without automatization of the vehicle guidance. The maneuver recommendation covers lane change timing, lane change direction as well as the required acceleration or deceleration. The system architecture with its modules to estimate the maneuver recommendation is described as well as the HMI which presents the information to the driver on a display and by an additional steering-wheel torque. A core assistance module geared to the driver’s needs and the detection of driver’s intention based on motivators, inhibitors and indicators is explained in detail.

I. INTRODUCTION

According to accident statistics, lane changing is a very demanding maneuver. 13 % of all accidents with injured persons on German freeways in 2009 were caused by collisions by vehicles driving laterally in the same direction [1] and an analysis of the German In-Depth Accident Study [2] from 1985 to 1999 shows that on average more than 5 % of accidents occurred while changing lane. The driver faces a high mental workload [3], being stressed by the great number of tasks which partially have to be carried out in parallel. For example, the driver has to control the longitudinal and the lateral dynamics and check for vehicles on several lanes at the same time. For this reason, many vehicle manufacturers offer Advanced Driver Assistance Systems, which are referred to as Lane Change Decision Aid Systems (LCDAS) in accordance with ISO 17387 [4]. Most of these systems inform the driver about vehicles on the adjacent lanes and using visual elements in the outer mirror or in the a-pillar, steering wheel vibrations or acoustic signals, warn him/her of a dangerous lane change situation as soon as s/he applies the turn indicator. While such a warning might relieve the situation, the driver is nevertheless unable to perform the lane change and his/her intention will continue to exist.

Just a few research projects dealted with the integrated assistance of several lane change tasks. A combination of conventional Advanced Driver Assistance Systems, namely Lane Departure Warning (LDW), Lane Keeping Assistance System (LKAS) and LCDAS, is introduced and evaluated in [5]. An integrated lateral and longitudinal controller, which uses the functions of Adaptive Cruise Control (ACC), LDW, LKAS and LCDAS, is introduced in [6]. The warning system is supplemented by haptic steering recommendation, as shown in [7]. Although these systems address more than just one task, they do not address the whole lane change maneuver, starting with the driver’s lane change intention generation and ending with the vehicle’s movement from the initial lane to the final lane. Additionally, they do not motivate the driver to change the lane in case his intention is detected by the system. The approaches made are not driver-focused. Accordingly, the methodical approaches are not top-down.

For this reason, a maneuver-based lane change assistance system has been developed that assists the driver during the entire maneuver without automatization of the vehicle’s guidance. The maneuver assistance is characterized by the combination of the single tasks. It is implemented in a prototype vehicle and will be evaluated in tests with test persons. This assistance concept addresses the driver’s workload, comfort and safety during lane changing.

II. MANEUVER ASSISTANCE AND RECOMMENDATION

This paper deals with the first of two system development phases: the development process through to the implementation of the system in a prototype vehicle, and the validation process to evaluate the system. The development phase focuses on the driver and is based on the question: What information does the driver need to perform a lane change safely? Interviews with test persons to answer this question might lead to unreliable results, as most drivers are not able to express their demands in an appropriate manner. An analysis of the driver’s actions shows just the physical, but not the mental tasks. Therefore, the information needed by the driver is extracted from a scenario catalogue, containing scenario parameters and providing driving alternatives taken from fundamental scenarios. The scenario catalogue includes the parameters: number of adjacent lanes, number and position of vehicles on adjacent lanes, the lane change cause and the lane change direction. One fundamental scenario and the corresponding driving alternatives are shown in figure 1. In this scenario the driver in the prototype vehicle (PV) has three alternatives when
approaching a slower vehicle: to stay on the initial lane and to adjust the velocity to a vehicle ahead, to change lane in front of the vehicle on the adjacent lane or to change lane as soon as the adjacent vehicle has passed and to adjust the velocity. The slower vehicle ahead which triggers the wish to change lane is not shown in the figure.

Fig. 1. Elemental Scenario showing the prototype vehicle (PV), a vehicle on the adjacent lane and the driver’s alternatives.

This basic scenario already shows the need for an alternative evaluation model because there is more than one gap on the adjacent lane.

Having identified the necessary information for a lane change, this has to be processed from the sensor signals and presented to the driver in an easily comprehensible way. The information needed for a safe lane change and an adequate gap can be combined to a maneuver recommendation consisting of the beginning and the ending of the lane change phase, the minimal acceleration/deceleration needed and the lane change direction. The beginning of the lane change phase characterizes the earliest point in time for a safe lane change assuming the driver acts upon the recommended acceleration. The ending of the lane change phase characterizes the latest point in time for a safe lane change. The information about the ending of the lane change phase is only presented to the driver when the lane change is possible.

A representation of the surroundings, showing the vehicles and gaps around the prototype vehicle, is assumed to be dispensable. The driver uses this piece of information only to confirm the interpretation of the surroundings and the decision supplied by the system. Given that the system works reliably the driver will trust the maneuver recommendation and the information is unnecessary. Therefore, a representation of the surroundings is not included in the maneuver recommendation.

III. SYSTEM ARCHITECTURE

The system architecture which derives the maneuver recommendation from the sensor data features the following properties:

- all sub functions (realized in system components called modules) are known,
- the sub-functions and accordingly the modules are structured,
- the interfaces between the modules are defined.

The inner layout of the system is illustrated by the system architecture in figure 2. The considered level of abstraction is the functional (or logical) system architecture which defines the system specifications and models the functions in an abstract manner without providing the detailed algorithms as defined in [8].

Fig. 2. System Architecture (PONR = Point-of-no-return)

The system specifications were defined in line with the driver’s requirements on the system. Subsequently, the specifications were clustered in groups with similar content to form the system modules.

The identified modules are categorized as data acquisition, data processing and data output.

Data acquisition: This part of the architecture consists of the sensors and the sensor data fusion. The sensors deliver the data describing the environment and the state of the prototype vehicle. These data are the distances, the relative velocities and optionally the lane positions of other vehicles and/or obstacles on the one hand, and data from the prototype vehicle such as velocity, longitudinal and lateral acceleration and position in the lane on the other.

Data processing: The modules for data processing are required to provide the maneuver recommendation based on the environment data from the sensors. The modules are:

- Driving Alternative Evaluation: The main task of this module is to identify gaps which are adequate for a lane change maneuver. For each gap the required longitudinal acceleration to reach the gap, the time to start the lane change and the available time for the lane change are calculated. From all of the adequate gaps the foremost one is chosen by the algorithm. In accordance with German traffic rules, overtaking on the right is excluded.
- Output Control: Based on the current system state and driving situation, this module decides whether a maneuver recommendation for lane changing can be provided to the driver. The output is deactivated if the system state check declares that the system is not ready or if the lane change maneuver has been finished. Furthermore, when a driver has already begun trying to reach a specific gap, the output control can hold on to a gap even if the Driving Alternative Evaluation chooses another one. In this situation a gap change might confuse the driver and thus reduce the acceptance of the system.
- Sensor Diagnosis: This module checks the hard- and software (e.g. sensors and CAN bus) for proper functioning and delivers a sensor diagnosis signal into the System State Check.
**System State Check:** Based on the Sensor Diagnosis signal, the prototype vehicle’s velocity and the driver’s system activation request this module outputs the system state signal.

**Lane Change Abortion Check:** When a lane change is started, this module continuously checks whether a maneuver can be safely executed. If the gap restricting car ahead suddenly starts to decelerate and a collision seems possible, the driver is warned to abort the lane change.

**Lane Allocation:** To identify possible gaps for lane changing, information is needed about the lane allocation of all detected vehicles. If this information is not given by the sensors, this module outputs the lane of each vehicle. Hence, this module is optional in the logical system architecture.

**Data output:** The Data Output mainly consists of the Human-Machine-Interface (HMI) to present the maneuver recommendation.

The presentation of the maneuver recommendation is based on four so-called pre-defined open loop control programs, which are shown in table I: no lane change, lane change with acceleration, lane change with deceleration and lane change without acceleration. One situation which can occur in real traffic is not recommended by the system for safety reasons: a lane change with deceleration and subsequent acceleration, which is necessary to avoid a dangerous situation. Therefore, this velocity course does not exist in table I.

For the presentation of the maneuver recommendation, visualization of the detailed advice on a display was chosen. A visual element was chosen because an acoustic element might bother and expose the driver; and a single, haptic element is assumed to be unable to transmit the maneuver recommendation.

On the other hand, the driver is not able to look at the display all the time. To avoid a decrease in safety, the display is supplemented by a steering wheel actuator which is able to influence the steering wheel torque. The additional steering wheel torque indicates the timing and the direction information similar to an inverse LKAS.

To visualize the pre-defined open-loop control programs and their information concerning timing, direction and longitudinal dynamics, a design development process led to the following four, numbered concepts.

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\uparrow$</td>
<td>no lane change</td>
<td>ride on initial lane velocity adjustment wait for gap</td>
</tr>
<tr>
<td>$\uparrow$</td>
<td>lane change with acceleration</td>
<td>acceleration lane change</td>
</tr>
<tr>
<td>$\downarrow$</td>
<td>lane change with deceleration</td>
<td>deceleration lane change</td>
</tr>
<tr>
<td>$\downarrow$</td>
<td>lane change without acceleration</td>
<td>constant velocity lane change</td>
</tr>
</tbody>
</table>

In designing the concepts, both guidelines [11] and engineering standards [9], [10] were taken into account as well as criteria such as distraction, joy of use, comprehensibility and intuitional understanding.

Figure 3 shows the first concept in two different situations. On the left hand side of this figure, the lane change is not possible. Therefore, the frame of the time bar on the left and the arrow showing the lane change direction are colored red. The filling status of the time bar and the triangle in the middle of the visualization, which symbolizes the acceleration, are colored white. The increase of the time bar level represents the earliest, safe moment to change lanes. On the right hand side of the figure, the frame of the time bar and the arrow are colored green, expressing that the lane change is possible. They are located on the right hand side showing the driver that a lane change to the right is being considered. The level of the time bar indicates the time left for a safe lane change. The triangle in the middle of the visualization expresses the differential acceleration, not the required acceleration, because it is assumed that the driver needs both the required acceleration as well as the actual acceleration. A high difference between the actual and the required velocity is expressed by two stacked triangles.
Equality is expressed by a circle. The background of all four concepts is black.

Figure 4 shows the second concept which consists of an arrow pointing left or right depending on the lane change direction. At the bottom of the arrow, the longitudinal information is presented. The level of the bar indicates the timing. The opportunity for a safe lane change is represented by the color, as in concept I, and by the dashed or continuous line markings.

In the third visualization concept shown in figure 5, the timing information is given by the horizontal bar. The situation pictured on the right indicates that a lane change to the right is possible. Therefore, the arrow to the right is colored green and the arrow to the left is grey. The latest moment for a safe lane change is represented by the end of the green phase in the horizontal bar which is followed by a red phase. In contrast to the first two concepts, the driver is able to simultaneously see the time to the beginning and the end of the lane change. The longitudinal dynamics information is shown by the white arrow in the middle.

Figure 6 shows the fourth visualization concept. The longitudinal dynamics information is provided in the middle of the visualization by triangles and a circle, respectively. Lane change is not possible in the situation shown on the left hand side of the figure. Therefore, the arrow to the lane change direction is white with a red frame. When a lane change is safe, the arrow turns green. The grey frame around the longitudinal dynamics information represents the adjacent lanes. A blue area shows the relevant gap coming from behind the prototype vehicle in the shown scenario. When the blue area is completely inside the arrow, a lane change is possible.

Interpreting a bird’s eye view seems to be very difficult because this view differs from that of the driver’s. Therefore, the more abstract concepts shown are expected to be more successful.

The four concepts have been evaluated in tests with test persons using the prototype vehicle.¹

V. MODULE: DRIVER INTENTION DETECTION

A. Motivation and Objective

LCDAS use the status of the direction indicator to infer the driver’s intention. However, the indicator is applied just a short time before changing lane as shown in [3]. At this point, relevant longitudinal dynamic changes to adjust to the final lane are no longer possible. In some cases the indicator may not be applied or applied for a very long time without having the possibility to change lane, for example if an adjacent lane does not exist. Other systems, e.g. described in [12] and [13], estimate the time to line crossing (TLC) by measuring the position of the vehicle on the lane and predicting the vehicle trajectory. Nevertheless, the lane change is detected only a very short time before crossing the lane markings and not at all during the preparation for a lane change. To assure effective assistance by the maneuver-based lane change assistance system, the detection of the driver’s lane change intention is necessary.

Consequently, an innovative, reliable and precocious detection of a lane change intention based on an interpretation of the vehicle’s environment is indispensable. [3] gives an extensive literature review on such methods. However, no driver intention detection system for a maneuver-based lane change assistance system realized in a vehicle and using surround sensing information is known.

B. Requirements

The maneuver-based lane change assistance system requires a precocious detection of the driver’s lane change intention. In this way, it becomes feasible to evaluate the driving alternatives and synchronize the prototype vehicle’s velocity with that of one of the vehicles on the final lane, and it is possible to initialize the lateral movement from the initial lane to the final lane. However, the detection has to be reliable. False negatives can be compensated by using the turn signal, the TLC information or a manual activation by

¹ The results of these tests will be available for the final version of the paper.
the driver with reduced driver’s acceptance. False Positives, e.g. a continuous lane change recommendation, would lead to an annoyance of the driver and the acceptance might decrease.

C. Concept

The lane change intention detection concept is based on the combination and evaluation of measurable parameters to infer a probability value. [14] classifies the parameters into motivators, inhibitors and indicators. The wish of the driver to execute a lane change is increased or decreased by the motivators and inhibitors. In general, they describe the driver’s environment, whereas indicators describe the behavior of the driver. Different conjunction methods are found from literature: In [15] different parameters are combined to estimate the driver’s satisfaction for each lane, [16] describes a binary conjunction method, [17] presents a benefit estimation method, a Hidden Markov Model is used in [18] to estimate the driver’s lane change intention, [19] describes a probabilistic network used to combine parameters. Good results were achieved in [20] using fuzzy logic. In addition fuzzy logic is flexible; the rules are easy to interpret and to adjust. Therefore, this method was chosen as conjunction method.

D. Parameters

The available parameters can be listed according to the spatial level of detail as shown in figure 7. The highest level of abstraction corresponds to the route, which consists of knots and directed edges and, amongst others, includes the duration and distances of the journey as well as the traffic density. The second level of abstraction is referred to as the road course describing the geometry of traffic routing and includes, for example the width, the curvature and the inclination of the road. The third level of abstraction corresponds to the track and is characterized by the lanes in a road network which includes, for example, the number of lanes, traffic signs and friction coefficients. The final level of abstraction incorporates the driver with the HMI and his/her physiology and the environment with obstacles and vehicles on the road.

Considering the vast number of potential indications for a lane change, the most relevant and reliable ones have to be identified. One identification criteria is the relevance to a scenario. According to [4], [21], [22] and confirmed by own tests, the most common and most dangerous scenario is a lane change to the left caused by a slower vehicle ahead. Therefore, this scenario was picked for the first implementation.

Another criterion used to identify the relevant parameters is the usage by the driver. Therefore, the following question is the focal point of interest: Which information does the driver use when developing a lane change wish? A common basis for several approaches is the lane-following model of [23], the lane changing model of [24] and a model for cooperative behavior by [25]. [26] underlines that the driver mainly uses visual information. Extensive evaluation of collected data to derive relevant variables has been done by [22] via logistic regression models and [27] via signal detection theory, for instance.

[28] names three possible approaches to parameter selection for an autoadaptive fuzzy-logic for maneuver identification: parameters that distinguish between driving maneuvers, learning the network with numerous parameters to subsequently exclude rarely used ones, and selecting parameters by expert knowledge. A „leave-one-out“ approach is taken to prove the algorithm’s ability to adapt to different drivers and to identify different maneuvers. Often, cognitive models are used to derive the driver’s intention to change lanes, usually consisting of a strategic, a tactical and an operational level ([28] and [30] in [3] and [31], [28]). According to [3], the selection of a sufficient gap has not been addressed by a cognitive model but appears to have been realized in driver models. The traffic simulation program Pelops uses an advanced driver model for lane changing, but is not explicitly designed to predict lane changes.

In addition, two more questions have to be answered in the future: What kind of information would the driver use, if it were available? Would this benefit the lane change detection system and driver acceptance and would it improve the maneuver-based lane change assistance system?

The final criterion for the inputs is the feasibility, which depends primarily on the sensor system of the prototype vehicle. The prototype vehicle is equipped with 6 radar sensors around the vehicle and a LKAS camera to detect all vehicles on the adjacent lanes and the lane markings.

The following parameters were chosen with reference to the criteria described: relative velocity and time gap to a vehicle ahead, performance of the vehicle and the desired velocity. When the prototype vehicle is approaching a vehicle ahead the lane change intention can easily be determined by the differential velocity, whereas in a situation with one vehicle following the other the desired velocity available from the ACC system supplies good results. The vehicle’s capability to achieve a certain differential velocity is a required prerequisite for overtaking.

The performance parameter of the vehicle compares the actual velocity with the velocity required for overtaking and evaluates the time needed for accelerating to the overtaking
speed. The acceleration is estimated taking into account the driving resistance and the available power.

VI. CONCLUSIONS AND OUTLOOK
To date, only single lane change tasks have been assisted. The maneuver-based lane change assistance system supplies a comprehensive, single-task-combining support and assists the driver from his/her first intention to change lanes through to the movement from the initial to the final lane without automatization of the vehicle guidance. The system architecture with the modules to supply the functionality of the system, an HMI and the core module to detect the driver intention have been developed. The system is being implemented in a prototype vehicle and will be validated and compared to common systems like LCDAS in the near future.

REFERENCES