A Cooperative Active Blind Spot Assistant as Example for Next-gen Cooperative Driver Assistance Systems (CoDAS)

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Abstract— **Vehicle-to-Vehicle communication has recently passed from a research topic to the subject of Field Operational Testing (FOT) and pilot deployment. Current state-of-the art Car-to-Car and Car-to-Infrastructure (C2X) functions will however only inform the driver, not interfere in actual vehicle operation. A logical next step after initial deployment will be sensor fusion to enhance actively intervening Advanced Driver Assistance Systems (ADAS) with information received over C2X. As the penetration rate of equipped vehicles increases over time, higher-level CoDAS functions become feasible. In this paper we present a concept for a cooperative active blind spot assistant (CABSA) as an exemplary function of these novel Cooperative Driver Assistance Systems. As the CABSA function improves an existing ADAS function, no negative effects are observed in low-penetration scenarios. The function was implemented with messages adhering European Telecommunications Standards Institute (ETSI) standards. Simulations and real-life tests show that the increase in operation range significantly expands the vehicle speed envelope upon which the system can prevent accidents compared to conventional blind-spot assistance.**

Keywords— C2X, V2X, cooperative driving, ADAS, CoDAS

I. INTRODUCTION

Recent advances in projects such as PRE-DRIVE C2X [1], simTD [2] or Score@F [3] have shown a technical maturity of C2X communication based on IEEE 802.11p [4] and ETSI TS 102 637 V1.2.1 [5]. A follow-up evaluation is currently conducted in field-operational tests on national (Safety Pilot [6], SISCOGA [7]) and international (DRIVE C2X [8]) levels. Vehicle manufacturers, government authorities and road operators have committed to market introduction of these "Day-1 functions" in near future. A first deployment is scheduled for 2015 with the "intelligent corridor" [9].

However, if arranged in the "inform, warn, act"-scale of driver assistance systems, none of the currently envisioned systems actually interfere in vehicle operations. This combination of actively intervening advanced driver assistance systems with information received over C2X is described as cooperative driver assistance systems (CoDAS) in [10].

CoDAS are currently undergoing first real-world tests. Tomorrow's Elastic Adaptive Mobility (TEAM) [11] is a European project that will perform field tests for CoDAS. Projects such as TEAM will give valuable insight on the impact of CoDAS and bring CoDAS closer to be ready for the market.

These systems can be classified by their integration-level of communication:

Implicit functions will use information from C2X to augment perception and situational awareness of existing ADAS functions. Mostly, cooperative awareness messages (CAM) can be used to enhance the knowledge about surrounding vehicles, thus improving the function. Notably, this level of integration requires no changes on the remote station and will work on current standards. In this paper we present CABSA as an example for implicit CoDAS.

Explicit functions actually require C2X communication to perform their tasks. This level will show distinct functions not possible with current sensor technology. They will still rely on standard messages, not requiring changes on the remote stations. Examples include cooperative lane change or cooperative overtaking assistance functions.

Finally, *collaborative* CoDAS describes functions which are active on two or more vehicles, interfering actively. Vehicles will thus be able to cooperate by negotiating common driving strategies and tactical maneuvers. These functions will require an amendment to communication standards, since current messages do not envisage stateful 1-to-1 communication. Examples include platooning, autonomous intersection handling or cooperative crash avoidance.

In this paper we will present an augmentation of an active blind spot assistance function as an example of implicit CoDAS. Current blind spot functions utilize sensor perception (commonly radar and camera) to detect vehicles driving on adjacent lanes. If a lane-change is detected (by proximity, lane detection and/or indicator status), such systems will warn the driver with audible and/or perceptible measures. An *active* blind spot assistance function (ABSA) will also intervene in actual vehicle operation to prevent a collision. Commonly, the Electronic Stability Control (ESC) system is activated to brake tires on the opposite side, thus inducing a yaw moment into the vehicle, preventing a lane change.

Systems currently in the market have the flaw of limited perception range due to sensors used, e.g. the radar used in production Daimler vehicles has a range of 30 meters [12] [13]. When considering the scenario of (fast) passing vehicles however, it is intuitive, that the perception range is directly limiting the relative speed of passing vehicles, in which a potential collision can be averted. CABSA therefore utilizes information received from C2X to improve the ABSA function. Initial results from field-operational testing e.g. in

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simTD indicate a communication range of up to 500 meters to be probable. Fig. 1 depicts the relation of perception range to relative vehicle speed, in which an accident can be avoided given a fixed time for lane change for both ABSA and CABSA.

Of course, all CoDAS functions require both vehicles to be equipped with communication units. In the particular case of CABSA, however, a missing communication link will mean, that the systems falls back to the normal radar-based ABSA. Thus, cooperation can provide a gain in safety but will not pose a problem in low penetration-rate scenarios. It is also noteworthy, that only the receiving vehicle needs to be equipped with the CABSA function. As standard CAM messages are used, any vehicle adhering to standards can fulfill the sender role.

In this paper we describe the concept, architecture and initial findings from a real-world implementation using state of the art wireless vehicular communication.

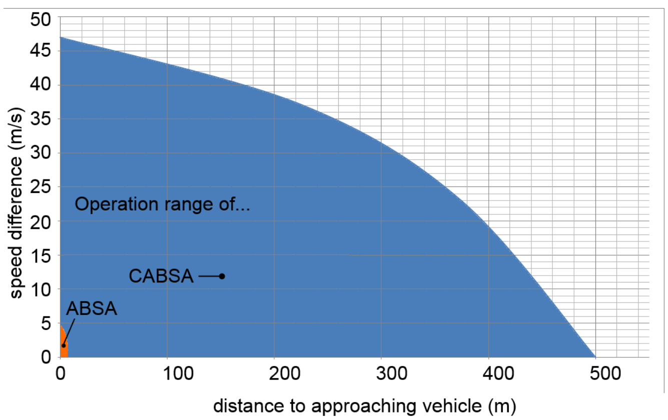

Fig. 1. Comparison of CABSA and ABSA

II. SYSTEM ARCHITECTURE

CABSA requires several inputs and outputs from and to the vehicle and the environment. The prototypical application is based on the ETSI reference architecture as exemplary described in the Drive C2X project [8]. A number of facilities provide simple access to several external sources.

The architecture of the system can be seen in Fig. 2. The software runs on two machines, the Application Unit (AU) and the Car Communication Unit (CCU). The CCU receives and sends C2X messages through its 802.11p wireless interface. It is connected to the AU by Ethernet. The C2X messages are sent to the AU over UDP sockets. The major part of the architecture stack on the AU side is implemented as bundles for the Knopflerfish OSGi Framework.

The bundles are grouped in three categories: the networking API provides access to the CCU, the facility layer offers basic functionalities for the applications, and the application layer. CABSA, just as other functions, belongs to the applications category. CABSA makes use of several facility components, namely Position & Time, Vehicle CAN bus access (VCA), Map Matching (MM), Human-Machine-Interface (HMI) Connector, and Logging. Moreover, CABSA uses the network facilities to send and receive wireless

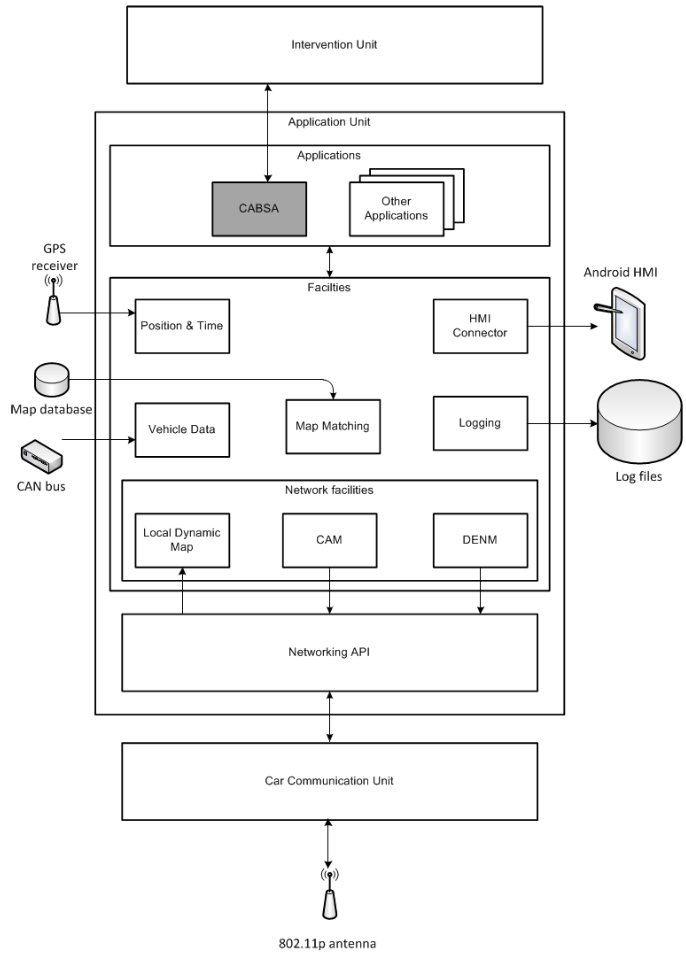

Fig. 2. System architecture

messages using the 802.11p standard and standardized ETSI CAM messages.

Wireless messages sent through the 802.11p network by surrounding vehicles are collected in the Local Dynamic Map (LDM). The application gets informed by the LDM about new vehicles and update of vehicles. The system CAM at 10 Hz. These messages contain, among other data, the position of the vehicle.

For localization, GPS is used, the data from the GPS antenna is accessed through the Position & Time bundle. The vehicle data from the CAN bus is required to get information about the indicator levers. It is retrieved through the VCA bundle. A local map database is used to compare the position of the ego vehicle and other vehicles.

CABSA provides three outputs. The first one is the HMI, which is implemented as an App for Android tablet PCs and smart phones. The Android device is connected to the AU by an on-board Wi-Fi. Here the user can see the warnings triggered by the application. The HMI is accessed through the HMI Connector bundle. This bundle collects the presentation requests of all applications and forwards it to the end device over a TCP socket. The second output are log files, which can be used to analyze the behavior of the CABSA application. The log files are also written by a dedicated bundle that creates the logs in a uniform way. The third output are signals to an

Intervention Unit. These signals were only used in the simulation environment, because for safety reason we cannot perform driving interventions on public roads.

We propose not to make actual driving interventions from the Application Unit, but rather have a separate Intervention Unit for driving-critical tasks. The purpose of this unit is to double-check received input on possible accident risk and to have a fail-safe fallback point. According to ISO 26262, all tasks flagged with an Automotive Safety Integrity Level (ASIL) level should be contained.

For CABSA, the Intervention Unit of ABSA can be used by adding cooperative information to the ABSA perception level. Thus, re-certification and re-engineering can be kept to a minimum.

During our research we implemented the basic CABSA algorithm in a test-bench simulator as a first stage. Later, real-world tests have been conducted using two C2X-equipped vehicles. As we wanted to avoid possibly dangerous situations, the Intervention Module was only activated in the simulator. Since the actual ESP activation is the same for CABSA and ABSA, intervention behavior can be expected to equal that of normal active blind-spot assistance functions.

III. System Implementation

The system logic of CABSA uses GPS position, vehicle data from the CAN bus, road maps and C2X messages as input. The workflow can be seen in Fig. 3. It is executed with a frequency of 10 Hz, which is also the update frequency of the GPS module.

First, the position from the GPS module is map-matched in order to verify that the vehicle is on a valid road. Otherwise, the processing cannot be performed. After that, the CAM messages from the LDM are processed, i.e. it is checked whether messages from neighboring vehicles have been received. If no other vehicle is in reach, the current execution of the workflow is stopped.

In case a CAM message is received from another vehicle, the position of the other vehicle is also map-matched. Only if both vehicles use the same road, the other vehicle is considered. Otherwise, the application waits for the next run.

Consequently the relevance calculation starts. First the driving directions of the vehicles are compared. The other vehicle is only relevant for further processing, if it is driving in the same direction. Otherwise it is not a candidate for blind spot detection.

If the vehicles are driving in the same direction, the distance and the speed difference of the vehicles are calculated. Based on this it is decided if the approaching vehicle is in the relevance area. The relevance area is a cone-shaped section behind the rear corners of the vehicle, i.e. the area that usually cannot be overseen by the driver due to the blind spot. The relevance area is the area, in which approaching vehicles are tracked and observed.

For the calculation of the relevance area the position, distance and speed of the vehicles are taken into account. The other vehicle must be directly next to or behind the rear corners of the vehicle, i.e. it must be on a lane next to the own lane. In order to examine if the other vehicle is within this cone, a vector directing from the ego vehicle to the other vehicle is created. This vector must lie in the range of the cone. Vehicles directly behind the ego vehicles are not considered to be in the relevance area.

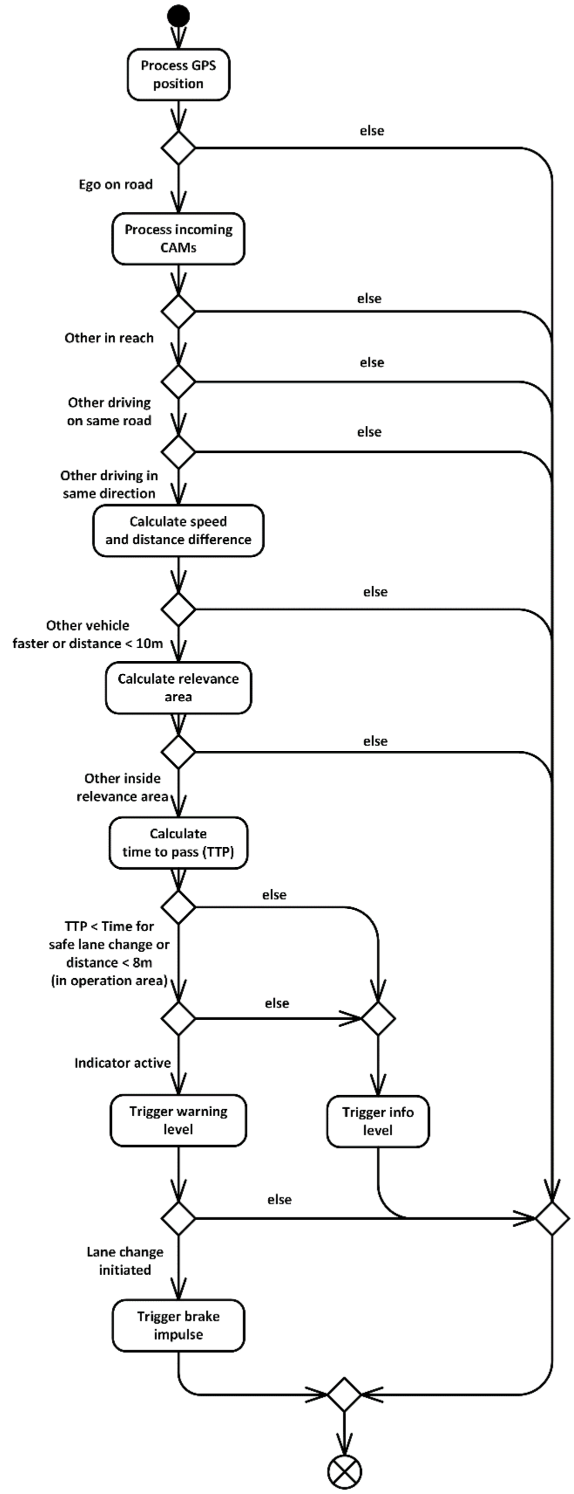

Fig. 3. Workflow of the application

For the distance a rule of thumbs of eight times the speed difference between the two vehicles is applied. As the speed difference is very low when two vehicles are driving side-by-side, the minimum depth of relevance area cone is 10 meters. When the other vehicle is in the relevance area, the information level is triggered.

Fig. 4. HMI warning screen

Afterwards, the operation area is calculated. An approaching vehicle enters the operation area, when it is driving on a lane left or right of the ego vehicle and the time to pass (TTP) the ego vehicle is smaller than the time which would be needed for the ego vehicle for a safe lane change. The TTP is calculated by dividing the distance to the vehicle in the blind spot through the speed difference. To get the TTP in milliseconds, the result is multiplied by the factor 1000.

$$ttp[ms] = 1000 * \frac{dist[m]}{|\delta v[{}^{m}/_{s}]|} \qquad (1)$$

If the TTP is smaller than a defined time for a safe lane change or the distance is smaller than 8 meters, the approaching vehicle is considered to be in the operation area. The time for a safe lane change by default is set to 5000 milliseconds. This value was identified through test drives. As vehicles that drive side-by-side have a very low speed difference, vehicles that are closer than 10 meters are always considered to be in the operation area.

Moreover, it is checked if a lane change is intended. Therefore, the indicator signal is taken into account. The data from the CAN bus is updated every 50 milliseconds. If another vehicle is within the operation area and the indicator lever is set, the warning level is triggered.

When the information level is triggered, i.e. the approaching vehicle is in the relevance area, a screen presentation is built. This screen presentation contains the distance, the risk status (relevance area) and the status of the indicator signal. This screen presentation is then sent to the HMI Connector bundle, which creates a screen request for the Android client. If the approaching vehicle is in the operation area, a bigger screen presentation containing the distance, risk status (operation area) and the status of the indicator signal is shown. Moreover, an acoustic alert is triggered. The warning screen of the HMI can be seen in Fig. 4. It shows that the overtaking vehicle is approaching on the left side. Moreover green arrow shows the indicator lever signal of the ego vehicle. The warning and information levels are also logged for evaluation purposes.

The simulation environment adds three more components to the architecture. The Driver Communicator receives messages from the applications. The messages are unpacked and the required steering commands are sent to the second component, the Driver Simulator. This component simulates the behavior of the driver and processes feedback from the Highway Simulator. The Highway Simulator eventually transforms the steering commands into simulated impulses.

In the simulation environment, additionally the Intervention Unit is simulated. This unit features a simple emulation of the ESC, which would give a brake impulse in the real car. CABSA interacts with this unit and can give abort messages when a simulated lane-changes is detected. The Intervention Unit translates this command into an action for the simulator, and finally emulates the impulse, aborting the initiated lane change.

IV. RESULTS

For our real-world tests we equipped two vehicles with AUs and CCUs. Due to safety reasons, no Intervention Unit was attached, thus the output was only visible on the HMI and in the log files. We made twenty test runs for each scenario on public roads in Berlin, Germany.

The application was tested with two different scenarios. The first one simulates the behavior, the application is intended for. The ego vehicle starts to drive and the other vehicle is following a few seconds later, so that at the beginning there is a gap between the two vehicles. The other vehicle overtakes with a constant speed that is approximately 10 m/s higher than the ego speed.

Thereby, the correctness of all relevant values can be validated, i.e. the distance and speed difference, the length of the relevance area, and the TTP. The correct classification of the other vehicle as “not relevant”, “in relevance area”, and “in operation area” can be validated as well.

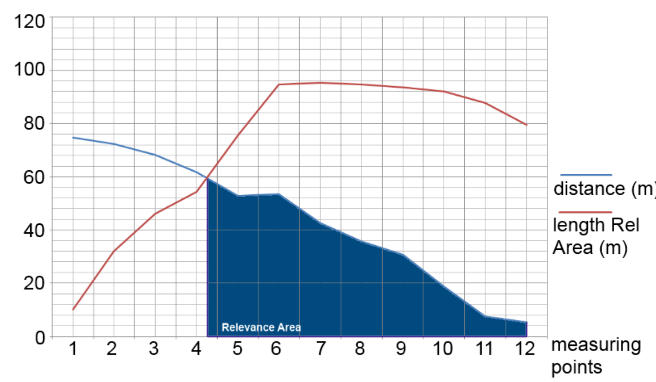

Fig. 5. Relation relevance area-to-distance (Scenario 1)

In the log files the distance and speed difference of the two vehicles, the length of the relevance area, the time to pass and the decision whether the other car is “in relevance area” and “in operation area” is recorded.

Fig. 5 shows the distance of the approaching vehicle to the ego vehicle (blue line). The red line depicts the size of the relevance area. It is increasing at the beginning, as the overtaking vehicle accelerates while the overtaken vehicle drives with an almost constant speed.

After the sixth measurement point, the approaching vehicle has reached its maximum speed, which is held almost constantly from that point on. At the same time the distance between the vehicles decreases. As the relevance area is eight times the speed difference, it grows to almost 100m. At the intersection point of the two curves, the distance between the two vehicles is smaller than the length of the relevance area. Hence the approaching vehicle is inside the relevance area.

In Fig. 6 the speed difference, the distance of the vehicles and derived time-to-pass are compared. The distance scale is non-linear as it shows the distance of the vehicle for a given TTP for illustrative reasons. The values on the y-axis represent the TTP at a certain point of time.

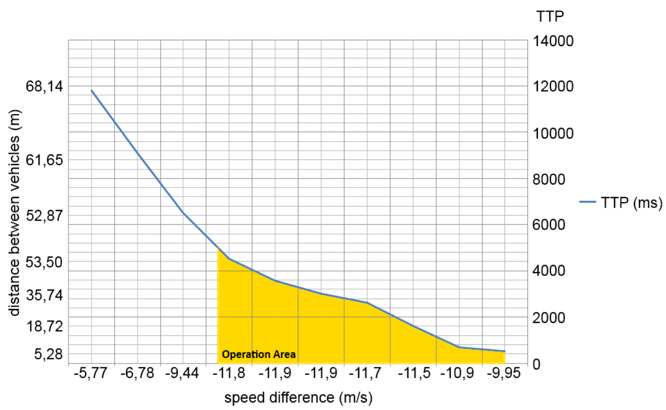

Fig. 6. Time-to-pass (Scenario 1)

When the TTP becomes smaller than 5000 milliseconds, the approaching vehicle is considered to be in the operation area. As in this scenario the speed of the overtaking vehicle is almost stable after a certain point of time, the operation area depends mainly on the distance of the vehicle.

In the second scenario two vehicles are driving side-by-side with a constant speed. Here it was tested if the approaching vehicle is constantly classified as "in relevance area" with a minimum relevance area of 10 meters.

These assumptions have proven valid. In the test runs with this scenario, the distance between the two vehicles never exceeds 80% of the threshold of 10 meters. Even though the TTP is very high (up to 905.000 ms), the relevance area is large enough to consider the other vehicle next to the ego vehicle as relevant.

V. Related Work

Basic blind spot assistance functions were introduced into the market in 2005 [14]. These assistants are usually based on radar technology and do not include Dedicated Short Range Communication (DSRC). Further advances have led to actively intervening systems, such as the Daimler Active Blind Spot Assist. This systems also applies radar sensors [15].

A blind spot assistant solely based on wireless communication is presented in [16]. In contrast to our approach, consumer Wi-Fi (802.11b) is used here. No active maneuvers are performed, the driver is only warned by HMI messages. Furthermore, it is not evaluated, how the system compares to conventional radar-based blind spot assistant.

Other functions combining active intervention and communication (CoDAS) include platooning (e.g. in the SARTRE and Chauffeur projects [17] [18]) and intersection assistance (e.g. in the CoCar project [19]).

VI. Conclusion

Actively intervening cooperative driver assistance systems (CoDAS) are a logical next link from current state of the art cooperative systems to ADAS functions. We presented three different levels of CoDAS systems, sorted by level of dependence on communication: *implicit*, *explicit* and *collaborative* functions.

As implicit functions promise the best feasibility in low-penetration scenarios expected after market introduction of C2X, we picked an example function, CABSA, to showcase how communication can improve an existing active driver assistance system.

Furthermore we explained the basic concept of CABSA and the underlying software architecture used. We conducted first trials in a dedicated simulation framework and finally implemented the functions in real test vehicles using standard C2X equipment adhering to ETSI and IEEE 802.11p.

Our tests with CABSA have proven that the basic principle and the implemented algorithm work well. During our field trials we found a high reliability and no false positives or negatives were experienced in several days of testing.

During the tests it was also shown that CABSA exceeds largely the range of common ABSA systems. During the tests vehicles as far away as 250 meters were recognized, a distance that is not feasible with short-range radars that are used in standard ABSA systems [11] [12]. We can therefore conclude that CABSA is a good candidate for first CoDAS assistance systems.

VII. Outlook

Future implementations of CABSA should implement the Intervention Unit as well to test the full system. To do so, writing access to either an existing ABSA controller or to the ESP system is necessary. In further versions, the data from C2X communication could also be fused with radar measurements from the existing ABSA system, so that uncertain situations can be handled better.

Any testing of actively interfering driver assistance systems require a private test track, as they are highly safety critical. On private test tracks also scenarios with more than two vehicles can be tested, e.g. several vehicles in a row overtaking or three cars next to each other.

Real-world tests of CABSA should be carried out on closed test-tracks due to the dangerous nature of active interventions. It would be especially interesting to conduct comparison between ABSA and CABSA. These technical tests would give valuable results for a further evaluation of CABSA.

Another important point that should be addressed after the technical evaluation of CABSA is user acceptance. In field tests normally a large group of drivers without knowledge about the technical background uses the system. Interviews with the drivers give valuable insight about the driver acceptance. The results should be compared to user acceptance tests of conventional blind spot assistants.

A first next development step is the integration with existing passive blind spot assistants for the visual warnings. Hence not only the Android HMI could be used, but the actual warning systems in the side mirrors as they are used in commercially available blind spot assistants. Thereby, a look-and-feel would be achieved that drivers are already acquainted with.

Our system uses GPS position only. In future work it could be evaluated how bad GPS receptions affects the system. Current research projects also investigate the usage of cooperative positioning to enhance standard GPS with cooperative knowledge. Additional relative positioning information might be available from sensors such as camera systems for relative and absolute lane information.

The approach assumes that the driver abides by the driving rules. For a solution that is ready for the market, also uncivil driving behavior could be considered. For instance it might be possible that a driver changes lanes without using the indicator lever. An augmentation with lane-monitoring systems is advised. Also, the steering-wheel angle along with map data could be used as indicator for lane change.

For further research, the system should be compared to a conventional blind spot assistant. Thereby the number of false positive and negative recognitions can be compared. Hence, it can be investigated how many critical situations can be avoided with CABSA that a conventional system would ignore.

The presented system can also be applied for lane-level map matching. With knowledge about cars driving on the right or the left of oneself, the own lane can be estimated. Further work on CoDAS functions on the three different levels will be taken on with other exemplary functions.

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