ADVANCED DRIVER ASSISTANCE SYSTEMS FOR MOTORCYCLES: CONCEPT OF A LANE CHANGE ASSIST

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ABSTRACT

In 2015, there were 12.611 registered motorcycle accidents in Germany. About twenty-five percent of all these accidents were caused by a lane change maneuver. Such accidents put the human lives in severe danger and might lead to serious injuries (AIS 3+) which need a long period of recovery. For that reason, different safety concepts for motorcycles are being investigated. The main challenge here is about finding an adequate safety concept, which is able to support the driver while changing the lane.

A benchmark of sensor systems in a virtual environment has shown that imaging sensors can be used to design a Lane Change Assist (LCA) in a compact package. This can be realized with two cameras allowing the sensor system to survey the complete safety area. The image processing is based on advanced algorithms, which detects objects on the driving way and lane markings. Thus, the image will be further processed for transforming the detection resultant points into an orthogonal view. This perspective shows the lane markings and the rearward surrounding cars. The distance calculation is based on the scaling ratio between the orthogonal view and the reality. At this point the algorithm is able to calculate the safety area in relation to the differential velocity. When the safety distance between the motorcycle and the car is too small, the LCA initiates appropriate visual and haptic warning signals. In addition to that, the motorcycle will have a pull upright to support the driver to react earlier in such situations.

The imaging sensor based Lane Change Assist is able to detect objects and lane markings. In addition, the LCA can be applied to every motorcycle, due to the compact package form. This research topic has a relevance to the technical session *#6: Crash Avoidance Technologies.*

INTRODUCTION

Accident analysis

According to the statistics of the Federal Statistical Office (DESTATIS), around 12611 motorcycle accidents with personal injuries happened on German roads in 2015. Thereby 24 percent of those accidents can be regarded as those, which are relevant for a two-wheeled vehicle (motorcycle) Lane Change Assistant as shown in the diagram in Figure 1. Those include each lane changing overtaking maneuver that led to a collision with nearby driving vehicles(s).
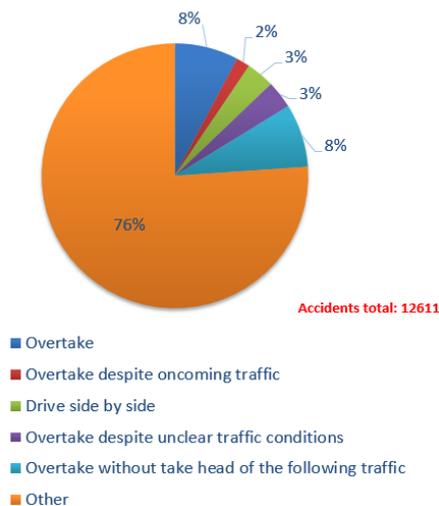

Figure 1. Federal Statistical Office (DESTATIS) motorcycle accident statistics 2015 [1]; Own representation

Additional statistics from the German In-Depth Accident Study (GIDAS) published in 2010, showed that 17% of all accidents where two wheel vehicles were involved are caused by an incorrect running lane change [2].

On the basis of these statistics, it is obvious that a Lane Change Assistant for a motorcycle is necessary for increasing the driver's safety and in addition improves driving comfort for the driver. With a lane change system, it would be possible to prevent up to 17-24% of all accidents that ended with persons injuries in Germany and thus worldwide.
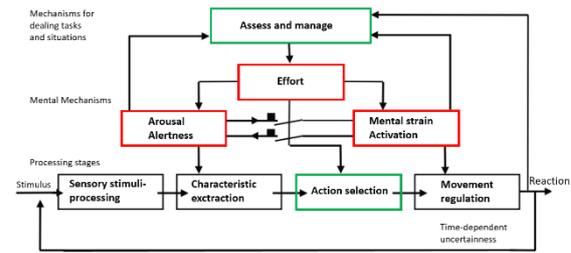
Motorcyclist alertness

Figure 2. Effort regulation in the information processing by Sanders (1983) [3]; Own representation

The effort regulation in the information processing after Sanders can be seen in figure 2 [3]. With this, it can be explained why a lane change might be incorrectly carried out. Indeed, the required psychophysical energy for attention and activation awareness for actions such as the lane change action is provided by a central resource. The capacity of this central resource varies from one person to another. This capacity is as well influenced by temporally variable factors which can lead to situations where the capacity of the central resource is weakened or not fully available. Indeed, an increasing demand for capacity during an activity increases the required effort(s). The activation depends on the capacity and motivation behind this effort(s). In case where the available variable capacity is exhausted, it cannot be instantaneously further increased for the required efforts. Such cases where low capacities occur are due to fatigue and monotony. In addition, the inefficient distribution of the efforts on the tasks can lead to reducing the attention and awareness levels. These occur for instance in anxiety, confusion, anger, agitation or muscle tension, etc. [3]. Moreover, confusing situations, distraction and carelessness can cause that a lane change is wrongly done. As marked in Figure 2, the driver can be supported through a Lane Change Assistant in the psychological mechanisms (red mark) such that a controlled positive effect on the action (green marking) is added.

STATE-OF-THE-ART

Lane Change Assistant car

Lane Change Assistants [4] are already established techniques in passenger cars for a long time. The detection of vehicles on the neighboring lane occur depending on the manufacturer approach using radar sensors (24 GHz or 77 GHz), cameras or laser scanners. Here a visual warning is carried out in dangerous situation, if no indicator for lane changing is set. A higher warning level is mostly activated when the indicator is set. Usually, optical warning signals, as seen in Figure 4 at an Audi Side View Assist, are placed in the side mirrors. Often, the optical warning is also placed in A-pillar or Head up display. Warning signals are displayed in optical form by means

of light, acoustic in the form of warning sounds or haptic vibration on the steering wheel or seat. There are also active systems, which alert not only the driver, but also actively intervene in the steering of the vehicle. With such systems, the track can be kept or changed. The driver can overrule the system at any time.
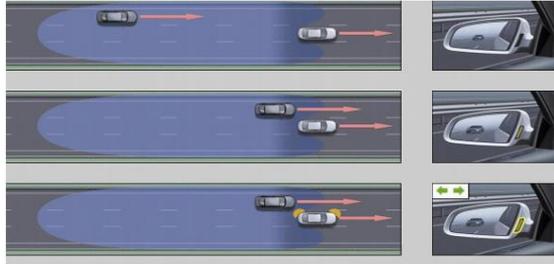

Figure 3: Example of Warning Signal in a car [5]

Side View Assist

Currently BMW is offering the world's first environmentally-friendly driving assistance system in two-wheel-drive vehicles the Side View Assist (SVA) [2]. In a Maxi-Scooter BMW C 650 GT, the system warns the driver visually if there is a vehicle inside the blind spot. The warning signal is communicated in form of a luminous triangle in the mirror base. When the signal is disarmed and the blinker is activated, the triangle symbol begins to flash. The system operates with four Bosch ultrasonic sensors (two front and two rear), which detect the area around the vehicle with a radius of five meters. The rear sensors cover the blind spot. [6] The rear sensors cover the blind spot. The two front sensors are used for plausibility checks, in which you distinguish opposite, parked and relevant traffic users.
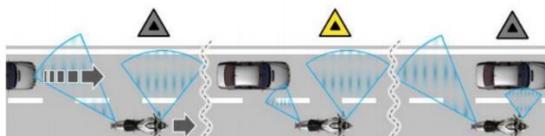

Figure 4: BMW Lane Chance Assist sensor cone [2]

Moto Riding Assist

A further assistance system for motorcycles, which this time has in relation to the moment of the pulled upright, is the Moto Riding Assist. The motorcycle by Honda [7] is able to preserve in the state of balance. The vehicle is also able to drive in a self-controlled manner without a driver in step-tempo. In addition, it is equipped with a mechanism which allows the steering head angle to be varied. Thus, the wheelbase can be changed for the benefit of higher driving and standing stability in slow locomotion.

METHODOLOGY

Simulation in the virtual environment

Due to safety-critical aspects, it is imperative to test driver assistance systems before they can be released and used in the normal road traffic. The developer must ensure that the expected risk in dangerous situations through the use of the assistance system is lower than without. This leads to a considerable test effort, which is sometimes one of the most time-consuming and costly phases in software development. In order to profit in terms of reproducibility, flexibility, cost reduction and the process to create test and evaluation possibilities for specifications and solutions at the beginning of a vehicle development, the simulation tool PreScan is predestined for this purpose. The scenarios in the tool can be defined and executed in a virtual real-time based GPU. In addition, sensor concepts can be verified through this simulation tool.

Benchmark sensors

To make an appropriate selection of a sensor for a motorized two-wheel vehicle, a benchmark in the virtual environment was conducted. Here, the system should ensure detection in the blind spot and fast vehicles coming from behind.

The challenge compared to a lane changing assistant in motor four wheeled vehicles is that due to the driving dynamics of a motorcycle during a cornering, a roll angle is created. For this purpose, environmental sensors must ensure the coverage of the complete hazardous area. Figure 5 shows the danger area and field of view of the motorcyclist.
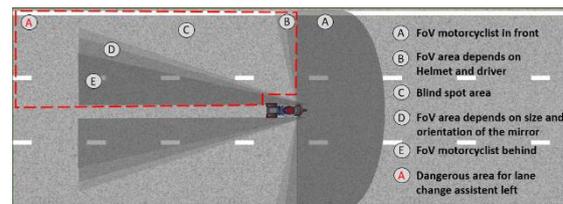

Figure 5. Field of view motorcyclist and danger area for lane change scenario

The danger zone for this concept should not only capture the blind spot, but also to view the rear, to even alert of quickly approaching vehicles. Scenarios as shown in Figure 6 can be seen as lane change scenarios.

To classify suitable sensors, virtual scenarios were modeled in PreScan, which cause a strong roll angle in the motorcycle model while driving on narrow curves. Thereby, no mechanical compensation of the roll angle should be performed.
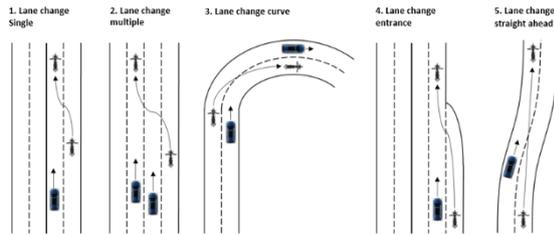
Figure 6. Possible lane change scenarios

Selected sensors were considered more closely for the benchmark in the virtual environment with some scenarios including curves. The attached sensors were checked for the covering of the dangers area (Figure 7). Furthermore, by varying the inclination of the sensor pairs A-D the achievement of better results has been evaluated. The individual sensor pairs are described below.

A: This scenario simulates situation, when cornering. In this case the cover of the sensor for the complete rear road is not guaranteed. In fact, the curve inner track can be not completely detected depending on the curvature degree and the inclination degree of the motorcycle for such a situation, where a blind spot occurs, the fisheye camera is ideal, because it completely covers the blind spot.

B: The scenario B deals with the case where two MFC2 cameras do not cover enough the neighboring track. These cameras are different from fisheye and were considered in this scenario for comparison with the settings in scenario A.

Figure 7. Benchmark Sensors in PreScan - Part 1

C: Instead of the camera from Continental, here two SCam3 of TRW were tested. Only after variation of the inclination to 10 °, a complete cover of the danger area was given. However, with the variation, the sensor cone protrudes too far upwards for the trace detection. However, the sensor cable protrudes too far upwards with the variation for the track detection.

D: The Blue Eagle First Sensor camera is ideal for the view to the rear. With this, a complete cover can be granted in any situation. Bosch Ultrasonic sensors are not suitable when cornering, due to the low vertical field of view. Also, when you change the inclination to 13° you will lose the potential collision partner on the curve exterior as shown in Figure 8.

Figure 8. Benchmark Sensors in PreScan - Part 2

E: The two sensors from First Sensor are predestined for this concept. With these, they have the full area coverage in all situations.

F: The short-range radar from Continental has very good horizontal coverage. With the small vertical angle of view of 12°, there is no cover on the tracks even at small roll angle situations.

Figure 9. Benchmark Sensors in PreScan - Part 3

G: The Short-Range Lidar sensors are relatively large from the package and there is also no cover when slanted. The visibility of the sensor is only 10 m.

Figure 10. Benchmark Sensors in PreScan - Part 4

Other: Time-of-Flight cameras could also be considered but they also have a limited range. Laser scanners are not considered due to the cost and installation space. As an alternative to mono-camera, a stereo solution would also be conceivable. However, these would bring more space, elaborate calibration and more cost for the same result.

Finally, the sensor combination of a mono-camera sensor and a fisheye camera sensor is the best solution for a Lane Changing Assistant for motorcycles. These can be installed in a compact manner and are relatively inexpensive to the other sensors. In addition, they would cover the danger area even in the case of deeper motorcycles.

Human Machine Interface (HMI)

The following paragraph describes how the warning for the motorcyclist can look, depending on the risk situation. Three warning levels are described in this concept:
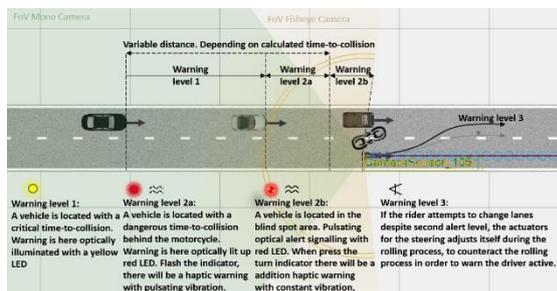

Figure 11. Illustration of Warning Signals for Lane Change Assist motorcycle

Alert level 1: A vehicle is approaching at a higher speed than that of the motorcycle. Through the computation of the time-to-collision, conclusions can be derived whether the vehicle is at a critical distance from the motorcycle. For this a warning with a constant yellow LED illuminating will be displayed.

Warning level 2a: A vehicle is with the actual time-to-collision in a dangerous area behind the motorcycle. This is followed by an optical warning with a constantly red LED. When the motorcyclists set the indicator, there will be an addition warning with a pulsing vibration on the steering wheel or under the seat.

Warning level 2b: if a vehicle is in the blind spot a warning is given with a lit up red LED will start. When the driver sets the indicator, the optical warning signal pulses and the tactile warning vibrates constantly. If the driver (without a turn signal) is too close to a vehicle, the warning signals are also used here as with indicators.

Warning level 3: if the driver initiates a lane change despite the warning level 2, the steering actuator engages early and changes the steering angle (up to 2 °) of the front wheel in the direction of the roll angle. As a result, the motorcycle has a set-up torque that warns the driver in addition. If the driver still wants to change the lane, he can easily override this.

Calculation of the moment of installation

The rotating front wheel has an angular momentum, which causes gyroscopic reaction moments when turning around the vertical axis, or skew. The angular momentum depends on the moment of inertia and the angular velocity of the wheel.

$$L = J * \omega \ [kg * m^2]$$

With this, the reaction torque can be described which has the cause for putting up the motorcycle. This depends on the angular momentum and the steering speed.

$$M = L * \omega_L \ [Nm]$$

The actuators should be able to vary the steering speed such that different reaction moments can be hauled.

Algorithm approaches

The proposed Lane Change Assist algorithm consists of the following stages: definition of the Region of Interest (ROI), Lane Detection, Object Detection, Homography and time-to-collision with triggering the actuators as shown in Figure 12. The aim of the proposed algorithm is to detect the positions of the lane and the vehicles behind the motorcycle. For this purpose, first we reduce the image for less computational complexity. However, since the motorcycle can lead to pitch and roll angles, these must be considered when determining the ROI. Afterwards a neural network with the deep reinforcement learning function search in the image the lane and possible objects behind the motorcycle. After that the points with the information about the lane and the objects

will be transformed into the orthogonal view. For this, there are for each roll and pitch angle an own transformation matrix, which were previously created automated in PreScan.
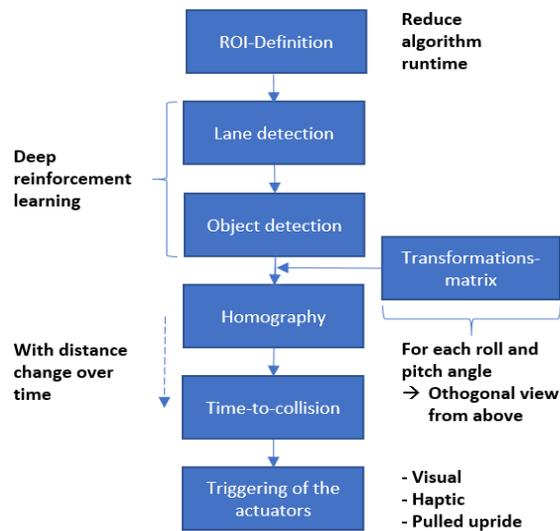

Figure 12. The flowchart of the algorithm

Based on this data, the algorithm is able to determine the relative position of the lane and the objects behind to the motorcycle.

ROI definition

At the beginning of the algorithm, the image must be preprocessed to compensate the pitch and roll angle. For this purpose, cropping of the image is automatically done using a predefined transformation table. Cropping or, more precisely, defining an ROI serves to improve the detection by the algorithm and enormously reduce the algorithm runtime. The size of the ROI is not constant as the visible range changes due to the pitch angle. Thus, there is a previously defined ROI size for each pitch angle as shown in Figure 14 (d).
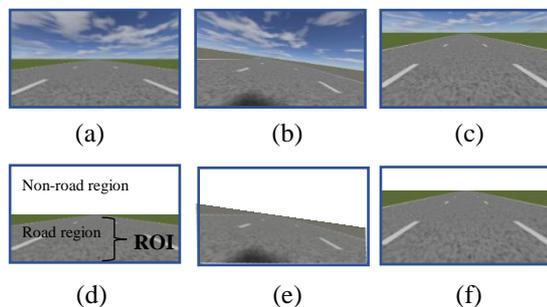

Figure 14. (a) original image-1, (b) original image-2, (c) original image-3, (d) cropped image-1, (e) cropped image-2, (f) cropped image-3

Lane and object detection

After determining the ROI, the position of the track and the objects behind the motorcycle is detected using the Deep Reinforcement Learning Method, as shown in Figure 5.
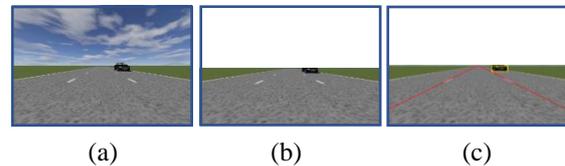

Figure 15. (a) original image-4, (b) cropped image-4, (c) detected lane and object in image-4

Deep reinforcement learning

Reinforcement learning (RL) usually solves sequential decision making problems. An RL agent interacts with an environment over time (Figure 4).
At each time step t, the agent receives a state s_t and selects an action a_t from some action space A, following a policy $\pi(a_t|s_t)$, which is the agent's behavior. In an episodic problem, this process continues until the agent reaches a terminal state and then it restarts. The agent aims to maximize the expectation of such long-term return from each state. The return R_t is the discounted, accumulated reward with the discount factor $\gamma \in (0; 1]$.

$$R_t = \sum_{k=0}^{\infty} \gamma^k r_{t+k}$$

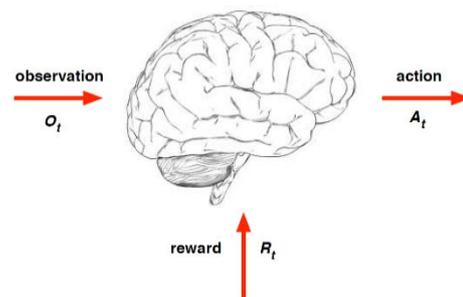The agent aims to maximize the expectation of such long-term return from each state. [8]

Figure 16. Principle of deep reinforcement learning [9]

Homography

Homography is the transformation of an image from the camera coordinates into another coordinate. There are for each roll and pitch angle one own transformation matrix. With that you are able to compensate the roll position of a motorcycle. After the detection of the lane and the objects, the points are transformed using the transformation matrix into the orthogonal view from above. Now it is possible

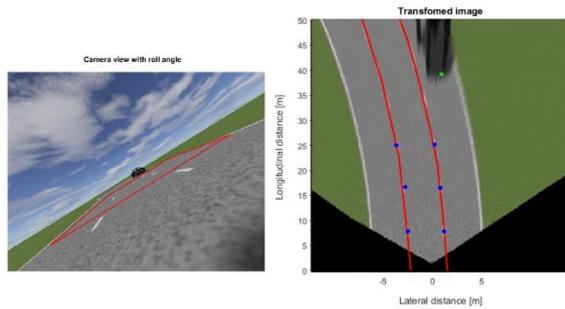with the scaling to determine the relative position of the lane and the objects to the motorcycle. [10]

Figure 17. Left: Camera view roll angle and base - Right: homography of the detected points

Time-to-collision [11]

For the time-to-collision, it is necessary to use at least two consecutive frames to detect the relative speed of the objects. For this purpose, the distance from the first frame is stored and subtracted from the second frame, whereby the distance change can be determined. The relative velocity and time-to-collision can then be calculated using the following formula.
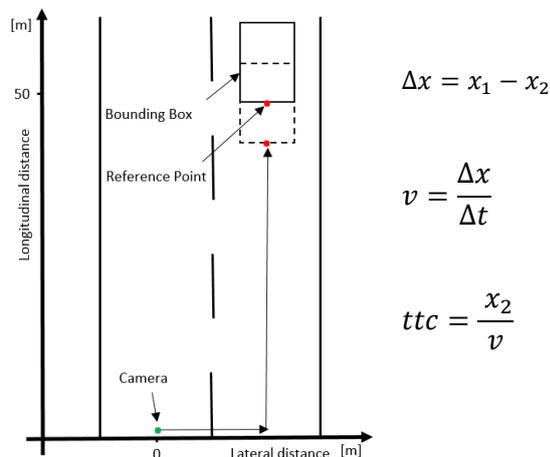

$$\Delta x = x_1 - x_2$$

$$v = \frac{\Delta x}{\Delta t}$$

$$ttc = \frac{x_2}{v}$$

Figure 18. Time-to-collision schema

DISCUSSION

One of the main challenge for lane change system in motorcycles compared to passenger cars is caused by the resulting roll angle which occurs when driving through a curved way. This can be solved using the homography presentation. Restrictions herby are that during the transformation to the orthogonal view, the horizon is taken for reference as a plane. In the case of height differences such as hills, the reference point of an object is displaced after transformation. As a result, the measured distance required in order to compute the time-to-collision is not correct. In order to avoid a wrong measurement

in such situation, permanent redundancy is created over the size change of an object detection. By changing the scaling in a time interval, the time-to-collision can also be described [12]. Using the deep learning method, the algorithm can be trained similarly to a human brain. If there are situations which were not taken into account during the conceptualization and training of the algorithm, the neural network can assign it in its experience and decide accordingly. Here the functionality can be trained and tested in the virtual environment of PreScan. The trained neuronal network using simulated data cannot be directly transferred to the real world. However, the algorithm can further be used and the training has to be done on the real street again.

SUMMARY

A Lane Change Assistant for motorcycles is nowadays mandatory in order to increase the safety for motorcyclists and other road users. About 17-24% of all accidents with personal injuries could be reduced with this system. To cover the full range of risk, camera sensors are predestined for this. Cameras can also be mounted on the motorcycle in a compact design. A lane change system can be fitted on almost all two wheel vehicles, even subsequent. The current amount of two-wheel vehicles is located in Germany with over 4.2 million and rising almost constantly by 100,000 vehicles each year [13]. Through advanced image processing and data analysis methods (Deep Reinforcement learning), the Lane Change Assistant us able to analyze in real time the input images and monitor the lanes, nearby traffic and objects, deliver distances and information about the traffic situation. That information is used to support the driver for safe driving and safe overtaking manoeuvers.

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