Anticipation of a Driver's Pathway

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Abstract. Most car accidents occur due to rear-end collisions or lane departures. The number of such accidents can be reduced, if the driver knows more precisely, where the car is heading to and at which distance it can stop. Combinations of optical and haptical presentation schemes try to support the driver in his primary task. Such driving-loop-embedded schemes require detailed analysis to determine if distractive effects are minimized and driving performance will actually increase.

This paper aims to make a survey of the current research directions, design issues and partial results, as presented in the related published works.

1 Introduction

Statistics show that most car accidents occur due to human errors regarding correct appreciation in the longitudinal and lateral traffic. A study made by the Federal Statistical Office in Germany revealed the fact that the two main causes of accidents are the Departure of Lane and the Crash in longitudinal traffic. A graphical representation can be seen in figure 1.

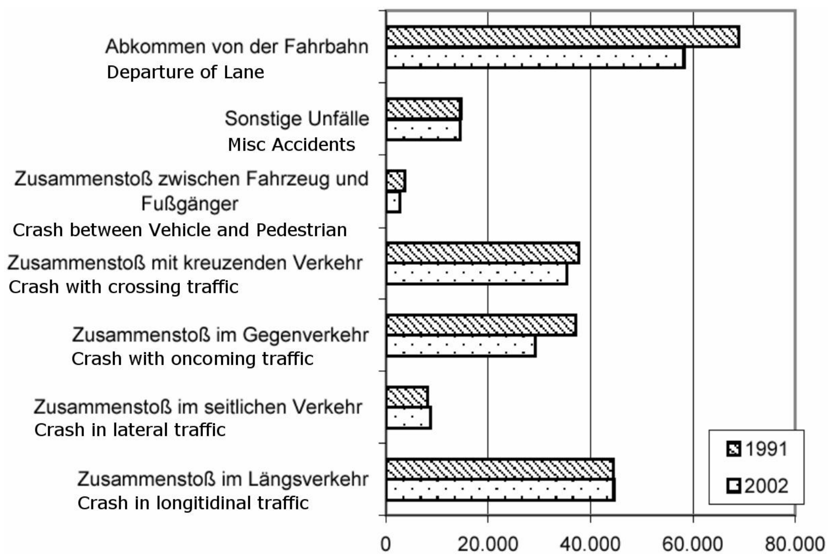

Figure 1: Distribution of accident counts in 2002, in Germany (adopted from [STA02])

First solutions that were developed to support the driver by their main task are the so called Adaptive Cruise Control Systems (ACC). They were thought to actually replace the driver by overtaking the control of accelerating and breaking. This is the situation of an out-of-the-loop system and it is a fact that such systems have a bad behavior in time-critical situations. Section 3.1 of this paper will describe those systems in more detail and the problems that occur when using them.

In order to adapt the ACC systems to time-critical tasks, a step back in the automation levels has to be done: from the delegation of tasks by the driver to the system (ACC case), to mutual cooperation between the driver and the system. [POP07] describe the automation levels and their current implementations in more detail.

Among the latest research there is an orientation toward visual support by means of additional displays on the board of the car or by means of Head-Up-Displays. Measurements show that the first ones may have distractive effects, thus bad behavior in time-critical cases. Current research deals with designing and building 3D Head-Up-Displays with the help of Augmented Reality which might improve the driving performance. Tests are still being carried out and some of the results so far are being presented at the end of this paper.

2 Related Work

Sullivan et al. [SUL06] has implemented and tested an assistance system for vessel navigation. The current status of the vessel and the predicted position in a short time in future are showed on an additional display. Thus, the salesman actually has to steer the predictor such that it remains on the predefined track. The results of the tests carried out for both novice and experienced salesmen shown an improvement for both categories when using the predictor (see figure 2).

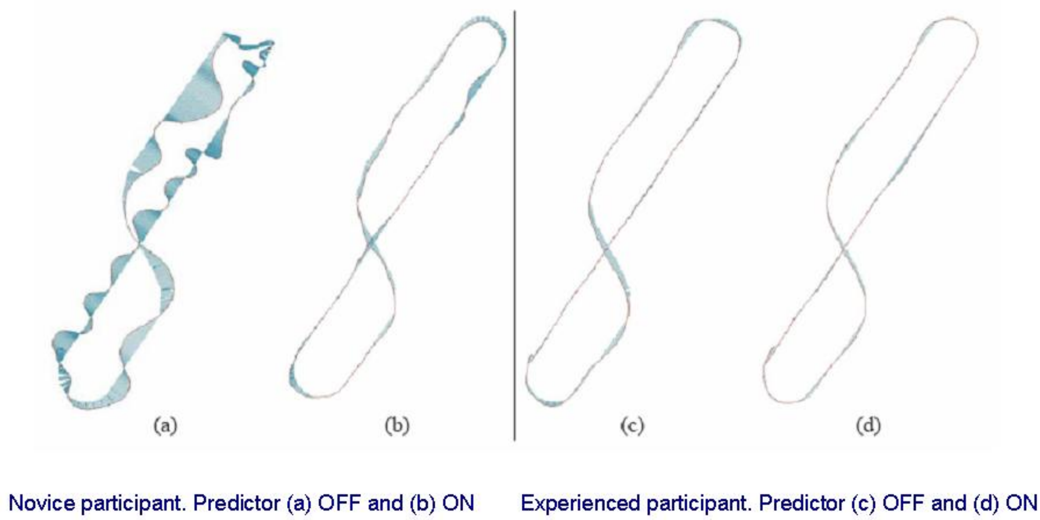

Figure 2: Samples of cross-track distance.(adopted from [SUL06])

From the time-critical point of view, there is a big difference between the steering of a vessel and the driving of a car. While in the first case there is a relatively big delay in the response of the ship to the steering, when driving a car, there are immediate effects for every

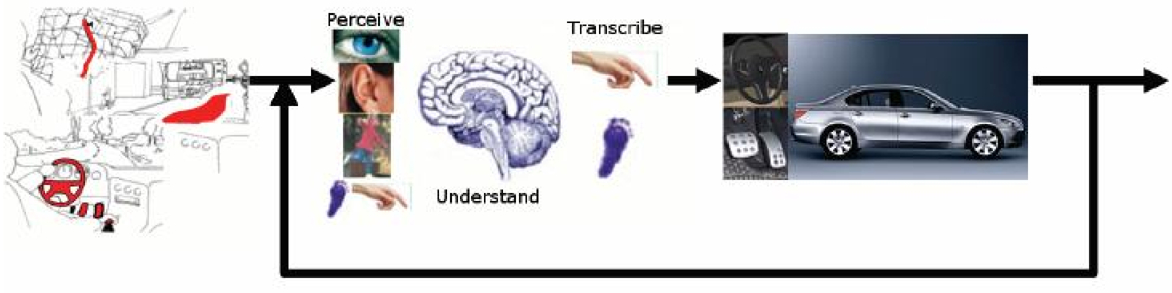

Figure 3: The driving-loop. (adopted from [POP07])

maneuver. Thus, another way to display the future position anticipation is needed.

Studies carried out in the airplane sector tried to prove whether situational awareness in conjunction with course support can be improved without increasing the pilots workload. Kramer et al. [KRE04] achieved good results while testing different display schemes on the HUD of the airplane. The best ones were for the case of a dynamic tunnel with a follow-me guidance. Tönnis used this result later to derive 3D HUD schemes for cars [TON06].

3 Related Concepts

The driving task composes of three main activities which have to be continuously fulfilled by the driver: navigation, stabilization and maneuvering [BER70]. In order to do so, they have to execute a so called control circuit or driving loop: perceive input by all senses, process it and then transcribe the next steps of the driving plan into manipulations of the steering wheel, the gas and the brake pedals [BUB93]. See figure 3.

Driving assistance systems are meant to partially or totally automate the driving loop. Some systems replace the role of the driver in the loop and shift their task to that of a supervisor. This is a so called out-of-the-loop implementation. The other possibility is to support the driver instead of replacing them, i.e. keeping them in-the-loop. Those two types correspond to two different levels of automation: the functional delegation cooperation mode and the mutual cooperation mode [END95].

3.1 Adaptive Cruise Control System

ACC Systems are out-of-the-loop implementations of the function delegation cooperation mode. The driver has the possibility to set the wanted speed and the desired following distance. The later is measured in seconds and it represents the time that is going to pass until the own car will reach the point the car in front is at the present time, given the speed remains the same. If the car in front drives at a lower speed compared to the own car, the system will decrease the own speed such that the distance to the car in front remains in the limits set for the desired following distance.

After setting those two parameters, the driver gives over the control to the system. This will keep track of the cars status, accelerating until the wanted speed is reached or, if in following modus, breaking until the desired following distance is achieved. In this situation the driver is not taking part to the loop anymore, but has only a supervisor role.

If a critical task appears and the ACC System is not able to handle it, it will immediately signal that to the driver requiring him to take over the control. This is the very weak point of the implementation, as the driver is being put in the situation to suddenly jump back in the loop and interpret the situation which he might not be aware of.

An example of a time-critical situation is when a car driving at a very low speed cuts in front of the own car. At this point the system will notice that, with a normal breaking peace, it is not going to be able to maintain the desired following distance and will require for the driver to take over the control.

On the other hand, the ACC System can also be considered an in-the-loop implementation, regarding the lateral driving assistance. It keeps track of the lane margins and warns in case of a lane departure. But it does not take control over the steering wheel. It is still the driver's task to turn or change directions and, of course, to react in the case of a lane departure.

3.2 Active Gas Pedal System

As an implementation of the mutual control cooperation mode, the AGP Systems are a step backward in the automation levels, comparing to the ACC longitudinal assistance. But they offer a better response to the time-critical situations by keeping the driver in-the-loop. One can set the same two parameters as for the ACC systems, but instead of taking over the entire control loop, this system only assists the driver. To keep running at the wanted speed, AGP does not take over the full control of the gas pedal, but it sets a resistance point on the gas pedal at the position which once achieved would give the specific speed. The driver can choose either to accept this hint and stop at this position or to overcome it by applying a higher force to reach a higher speed. See figure 4(a).

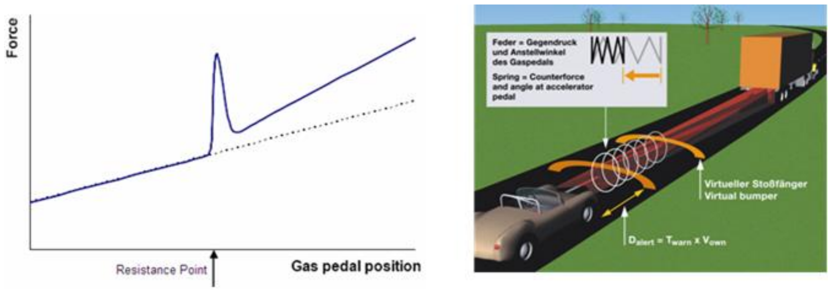

Figure 4: Active Gas Pedal with (a) resistance point and (b) active force (figures adopted from [POP07] and [CON04]).

Another possibility is that of using active force. The gas pedal acts as it would push on a spring which contracts when the distance to the car in front decreases. Thus a counterforce appears in the pedal and the driver tends to stop accelerating. See figure 4(b).

3.3 Head-Down & Head-Up Displays

Automation systems use different interfaces to communicate with the driver. The most common ones are those based on visual perception, by which the human being can perceive the biggest amount of data in a very short time. One way to present the information in this case is an additional display installed on-the-board of the car. In figure 5(a) there is an example of such a display integrated in the ACC System of a BMW car.

Figure 5: a. (Left)Secondary display used by ACC system. b. (Right) Head-Up Display (courtesy of BMW)

These are the so called *Head-Down Displays*. In order to check the current status, the driver has to move his glance from the road in front down to the display on the board. The time needed to do one check might seem very small, but when taking into account the frequency of all subsequent checkings during a cruise and the interruption caused in the normal road tracking, the use of Head-Down Displays could cause drivers an extra workload.

More than that, in the case of time-critical situations the driver must be announced as fast as possible. Having a lamp blinking somewhere on-the-board, out of the driver's normal sight frustum, cannot be a reliable warning system in this case.

A solution for these two main issues are the *Head-Up Displays*. The symbols representing the car state are mirrored directly on the windshield, at a fixed position. (figure 5(b)). The driver does not have to move sight and to focus on short position. The implementation of such systems must though be done carefully. First of all, the symbols on the windshield must not occlude elements on the road. Thus the location under the horizon, at the bottom of the windshield. Secondly, the color used to display the symbols has to contrast well with the gray of the road and to make the symbols easily distinguishable from elements of the real environment. As seen in the figure 5, BMW uses light green and light orange as displaying colors.

Other issues, like the amount of information that should be displayed or how to indicate changes of the status or critical situations, also make the subject of some studies and experiments, but they are not going to be covered in this paper.

4 3D Head-Up Displays

The HUDs presented in the section above are categorized as regular or 2D symbolic HUDs. Current research focuses on design and implementation of the next generation of such displays: the conformal or 3D HUDs.

4.1 Principle

The use of symbolic representation may become intuitive after a short accommodation, but it does not always suffice to properly perceive the environment. Consider for example the symbols used to represent the settings of the ACC Systems (figure 6). Comparing the two states of the symbol for the following distance one can easily see the difference, but the driver only sees one state at a time. How far away does really 2.0s represent? Where is the car going to stop if one is obliged to fully press the break pedal?

The idea behind 3D HUDs is to embed additional virtual elements in the real world by means of Augmented Reality. This would allow, for example, to put a mark right on the road in order to signal the position where the car is going to stop while breaking. The main difference to the symbolic representation is that the elements appear to be located in the driving scene. For a Head-Up Display this means that the image plane of the mirrored items lies directly on the street and not perpendicular to it (as in the regular HUDs), being thus able to provide depth information. See figure 7.

4.2 Design

Tönnis et al [TON06] designed a 3D HUD starting from the flight-tunnel presentations in airplanes. In doing so, there are some common, but also some different aspects between flight of a plane and driving of a car, that have to be taken into consideration.

First of all, the space dimension in which the movement takes place. For an airplane, there has to be assistance for all three dimensions. But a car mainly moves in only two directions: longitudinal and lateral. There is no vertical component of the speed, except the rare and special cases of "over or under crossing". This resulted in projecting the 3D flight-tunnel to a 2D drive-path to be displayed on the road. See figure 8.

The drive path shouldn't remain fixed in reference to the environment, but to the driver, such that it always shows the anticipated path that the car *is going to have* given the actual status. In contrast with that, the flight-tunnel is designed to show the path that the airplane *should have* and the pilot has the feeling of moving through the tunnel.

Regarding the cruising speed in the two cases, there is definitely a big difference. Airplanes are flying at very high speeds, thus the curvature of the flight-path cannot be too big. Meanwhile the speed of a car is relatively low and there can be curves with a very big curvature. So the drive-path representation must be adjusted to display these cases too.

Moreover, not that the car can run at a very low speed, but it can also completely stop. This is of course not the same for airplanes, where there is a limit for the minimum speed such that it can still maintain itself in the air.

A very important issue in the anticipation of the drive-path are the obstacles that might appear on the road. Unlike the air traffic, which is very sparse, in the land traffic there can always appear some car in front or some pedestrian on the street. To anticipate the possible stop position in these cases is vital. The solution was the introduction of the *breaking bar*. As seen in figure 8, this is situated at the end of the driving-path and it marks on the road the position where the own car would stop in the case of fully breaking. It can also rotate around

Figure 6: Symbols for desired following distance(left) and wanted speed(right) (adopted from [THO05])

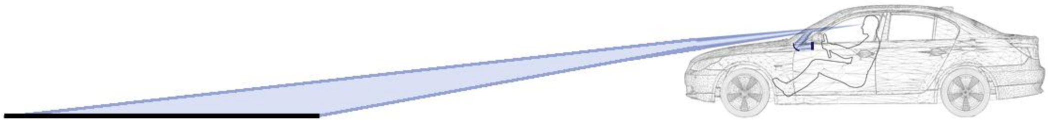

Figure 7: Image plane for a conformal HUD. (courtesy of BMW)

Figure 8: 3D HUD: Drive-path and breaking bar.(adopted from [TON06])

the vertical axes, such that if the car is going through a curve, the bar indicates exactly the anticipated position of the front of the car.

To indicate that there is an obstacle on the road and that the stop position is situated behind it, i.e. there could be a collision; the color of the bar should change. Another possibility is to change to a *"following modus"*, also indicated by the change of the color. In this case the bar will represent the distance to the obstacle and not the breaking distance anymore.

A common aspect to airplanes and cars is the lack of space to embed such new systems. Because of the large area that has to be mirrored to the windshield and also of the several lenses that have to be used to obtain the right plane on the road, the volume occupied by such a device might be as big as a couple of liters. This can prove difficult to encapsulate it in the already very full board of a car.

As for all other interfaces that are used while driving, the question regarding their possible distraction effects has to be answered. Would such a display scheme be a *perception tunneling* trigger? The theoretical answer is "no", but it still has to be proven by conducted experiments. The explanation is that the bar and the drive-path are items of an Augmented Reality and they are thus not going to be perceived as separate elements on their own. The driver is going to see the same environment as before, but enhanced with the new markups.

The next possible distraction is *cognitive capture*. This would mean that the driver is going to analyze why is the bar moving away, for example, instead of processing the information given by this changing, that is that the own speed has increased. Again, the theoretical answer is a positive one. By means of accommodation with the new system, the driver should begin to perceive the actual information given by the bar and not its behavior on its own. But this has again to be tested in a real driving environment.

4.3 Experiment

As no such HUDs have been built and embedded into a car yet, current experiments have to be carried out in driver simulators. Tönnis used such a simulator at the Technical University of Munich to test how driving performance and driver behavior is affected by different

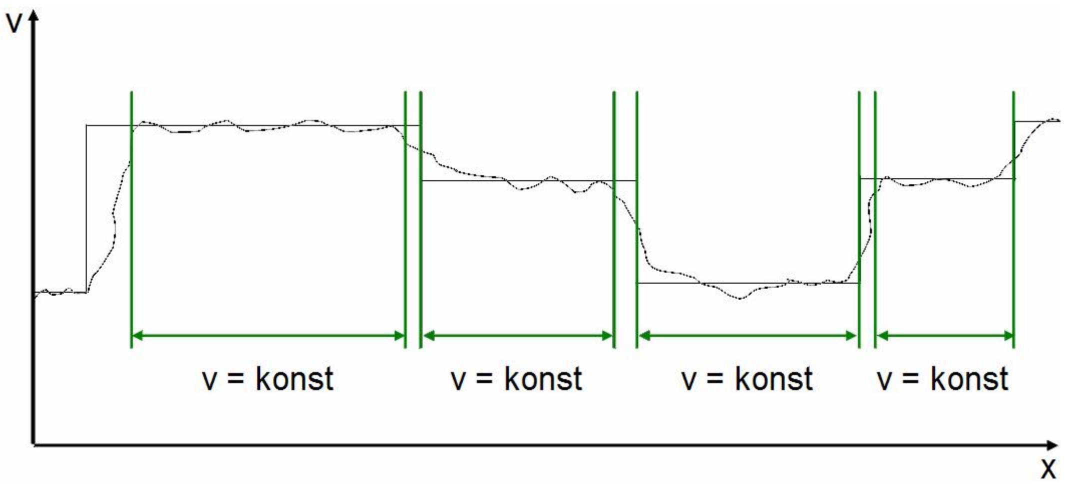

Figure 9: Simulated path divided in intervals according to traffic signs and the segments used for analysis.

presentation schemes.

Subjects of the experiment drove a modified BMW E30 convertible with automatic transmission and simulated motor sounds on a two-lane rural road course with long curves and some villages in between.

One of the objective measurements was the speed behavior. In order to track how the participants are following the traffic rules regarding speed constrains, the simulated path was divided into four intervals in dependence to the traffic signs. Data taken into consideration for analysis was only from road segments defined as follows: if there is a sign indicating that the driver should decrease the actual speed, then that is a hard border and the data is being registered from that very point; on the contrary, if there is a sign indicating that it is allowed to drive at a higher speed then there is going to take a while until the driver will accelerate to that limit speed. In this case they defined an offset of 5 km/h below the speed limit indicated on the sign. Only after passing this offset the tracked data is going to be used. Figure 9 shows the simulated path with the four intervals defined by the traffic signs, the allowed speed in each interval (denoted with the gray straight lines), one sample of the measured speed and the segments where the data was considered from (denoted with green bars).

The measurements for the lateral traffic evaluation were done on the entire path, regardless the above intervals.

4.4 Results

For longitudinal assistance, the mean difference between the driven and the allowed speed was computed, based on the four sections of the road. There was a significant result for the case of no assistance compared to the one with full visual assistance (breaking-bar and drive-path). In the first case the participants were driving with in average with 5 km/h too fast, while in the second case they were about 8.83 km/h faster than allowed (see figure 10(a)). This concludes in the fact that participants drove faster with visual assistance, which means they felt safer.

In the lane departure measurements all results were significant. The best performance in

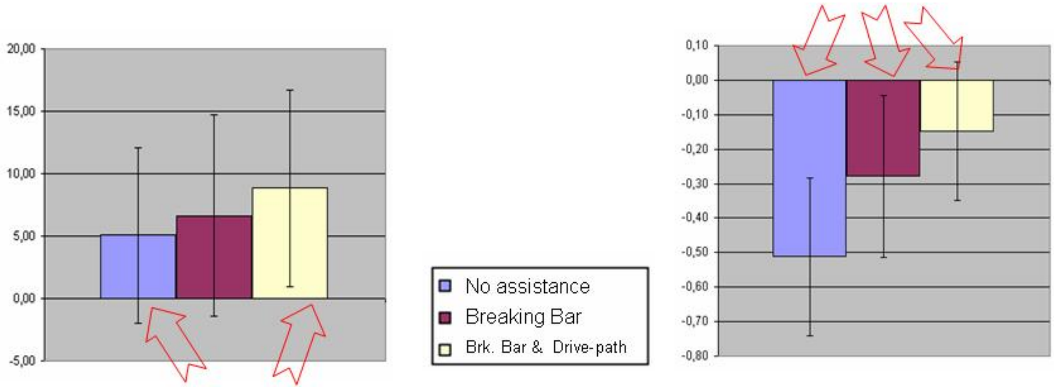

Figure 10: Objective Measurements. a. (Left) Longitudinal assistance: difference to allowed speed. b. (Right) Lateral assistance: lane departure

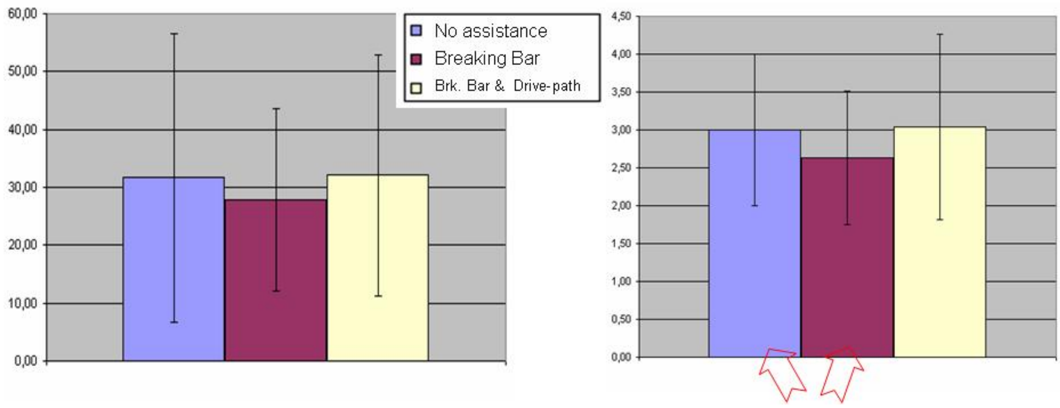

Figure 11: Subjective measurements. a. (Left) Overall Workload Index (NASA TLX). b. (Right) Overall driving quality

this case was obtained again when using both the breaking-bar and the drive-path visualization. As seen on the graphic in figure 10(b), there is always a trend to drive to the left of the lane, but with full visual assistance the drivers could keep their lane better.

For the subjective measurements the Overall Workload Index (computed after the NASA TLX test) shows that there are no significant differences between the three displaying schemes (see figure 11(a)). This translates to the fact that visual assistance doesn't introduce an extra load for the drivers.

The Overall Driving Quality was graded in the questionnaire in the German grading system. Among the three assistance schemes, the bar scheme ranks at the top position with an average value of 2.63, which is significant in comparison to driving without any assistance (3.00) (see figure 11(b)).

5 Summary

Based on the observation that pathway anticipation enables reduction of car accidents, this paper tried to make a survey of the existing solutions and related research.

There already exist some solutions for navy and aircraft which could be used as a reference in deriving new solutions for the automobile industry. The existing assistance systems implement a higher level of automation which makes them weak in dealing with time-critical situations. The AGP Systems make a step backward in the automation levels and implement an "in-the-loop" approach, thus avoiding the time critical weakness.

The next generation of Head-Up Displays could become the 3D HUDs, capable to provide depth information. Their design was derived from the flight-tunnel presentation in the airplanes. First experiments yield promising results, showing that 3D HUDs using the Breaking Bar enable better understanding of own car's movement. Though a complete analysis could only be carried out when such a system will be embedded in a real car and the drivers are going to be tested in real driving conditions and for a longer period of time

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