

# Vehicle in the Loop – Augmented Reality Application for Collision Mitigation Systems

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## Abstract

Up to now the reproducible and safe test of driver assistance systems proves to be very difficult. This is true especially for collision mitigation tests. In this article today's state of the art of test and simulation methods for driver assistance systems is summarized at first. Then a new simulation and test environment is presented: In future the function of driver assistance systems can be tested and evaluated economically, reproducibly and most important without danger for the test person and test vehicle.

To achieve this the real test vehicle is integrated into a traffic simulation by means of a vehicle in the loop (VIL) configuration. The vehicle does not move in real traffic but on open spaces or blocked off roads. It resorts to synthetic sensor data of a partly simulated environment. Methods and instruments of the augmented reality integrate the test driver into the synthetic outside traffic.

## 1. Introduction

Systems to improve driver safety provide an essential criterion for customers when deciding on buying a new car. They become an increasingly important provider of turnover and return in the car industry [1]. While only little progress can still be achieved in the classical field of passive safety at a relatively high cost, there are significantly more potentials in the development of systems for active safety [2].

A current topic of research and development are the autonomous intervening assistance systems for collision avoidance (CA) or collision mitigation (CM). As such systems need to mesh with the driving dynamics of a vehicle partly without an explicit action of the driver. Very high standards are required regarding functional safety and reliability of the single systems as well as their interaction with already existing vehicle systems.

With the increased complexity of these systems there are new demands on the test and simulation tools which are used in system development until they are ready for production. With the established methods current and future assistance systems can often be tested only within limits or not at all.

## 2. Problems with Testing Collision Mitigation Systems

The problems become especially apparent with collision mitigation systems which need to be secured also in safety critical traffic situations.

Developments of the systems already established in the market for adaptive cruise control (ACC, DISTRONIC) make safety functions possible (cf. Figure 1 - Collision Mitigation 1). The systems taking part in a braking are reparameterized for a deceleration effect as fast and high as possible. In a further stage the driver is being warned. (Collision Mitigation 2). If the vehicle falls short of a certain minimum distance depending on the speed (PNR, Point of no Return), a collision can not be avoided according to driving physics either by making way or by braking. Collision mitigation systems for automatic

emergency braking can reduce the energy brought into the accident and thereby mitigate its seriousness.

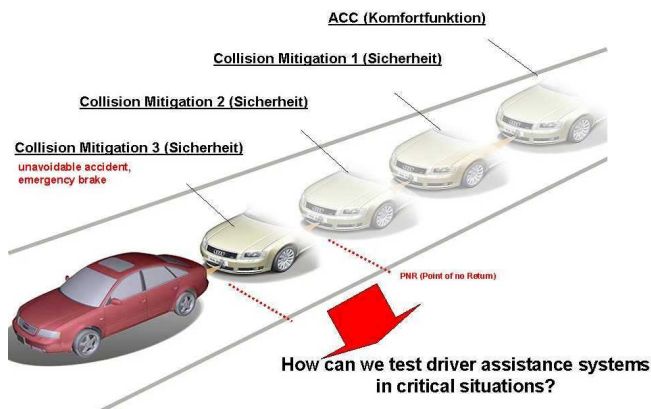


Figure 1: Development Trends of the ACC to a Collision Mitigation System

The moment for triggering an automatic emergency braking justifiable at the moment lies within a very short time slot immediately before a collision [3]. That is why a reproducible and above all safe test for the test driver of such systems has proved to be very difficult so far.

### 3. Test and Simulation Tools for Driver Assistance Systems

Driver assistance systems especially for safety critical situations demand a test and securing in (real and synthetic) traffic. The test tools available at the moment fulfill the demands for a realistic, reproducible, safe and at the same time resources saving test environment only within limits.

#### 3.1 Driving Simulators

Driving simulators can be clearly divided by their structure and their complexity. Driving simulators for driver assistance systems are used for analyzing the ergonomic aspects of human-machine-interface design and for usability and acceptance tests.

However, every driving simulation can only be a reproduction of reality. The discrepancy between real

driving and simulation leads to a deviation in behavior behind the wheel and can also result in simulator sickness. The simulator sickness is caused by the difference between the expected and experienced stimuli, its occurrence is connected with the human sensory perceptions in virtual worlds [4]. With frequent training the test drivers can adapt partially to the imperfections of the simulator. Symptoms like nausea, sickness, headache and eye problems may then be developed less often.

Driving simulators can be classified according to their moving system.

#### I. Static Simulators:

It is characteristic of static simulators that no acceleration forces are synthesized onto the simulator structure and in the end onto the driver. Therefore the vestibular and kinesthetic sensory organs cannot be stimulated. Static simulators are mainly composed of a fixed mockup with pedals and wheel as well as a monitor or a screen. The driver is integrated into the simulation environment through vision, hearing and via force feedback technologies also through haptic. Even though the static simulator represents a rather comprehensible system one has to calculate costs of more than 1 Mio. Euro for a simulator with a high quality viewing system.

#### II. Dynamic Simulators without Translation System

The main difference is a moving system onto which the mockup is installed. Hydraulic hexapod structures which facilitate a movement of the driver cabin in all six degrees of freedom are very common. That way acceleration stimuli can be simulated to a limited degree as they arise when accelerating, decelerating, driving curves in simple driving maneuvers. The restricted actuator space of the moving systems as well as the limited dynamics of the actuator set narrow limits to the traffic situations that can be represented realistically.

### III. Dynamic Simulators with Translation System

Dynamic driving simulators with an additional translational moving system improve the possibilities to reproduce complex driving maneuvers coherently. Normally the hexapod is moved by a sledge system. Compared to simulators without translation system it offers a widened room to move which also improves the synthesis of long lasting longitudinal and lateral accelerations. The NADS simulator costing about 50 Mio dollars is the largest one in this group worldwide.



Figure 2: Dynamic driving simulator of NHTSA

### **3.2 Traffic Flow Simulations**

The sphere of activity of driver assistance systems includes not only the immediate environment of a vehicle. As vehicles are increasingly equipped with systems like ACC for instance interactions between the ego vehicle and the traffic flow on the whole have to be secured as well. Whereas test tools like driving simulators and test vehicles are mainly used to check to what extend the system functionality is perceived as optimum by the driver, traffic flow simulations primarily facilitate an assessment according to macroscopic criteria like traffic density and throughput. The control set up of ACC systems also required tests for convoy stability for example as they were conducted with the traffic flow simulation Pelops [9]. Short-term variations in density in the traffic flow can already cause a traffic jam on road sections with a high volume of traffic. In the traffic flow simulation scenarios with different degrees of equipment

of the vehicles can be estimated. This evidence could not be achieved with field tests.

### **3.3 Test vehicles**

Rapid prototyping methods facilitate the use of functioning test samples in test vehicles very early on in the process of development. When testing assistance systems with test vehicles it proves to be a hindrance that the environment conditions of test drives in real traffic are hardly reproducible. This makes proceeding systematically according to the experimental design difficult and may become time consuming and costly. Testing within the context of safety critical traffic situations limits the test possibilities even further.

#### I. Testing in open spaces

Some tests on collision mitigation systems were conducted in open spaces [5]. The first difficulties arise when choosing suitable collision partners.

➤ Standing vehicles for example can be reproduced with foam material cubes bearing a mirror to reflect radar waves (Figure 3). Therefore there are many restrictions for the formulation of the questions. Firstly the reflected signal detected by the on-board sensors does not correspond with that coming from a real vehicle. Then many assistance systems will filter fixed objects from the object lists of the traffic environment for the time being due to the complexity of the classification task. Furthermore the foam material obstacles are not perceived as real danger by the test driver. Therefore the impression of the system functionality cannot be fully experienced and assessed. In the collision mitigation context such tests are suitable for rudimentary assessments of functions as well as for the easily comprehensible and effective demonstration of the functionality.

➤ Vehicles driving ahead can be imitated for instance by foam material cubes reflectively coated which are installed on remote controlled race buggies. The own condition of these objects is not recorded now so that

difficulties arise with the quantitative analysis of the function of collision mitigation systems. Alternatively radar mirrors can be fitted laterally staggered to real vehicles – for example with a wooden bar. However, the auxiliary vehicles are then necessarily within the immediate reach of the actual radar goal which may not have been the aim of the test set up.



Figure 3: Objects replacing Outside Traffic

➤ The test set up VEHIL in Helmond (NL) also takes up the concept of remote controlled outside vehicles. (Figure 4) [6]. In a hall 200 x 40 meters in size, the ego vehicle is fixed onto a rolling road dynamometer. The outside traffic of maximum two robot vehicles (Figure 4) moves on the open space in front of the ego vehicle with maximum 50 km/h speed difference. Latest 200 ms before a collision (Time to Collision, TTC) the robot vehicles get out of the way automatically with a high lateral dynamic. Therefore at the moment the focus of the installation lies on testing support systems like ACC and ACC Stop&Go for which the differential speed as well as the TTC are sufficient. The test possibilities for collision mitigation systems is restricted by both boundary conditions.

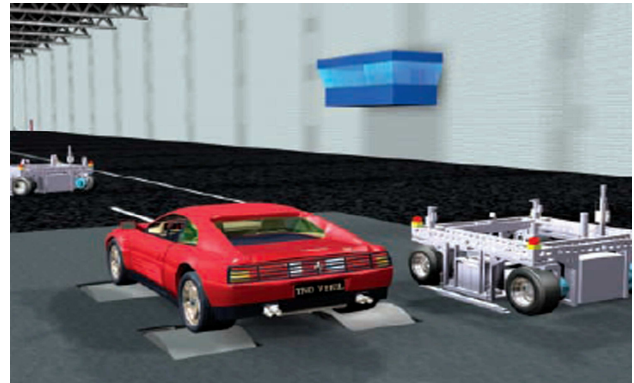


Figure 4: Test set up VEHIL

According to the operator of the test hall (TNO) the investment costs were 10 Mio Euro. This explains not only the prices for renting the installation, but shows as well the increasing market relevance and the necessity of new test facilities for driver assistance systems .

➤ Test environments in which the objects are control guided by track or lift systems do require complex transportable installations on the test sections. The routes of movement of the outside traffic are mostly given and can only be changed through prolonged alterations. Besides the geometric limitations further restrictions arise from the inflexibility of the system. Furthermore the collision objects need to be designed in a way that they can take the energy of an accident and at the same time they must be suitable for use at very high speeds.

### II. Testing in public road traffic

Unjustified triggering as well as none at all have to be regarded as one of the risks of collision mitigation systems such as an automatic emergency break. Both error classes have a damage potential [5].

No Fire tests in public road traffic facilitate the safe analysis of unjustified triggerings. The incorrect triggering can then be signaled to the test driver, for example, acoustically. At the same time the uncritical traffic situation filmed with a video camera is saved by

triggering and so are the synchronous data of the environment detection. A later analysis will then show the causes of the unjustified triggering.

Triggerings that did not occur cannot be secured in public road traffic in general. To carry the example of the emergency break function further – the test driver would then have to provoke collisions on purpose.

From the test methods for securing collision mitigation systems discussed here it is clear that alternatives for testing are needed. Like driving simulators they must offer a test environment that is safe, reproducible and sparing resources. But even complex moving systems are limited in the reproduction of the real dynamics of a vehicle. One approach is therefore combining a test vehicle with a virtual test environment.

#### 4. Test Carriers in a Virtual Traffic Environment

With hardware in the loop (HIL) – methods a real vehicle can become part of a traffic simulation software. This vehicle in the loop (VIL) configuration facilitates a testing of the function of driver assistance systems directly in a vehicle which however does not move in real traffic, but on open spaces or blocked off roads and resorts to synthetic sensor data of a partly simulated environment. Special advantages arise with securing assistance systems like an emergency break function for, because of a virtual vehicle ahead, also triggerings of the system that did not occur can be analyzed safely and reproducibly.

So far the traffic simulation software is visualized on a laptop near the driver or on displays on the dash board. This means that the test driver has to drive the vehicle and at the same time observe a visualization on a monitor and interpret it. The configuration demands driver reactions to events in two optically separated worlds.



Figure 5: Traffic Simulation in the Test Vehicle

To offer the driver a more comfortable and realistic view of the traffic situation the traffic simulation software can also be represented overlapping the driver's field of vision of the real world. Several methods and instruments of virtual reality (VR) make it possible to join the real and the computer generated world (augmented reality) convincingly [10],[11].

The necessary overlap can be realized technically with semi-transparent projections onto the wind screen for example or also with head mounted displays (HMDs).

Contrary to the visual systems in driving simulators it is always possible to have an extensive visual contact with the real environment. The driver is in a familiar vehicle environment and sees the natural elements of reference such as the horizontal line.

An essential advantage over testing assistance systems with driving simulators is that the moving system is no more necessary. All acceleration stimuli as well as the visual and acoustic environment information reach the driver naturally at the same time. That way the driver experiences – because they are real - genuine vestibular and kinesthetic stimuli. So the probability to get car sick can be lowered to the level of operating a car regularly. Only the overlapping projected vehicles of the traffic simulation are subjected to unavoidable delays because of finite process times for the calculation. In addition



inconsistencies arise when overlapping the real and virtual world as the simulation representation depends on dynamic vehicle sizes and software models. As it is to be expected that the main users of the simulation environment belong to a defined group with rather frequent and longer test drives the necessary adaptation phase to avoid car sickness is in a reasonable proportion to the useful life of the system.

### 5. Structure of the Test Carrier

An Audi A8 (4,2 liters Quattro) is used as test carrier at the moment. In its HIL - version "P-HIL" the traffic flow simulation software PELOPS offers the possibility to make the test carrier part of the virtual traffic flow [7]. For that the movement variables of the longitudinal speed, the lateral acceleration as well as the yaw rate are constantly read into the simulation software via the vehicle CAN. In principle the sensor signals are already standard in the Audi A8, but as such they do not meet the requirements of position accuracy. In addition to these sensors of the vehicle itself a high-precise strapped down motion analyser was therefore implemented which is supported also by a Correvit speed measurement system and by absolute position data via DGPS.

Therefore there are three location methods available in the vehicle:

- DGPS – Position data (absolute location method)
- Coupled navigation by integrative updating of the vehicle sensor dates (incremental method)
- Inertial navigation by strapped down motion analyser (incremental location method)

The fusion of the different sensors and systems with the aim of an integrated navigation increases the precision and availability for positioning in the traffic flow simulation markedly. A reliable method is the combination of the coupled or inertial navigation with satellite navigation [8]. The high-frequent estimates of position by the inertial navigation receives the low-frequent support with position data. That way a dynamic

and long-term stable positioning in the traffic flow simulation is possible. Through a DGPS connection with real time - kinematics the chosen realization with a strapped down ADMA (Automotive Dynamic Motion Analyzer) from GeneSys Electronic GmbH a local resolution up to 2 cm in the dynamic application. With reduced requirements of the long-term stable positioning it is possible to realize a positioning in Pelops based only on coupled navigation. This can be done with an improved estimation of the own state which is also part of a framework for the development of driver assistance systems.

Based on the position of the ego vehicle the traffic simulation software calculates the position data of the virtual outside traffic at a pulse rate of 20 ms and forwards the data to a framework for the development of driver assistance systems. Figure 6 shows the interfaces of the single components of the test carrier.

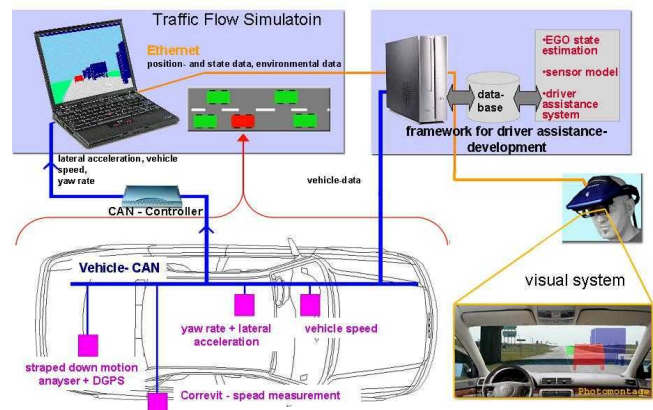


Figure 6: General Concept of the Test Carrier

### 6. Framework for the development of Driver Assistance Systems

The data input is stored in a common data basis in the framework and is available to various applications of the framework. The applications planned or necessary will be described in the following paragraphs. The framework is being developed at the moment. First sensor models are already in use.

### I. Sensor Models

Naturally real sensors cannot detect objects of a virtual traffic environment. Therefore sensor models for reproducing the sensor functionality become necessary. In a first step an ACC sensor model is implemented. The behavior of real radar sensors is mapped by reproducing the physical context in a C/C++ software model. As the sensor model runs on the basis of ideal Pelops environment data the typical disturbance variables and uncertainties of measurement have to be analyzed statistically as well and be included into the sensor model accordingly. Models of further environment sensors such as a video sensor are planned in the advanced developmental stage of the test carrier.

### II. Estimation of the own state

Within the framework of a data fusion it is possible to generate state data of higher confidence also with standard sensor systems. So it is possible to plausibleize the yaw rate by taking into consideration the sensor signals of the steering angle sensor, lateral acceleration and wheel speed differences. The data of the by strapped down motion analyser used in Pelops for positioning the ego vehicle are an appropriate reference system for assessing those state data which are generated with an state estimation from the standard vehicle sensors.

### III. Environment Detection with Sensor Data Fusion

Future driver assistance systems will improve their environment detection with a data fusion of several sensors. These are often based on different physical measurement methods and facilitate the combination of their respective specific advantages in a detailed environment model. Thus distances to the vehicles ahead and their speed can be determined well with radar sensors whereas the object geometry of these vehicles can hardly be recorded with them. Visual systems like video cameras offer a suitable method to classify the objects, yet they are very sensitive to environmental influences.

## **7. Components of an Augmented Reality (AR) – Visual System**

In the road traffic the driver registers the outside traffic surrounding him naturally through the window panes and the mirror. In the case of the virtual outside traffic calculated by Pelops it will be the task of a AR visual system to generate an equivalent view for the driver and to integrate him thus into the simulation environment. To limit the complexity during the development of the visual system only the view through the wind screen is enriched by a view of the virtual traffic in the first stage.

Therefore systems of augmented reality essentially require three components:

### I. Tracking Systems

Referring to the concrete case of application two tracking systems become necessary. Firstly the position of the vehicle relative to the lane has to be determined, secondly the position and orientation of the driver in the vehicle.

The position and orientation of the driver in the vehicle is subject to permanent changes. Activated by outer acceleration forces and largely compensated by corresponding movements of the driver a variable angle of vision through the windscreen ensues in the course of time. Head tracking systems make it possible to determine the position and orientation of the driver's head in all six degrees of freedom. The common magnetic systems can hardly be used due to numerous time and place variant magnetic fields in the interior of the vehicle. However, optic systems as laser and infrared systems or marker based camera methods promise a robust detection also when used in the vehicle. The tracking system „laserBIRD2“ (Ascension Technology Corporation) makes a determination of the position in all six degrees of freedom possible. For that a minimum working distance of 15 cm has to be kept between the laser scanner and the

sensor module, which weighs only 40 grams, on the driver's head.

Apart from that a detection of the vehicle position relative to the lane surface is necessary for a consistent representation of the outside traffic. The pitch and roll angle of the vehicle for example can be gathered from the data of the strapped down motion analyser. Also measurement systems like the Correvit "Pitch and Roll - System" facilitate a determination of the vehicle's position relative to the lane surface with three distance sensors.

## 2. Display Technology

Figure 7 shows a photomontage of a possible view of the virtual outside traffic through the windscreen. To visualize, the solutions possible have mainly a head bound display technology in transparent technology. The optic image combination by semi-transparent mirrors with "See Through" – HMDs guarantees, contrary to video-based HMDs the continuous visual contact with the environment. Thus they facilitate the safe use of the test environment even at high speeds. Current displays like the "AddVisor 150" (Saabtech) make a field of view (FOV) of 60° in the diagonal possible while the driver has to carry an additional head load of about 1.5 kilo.

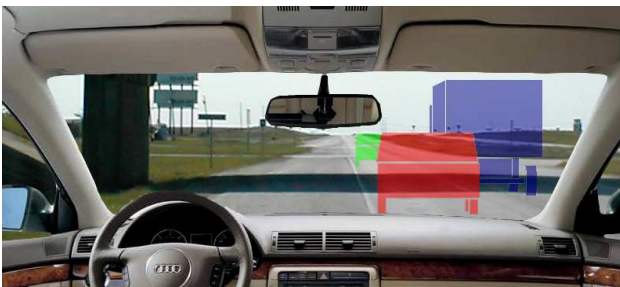


Figure 7: Visualization of Virtual Outside Traffic  
(Photomontage)

Projections onto the wind screen by a beamer fixed in the vehicle also facilitate a flashing and overlaying of virtual objects. But for that high candle powers are necessary, and also the small distance to the windscreen as the place of the image projection requires a permanent refocusing by the driver. Head up displays use the wind screen reflectively and thus make it possible to generate virtual images on a focal plane outside the vehicle. However, systems available on the market at the moment facilitate a flashing of additional objects generally only in small parts of the windscreen. Therefor the test carrier is primarily equipped for the variant with a HMD at the moment.

## 3. Visualisation Computer

The basic technology for calculating augmented scenes differs only insignificantly from the visualization in classic driving simulators. Open-GL graphic engines make it possible to fall back upon a largely standardized hard and software. The position and orientation of a virtual camera are adapted to the running time of the simulation from data of the head and vehicle tracking.

## **8. Summary**

A new test and simulation environment for driver assistance systems emerges with the development of the test carrier. It combines the advantages of a real vehicle dynamics in the test vehicle with the safety and reproducibility of driving simulators. Especially when testing active assistance systems new possibilities arise with the concept of virtual outside traffic in the real test vehicle.

At the moment the coupling of the test carrier with the traffic flow simulation is set for use on a flat dynamic area free of obstacles. For an advanced project stage its use on a blocked off road is also considered.



### Illustrations:

Figure 2 : NADS, University of Iowa

Figure 3 : Audi AG, Ingolstadt

Figure 4 : TNO Automotive, Holland

### References:

- [1] Oertel, Klaus - "Zukunftsmarkt Assistenzsysteme" - Automotive Electronics + Systems, Carl Hanser Verlag, Vol.11/12 - 2004, Seite 22-24
- [2] Kompaß, Klaus - "Integration Aktiver und Passiver Sicherheit - mehr Fahrerlebnis und besserer Insassenschutz", Baika Kooperationsforum Fahrerassistenzsysteme, April 2005
- [3] Kopischke, Stephan - "Entwicklung einer Notbremsfunktion mit Rapid Prototyping Methoden", Dissertation, Technische Universität Carolo - Wilhelmina zu Braunschweig, 2000
- [4] Stanney, Kay - "Human Factor Issues in Virtual Environments: A Review of the Literature", Presence (Vol.7, No.4), Seite 327-351, 1998
- [5] Holt, Volker von und Markus Maurer - "Aktive Sicherheitssysteme mit maschineller Wahrnehmung – Anforderungen, Potentiale und Einführungshemmnisse", Tagung: Aktive Sicherheit durch Fahrerassistenz, TU - München, 2004
- [6] VEHIL - TNO Automotive:  
<http://www.automotive.tno.nl>
- [7] Breuer, Karsten - "Verkehrsflusssimulation zur Entwicklung von Fahrerassistenzsystemen", Schriftenreihe Automobiltechnik, fka Aachen
- [8] Simon, Andreas - "Führung eines autonomen Straßenfahrzeugs mit redundanten Sensorsystemen", Dissertation, VDI - Reihe 12 Nr. 554, 2003
- [9] Hochstädter, Almut und Jens Ludmann - "Stabilität von Fahrzeugkolonnen und verkehrliche

Auswirkungen der Abstandsregelung", Vortrag im Haus der Technik (Essen), Dezember 1999

- [10] Azuma, Ronald – “A Survey of Augmented Reality”, In Presence: Teleoperators and Virtual Environments 6, 4 (August 1997), Seite 355-385
- [11] Azuma, Ronald, Yohan Baillet, Reinhold Behringer, Steven Feiner, Simon Julier und Blair MacIntyre – “Recent Advances in Augmented Reality” IEEE Comp. Graph. & App, vol. 21, no. 6 (Nov/Dec 2001), Seite 34 - 47