Presentation of the Augmented Reality (AR) in the test car Vehicle in the Loop

Vehicle in the Loop
An Innovative Approach to Linking Virtual and Real Testing

With the development of the Vehicle in the Loop, a test and simulation environment for driver assistance systems is presented by Audi, combining the advantages of a real test vehicle with the safety and reproducibility of driving simulators. By means of an "Optical see through Head Mounted Display", the virtual outside traffic, road demarcations, or other simulated objects are visualized to the driver realistically and with analogous contact while driving. Thanks to the concept of the virtual outside traffic, new possibilities open up especially for testing active driver assistance systems.

1 Motivation

In recent years; the Audi AG has extended successfully its product range and is planning to increase the number of models from 25 now to about 40 in the coming years following the so-called strategy 2015 to become the most successful premium manufacturer.

Apart from the design, the typical Audi driving properties provide the crucial buying criteria for customers. In the development department, these properties are, figuratively speaking, also "designed". Several hundreds of these intended properties, which are defined according to the three Audi brand values sportiness, sophistication, and progressiveness, are validated not only in driving tests, but also in simulation.

In addition, the resulting permanent monitoring of development maturity reduces the risk of changes becoming necessary later, and thus increases the planning reliability for those departments coming later in the process chain (purchasing, production, logistics, quality management, marketing and after sales service).

Yet, the virtual development cannot replace the hardware altogether, but it is used in addition and in support. The sensible complementation of virtual and physical models and methods, integrated into the product creation process, is therefore the challenge for developing properties in current vehicles. "The best of two worlds" [1] is thus a critical success factor for an efficient, transparent and qualitatively good product process, see **Figure 1**.

The considerably increasing complexity of the vehicle, propelled by the rising use of control systems and their integration into the vehicle, the growing variety of variants as well as the higher degree of individualization, would no longer be possible in the desired quality without simulation support. The availability and quality of simulation methods and their process integration thus becomes an essential condition as "conditio sine qua non" and, in addition, a pivotal competition factor.

Figure 2 shows some property forming control functions in the chassis, which are already implemented in present-day products. Many of them are adaptive, i.e. characteristic curves and settings change with the driving states. The resulting variety of setting possibilities and their feedback to driving and function behavior can no longer be tested without simulation support.

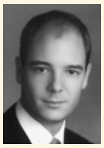
2 Development of Driver Sssistance Systems

Systems to improve driver safety provide an essential criterion for customers when deciding on buying a new car [2]. They become an increasingly important provider of turnover and return in the car industry. 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.

A current topic of research and development are the autonomous intervening

Figure 1: Linking virtual and physical testing as a success factor

Authors



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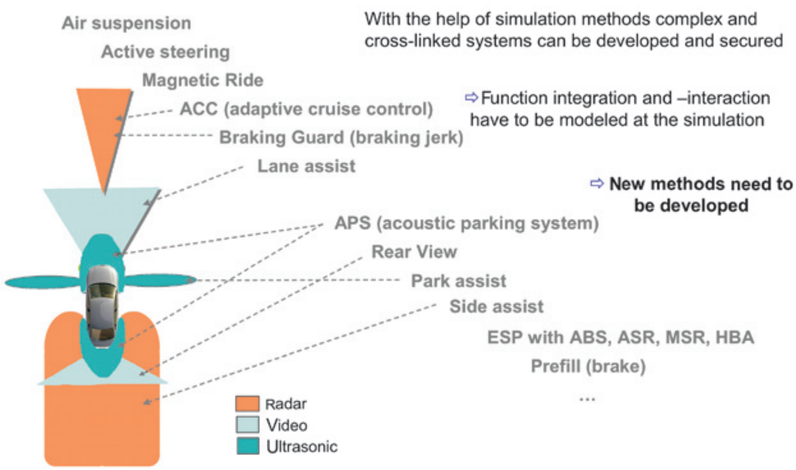


Figure 2: Example chassis: today's systems and functions in control

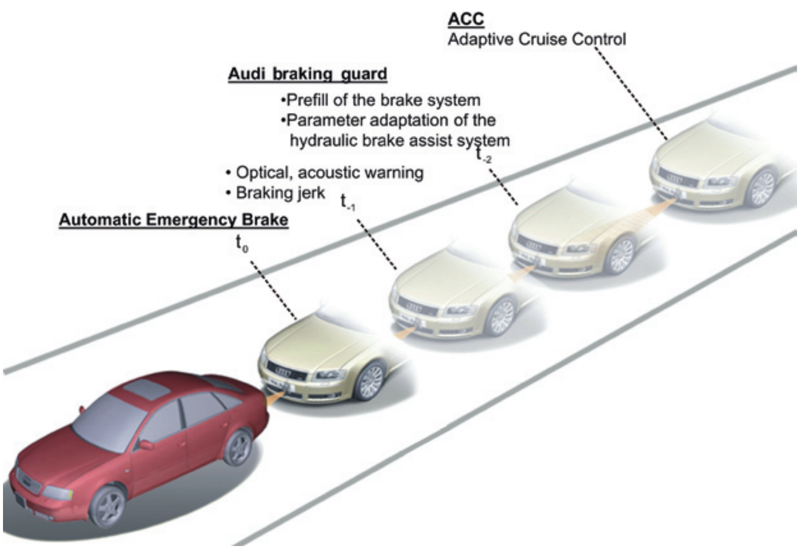


Figure 3: Development trend from ACC over Audi braking guard to automatic emergency breaking

assistance systems for collision avoidance (CA) or collision mitigation (CM). As these 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. 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 assistance systems has proved to be very difficult so far, **Figure 3**.

Driver assistance systems for safety critical situations demand testing and securing in almost real traffic conditions. The current state of the art are driving simulators, traffic flow simulations and test vehicles, which collide with substitutes such as foam cubes. However, the test tools available at the moment, an overview is shown in **Figure 4**, fulfill the demands for a realistic, reproducible, safe and at the same time resources-saving test environment only within limits.

3 Innovative Approach Vehicle in the Loop

From the common test methods for securing collision mitigation systems, it is clear that alternatives for testing are needed. Like driving simulators they must offer a test environment that is safe, reproducible and resources-saving. However, even complex moving systems are limited in the reproduction of the real dynamics of a vehicle [4].

The approach of the test setup Vehicle in the Loop (VIL) from Audi is therefore to combine the real test vehicle with a virtual test environment, and thus gain the advantages of both methods, Figure 4. By means of an "Optical see through Head Mounted Display", the virtual outside traffic, road is visualized to the driver realistically and with analogous contact while driving on a real road. By using the augmented reality technology, the real environment (for exampler the road and the houses at the road) remains totally visible to the driver. Thus, the Vehicle in the Loop system architecture 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, such as a test field.

With the help of sensor models, it is possible for driver assistance functions to react to virtual outside traffic, and the function can thus be tested realistically, but without danger for human and machine. Special advantages arise with securing assistance systems like an emergency brake function: Because of a virtual vehicle ahead, also triggerings of the system that did not occur can be analyzed safely and reproducibly.

3.1 Traffic Simulation and Visualization

Figure 5 shows the system architecture of the Vehicle in the Loop test setup [5]. The traffic simulation is designed in such a way that it facilitates the creation of reproducible lane change, braking and acceleration maneuvers of the simulated outside traffic with the help of different triggers.

The triggers for these maneuvers can be activated either relatively to other traffic participants (and thus also

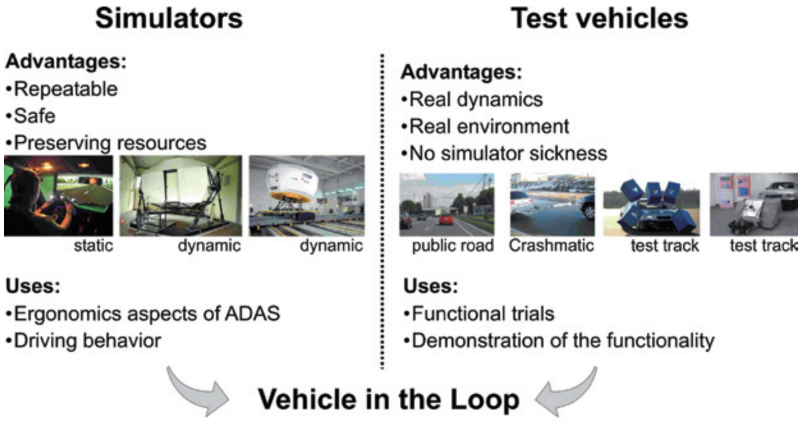


Figure 4: Vehicle in the Loop – test tools available at the moment and linking simulator and real vehicle

to one's own test vehicle) or by crossing an absolute location position. The virtual traffic can also move on autonomously, using a model of the longitudinal and lateral dynamics of a normal driver.

3.2 Positioning the Test Vehicle in the Traffic Simulation

To represent the correct road section in the traffic simulation, the position of the test vehicle on the test field has to be determined exactly. Therefore a high-precise strapped down motion analyzer with a DGPS connection is used. If either the number of the visible satellites goes down or the radio signal to the test vehicle for the DGPS correction data breaks off, the position of the test vehicle is continued to be determined by the high-precise strapped down motion analyzer. All signals on vehicle position and driving states are recorded on a separate CAN bus data logger and are thus available for the simulation.

3.3 Integrating the Driver with Augmented Reality

The drivers are not able to perceive the complete vehicle environment as it is present in the simulation, but are limited to their own visual field. Thus the visualization has to be limited to this natural visual field which keeps changing with the drivers' head position. Only the corresponding detail of the traffic simulation is to be shown in the Head Mounted

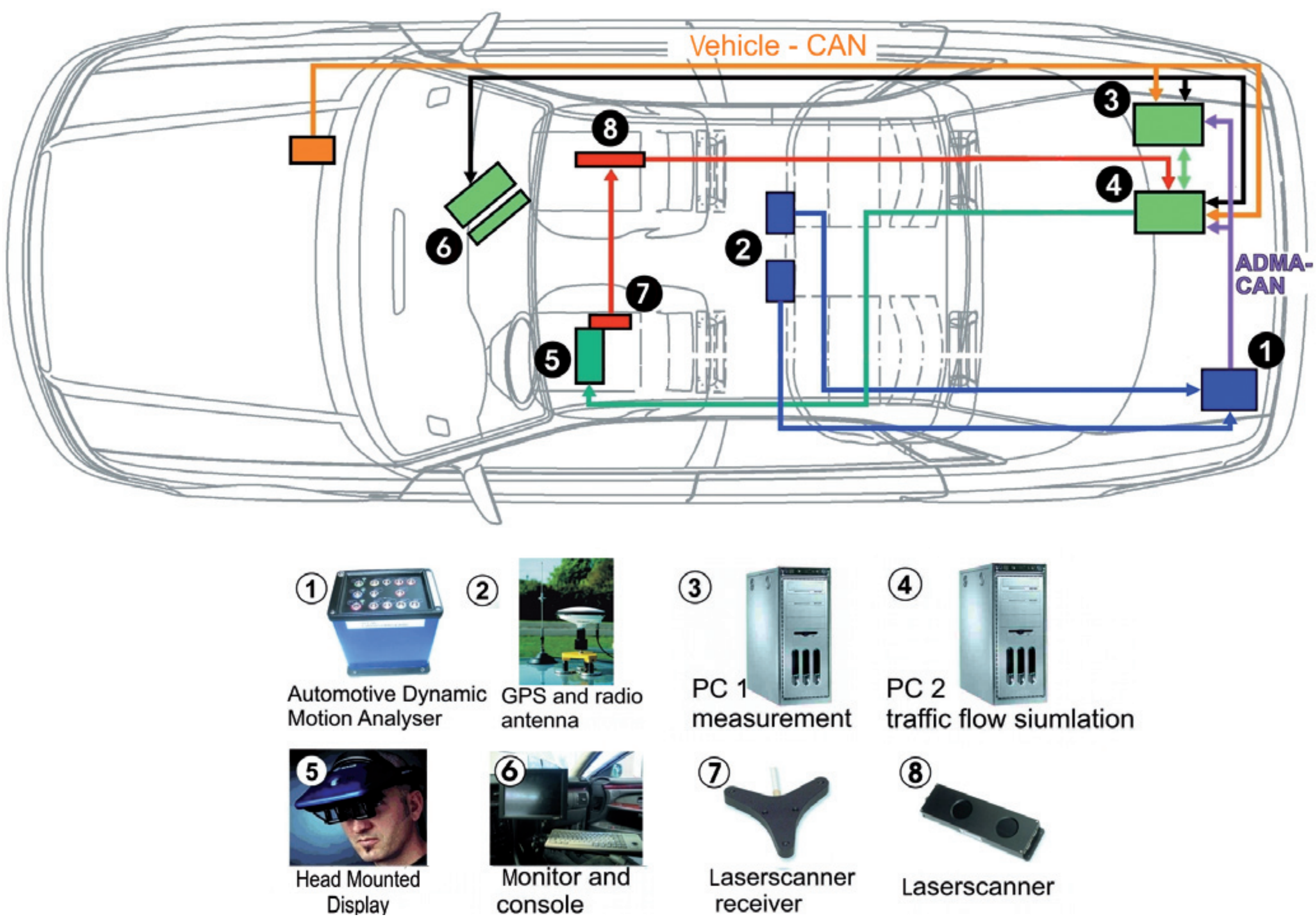


Figure 5: Vehicle in the Loop – system architecture of the test setup

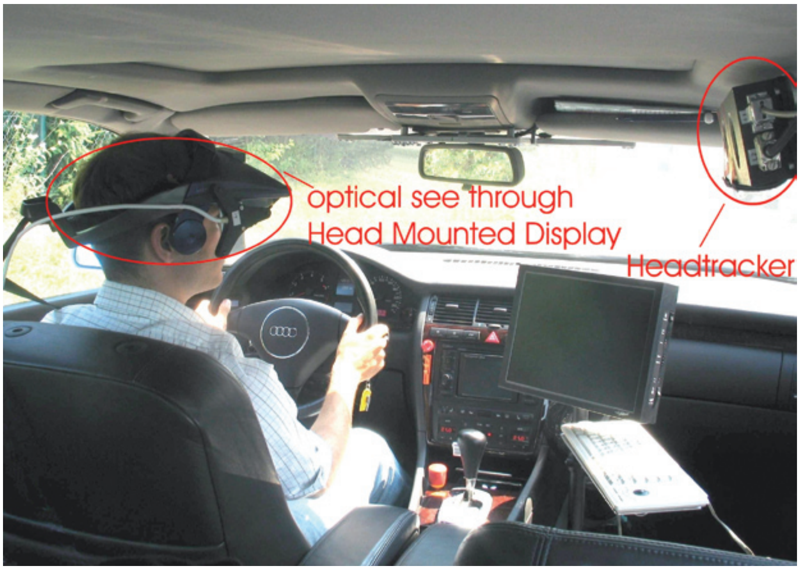


Figure 6: Head Mounted Display for the driver and head tracker in the test vehicle

Display, **Figure 6**. The quality of the Vehicle in the Loop test setup depends decisively on the exact agreement of this real visual field and the simulated traffic presented to the driver. The essential data on the position and the orientation of the drivers' head are collected by a head tracker, Figure 6, which is mounted on the side above the front-passenger's door.

From the data for the head and vehicle position received from the head tracker and the strapped down motion analyzer, the simulation calculates a visualization of the traffic scene from the driver's point of view. To enable the driver of the test vehicle to interpret the visualized traffic scene three-dimensionally, the Virtual Image Distance of the Head Mounted Display was fixed to 10m as monocular clues for depth perception dominate for larger distances. Also larger distances to the outside traffic can be presented credibly with these clues for depth perception.

In **Figure 7** an Augmented Reality representation of the Vehicle in the Loop is shown, where the test vehicle follows a virtual vehicle on the test field (left) or its handling course (right). To make these representations, a camera filming the scene during the drive was integrated in the Head Mounted Display. In addition to the virtual outside traffic, virtual lanes are visualized on the test field as no lane routing is given there. On the handling course, the virtual lanes do not need to be represented as the driver can get his orientation from the real lanes.

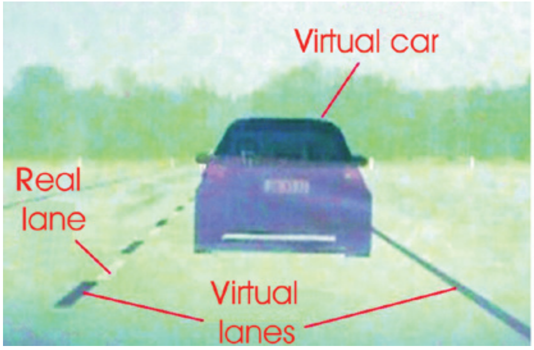
3.4 Sensor Models

The Vehicle in the Loop test setup is used for the development of driver assistance systems based on environment sensors. Obviously, real sensors cannot detect objects of a virtual traffic environment. Therefore sensor models for reproducing the sensor function become necessary. In a first step, a radar sensor model has been implemented. The behavior of real radar sensors is mapped by reproducing the physical context in a software model. Communication takes place according to a defined protocol in which, among other things, the position and state data of the simulated outside traffic are transferred from the simulation processor.

As the sensor model functions on the basis of ideal outside traffic position data from the traffic simulation, the typical disturbance input and measurement uncertainties of real sensors additionally had to be evaluated statistically and integrated into the sensor model accordingly. Especially the perception range, the x/y deviation and the separation possibility were recorded each for various road users (car, truck, motor cycle) and modeled on mathematical error equations.

4 Architecture of the Vehicle in the Loop

Figure 8 shows the architecture of the Vehicle in the Loop test setup. The data of the position and orientation of the test vehicle and the driver's head are transferred to a traffic simulation software online. In addition, the exact course of the road has to be stored in a track library in advance and also be transferred to the traffic simulation software. From the input data the traffic simulation calculates the position and orientation of the test vehicle on the road used and the position data of the virtual outside traffic. The traffic situation is visualized to the driver by means of an "Optical see through Head Mounted Dis-



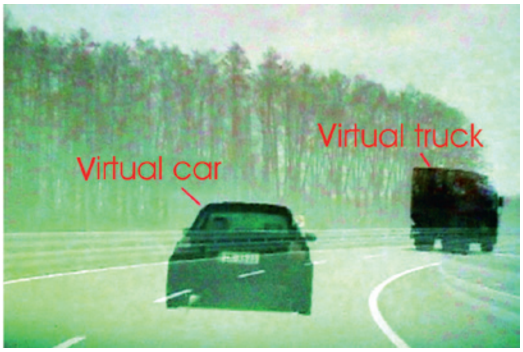


Figure 7: Augmented Reality demonstration of the test setup (left: test field, right: handling course)

play” depending on their head position and orientation.

With the help of sensor models, which receive the position and orientation data of the virtual traffic and one’s own test vehicle as input data from the traffic simulation, the input data for the driver assistance system are created. For example, an automatic emergency braking because of a simulated vehicle has effects on the driver-vehicle-environment loop. By reading in new position and situation data, the Vehicle in the Loop is closed.

5 Validation of the Vehicle in the Loop

In a study with 36 test persons, the question whether the Vehicle in the Loop test setup can serve as a development tool for development engineers was reviewed. Besides technical measurement data, the drivers’ subjective perception of the virtual outside traffic plays a decisive role. The standard to be set for the Vehicle in the Loop test setup is therefore that the driver perceives the traffic as realistically as possible. Thus, the focal point of the study was whether the test persons’ driving behavior in tests with a virtual vehicle ahead was similar to their behavior in tests with a real vehicle ahead.

These standards were checked on the basis of two data sources. On the one hand a questionnaire gives solutions for the subjective perception of the simulated traffic and the interaction between the simulation and the dynamic properties. On the other hand, new insights were gained by comparing driver reactions to simulated and real traffic in defined driving maneuvers (traffic situations). For this, objective data of both drives (real/simulated traffic) were recorded and compared.

The study has proved that the Vehicle in the Loop test setup is suitable as a future development tool. The simulation of the virtual outside traffic by the Vehicle in the Loop and correspondingly the driving experience in the virtual tests is very realistic. The test drivers showed a similar driving behavior in the drives with a virtual vehicle ahead like in the real tests. They can imagine working with the Vehicle in the Loop as a development tool and are convinced that critical driving maneuvers can be represented realistically.

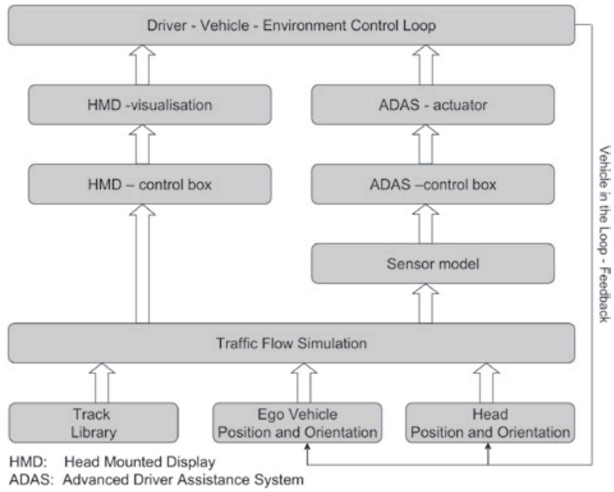


Figure 8: Functional architecture of the test setup Vehicle in the Loop

A short training phase of about 15 minutes was sufficient to become acquainted with the Vehicle in the Loop system. When operating this system often, the user gets quickly accustomed to the built-in measurement instruments and to wearing the Head Mounted Display. The problem of motion sickness, known from conventional driving simulators, is avoided thanks to the Vehicle in the Loop test setup [6].

6 Conclusion

The use of virtual development techniques is currently a decisive success factor in product development. Vehicle properties can thus be determined at an early point in time leading to a higher degree of maturity even before the setup of the first prototype.

Besides reducing the development time and loops, virtual development methods are used intensively as securing tools for the ever growing complexity and variety of variants. In the future development process of the car industry, it will also be crucial for developing driver assistance systems to define a constant and tuned tool chain consisting of Software in the Loop (SIL), Hardware in the Loop (HIL), Vehicle in the Loop (VIL), and real tests. Their single components need to be perfectly tuned, but their range of application must be clearly distinguished as well. Thanks to this constant tool chain, less interface adjustments will be necessary resulting in a potential for development and expense reduction.

Virtual development will never replace conventional development completely. However, the conventional development already comes up to the limiting factors of its feasibility. Therefore it is necessary to search for a reasonable and entrepreneurially economical complementation of both methods. The development method “Vehicle in the Loop – the best of two worlds” is a prominent example. It demonstrates what the Audi motto “Vorsprung durch Technik” – Advancement through Technology – means in the true sense of the word during the development phase.

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