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CURRENT TEST METHODS

OEMs and suppliers use various test and evaluation methods to validate the functional safety of Advanced Driver Assistance Systems (ADAS), depending on the development stage. Simulation methods such as Model-in-the-Loop (MiL) and Software-in-the-Loop (SiL) are primarly used in early development stages while Hardware-in-the-Loop (HiL) is used in a later stage. The systems are integrated into a virtual vehicle and tested in virtual test driving. This makes it possible to carry out a large number of tests in conditions that can be configured as desired and reproduced in a very short period of time [1]. These simulative methods, however, are no substitute for real-world road tests. Even though the current models are very good, they harbour the uncertainty that the results cannot be exactly transferred to the real-world behaviour of the vehicle. Furthermore, a subjective evaluation in road tests is indispensable for ensuring acceptance by the driver.

However, the rising complexity of the systems leads to a steady increase of cost and effort involved in testing ADAS in conventional road tests. Whereas for parking assistance systems only stationary objects typically have to be varied in order to represent different parking scenarios, accident avoidance systems, such as emergency braking assistance, require at least one potential opponent in the crash scenario. So-called dummy targets serve this purpose in currently used methods (for example in [2]). These targets are mainly designed for rear-end collisions in longitudinal traffic. Other relevant traffic situations, such as traffic crossing at an intersection, vehicles suddenly cutting in or see ❶ the hazard

CONSISTENT TEST METHOD FOR ASSISTANCE SYSTEMS

After HiL and SiL, new Vehicle-in-the-Loop (ViL) simulation is an innovative method to handle the complexity during functional validation of driver assistance systems and to decrease test effort at the same time. This method combines the advantages of test driving and simulation by integrating a real vehicle in a virtual traffic environment. IPG Automotive and FZI Research Centre for Information Technology developed the Vehicle-in-the-Loop test concept, with which assistance systems like parking assistant, traffic crossing assistant and pedestrian detection can be ensured amazingly.

of collisions with pedestrians or cyclists can only be investigated to a limited extent or with a considerable investment of cost and effort.

VEHICLE-IN-THE-LOOP APPROACH

The Vehicle-in-the-Loop (ViL) method overcomes the limits of traditionally known procedures by combining the methods of simulation and conventional road testing. For this purpose, a real-world vehicle is embedded into a virtual environment (with traffic, signs, road markings, etc.) and tested in a cleared outdoor area [3]. The test method has already been implemented successfully by using the example of the parking assistant. This linking of the real and virtual world in this case allows the following test procedure to be run: A real-world test vehicle detects simulated parked vehicles via virtual sensors. This information is transmitted to the electronic control unit (ECU). It evaluates the perceived situation, measures the parking space and allows the vehicle to automatically pull into the virtual parking space. This test concept offers the following advantages:

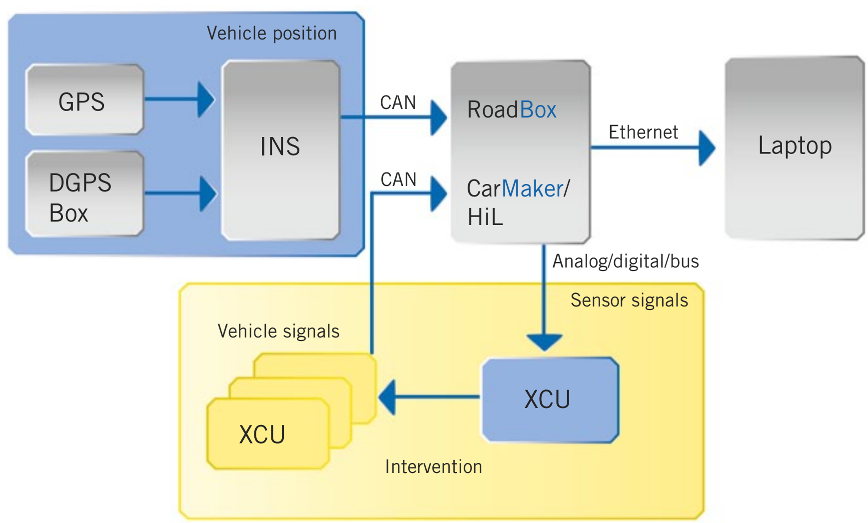
- real-world vehicle dynamics
- less investment of material than in the exclusive use of real-world road tests
- reproducible test conditions
- scenarios allowing optional configurations.

Examples of other fields of application for ViL include the testing of lane change assistance, emergency-braking assistance with and without pedestrian or cyclist detection and the investigation of complex, autonomous driving functions in virtual traffic flow.

IPG Automotive and FZI Research Centre for Information Technology have

❶ Application scenario for an emergency-braking assistant on pedestrians for the Vehicle-in-the-Loop method made this ViL approach suitable for consistent use in the development of ADAS. The implementation is based on the CarMaker open integration and test platform which is used in all development stages for virtual test driving. This platform already provides the prerequisites for simulation-based investigations of ADAS in all significant use cases. Therefore, the actual challenge was to realise the interfaces between the real-world vehicle, the virtual environment and the human driver.

❷ Real-world parking manoeuvre (pictures above) and in the ViL test environment (pictures below)



❸ Schematic representation of the functional principle of a ViL configuration

LINKING OF REAL AND VIRTUAL WORLDS

In CarMaker, individual test scenarios with mobile traffic objects (for example passenger cars, buses, pedestrians) and stationary objects (for example parked vehicles, construction sites, trees) can be generated. The movements of the individual traffic objects are configured based on the course of manoeuvres, which makes them independent of special vehicles or routes. Likewise, it is possible for traffic to move autonomously in the virtual traffic environment.

The real-world test vehicle is embedded in the virtual traffic environment via the vehicle model of CarMaker, ❷. While it is being driven in the cleared outdoor area, the virtual ego vehicle moves in virtual traffic synchronously to the real-world vehicle. Sensor models in the virtual vehicle capture the simulated objects and transmit the signals to the ECUs in real time. These can either be the real-world ECUs of the test vehicle (HiL) or virtual ECUs (MiL/SiL), depending on the state of the development.

The exact acquisition of the position and movements of the vehicle in reality is a prerequisite for this linking. These data are determined by means of DGPS supported dead reckoning (Inertial Navigation System, INS). When using a Kalman filter commercially available systems deliver a positional accuracy of 1 to 2 cm. CarMaker runs on an Xpack4 real-time system in the RoadBox version. This system is very powerful so that all the data are processed in a single computing cycle. If required, the analogous and digital signals can be recorded. Xpack4 supports the established bus systems such as LIN, CAN, FlexRay, Ethernet and the corresponding protocols such as SPI, PSI5, CCP and XCP for this purpose, ❸.

There are two possibilities to integrate the driver into the test process – depending on whether simple monitoring of the test run suffices or the aim is to achieve a realistic “driving feeling” on the part of the driver or test subject. In the first case, the IPGMovie 3D real-time animation is displayed on the monitors in the vehicle. In the second case, the driver wears augmented reality glasses with see-through technology. In this application, the virtual traffic objects, generated by IPGMovie, are projected on the displays of the glasses while the real world remains perceptible through the semi-transparent glasses.

The glasses are equipped with an inertial measurement unit which is used to determine the accelerations and rotation

❹ Test drive with augmented reality glasses (top) and head posture recognition visualised in the virtual model (bottom)

❺ Consistency of the ViL method in the V process

rates of the head. In addition, the camera in the glasses, by means of an optical marker on the instrument panel, corrects the orientation of the driver's head that has been estimated by the inertial sensors [4]. ❹ shows how, based on this information, the head posture during the drive is mirrored in the virtual environment and the driver looks at the real and virtual worlds according to his line of vision.

CONSISTENT USE IN THE V PROCESS

The ViL test concept implemented by IPG Automotive and FZI can be consistently used in model-based development through to validation in the vehicle, ❺. The open interfaces and standards of the test platform create the prerequisite for this. For MiL simulation, models can be directly integrated into the simulation environment as C-Code or as Simulink models. In addition, CarMaker supports the Functional Mock-up Interface (FMI) standard so that the models can be incorporated as Functional Mock-up Units (FMUs). Furthermore, software components (for example Autosar based systems) can be taken into operation on a virtual ECU and integrated into the vehicle (SiL). Even real-world electronic control units such as prototype ECUs or ECUs from other vehicles can be integrated into CarMaker (HiL).

In the ViL test, the models, just like the ECUs in the real-world vehicle, operate in real time. This makes it possible to prepare various function states in the office simulation and to subsequently test them in the same scenarios and in the same test environment in the real-world vehicle. This way, the functions can already be "experienced" in early development stages of the V process when no hardware is available yet. Consequently, the focus is not only placed on the special individual function but is directed towards the whole vehicle. The customer's driving experience can be included at an early stage as well. To investigate the acceptance of new functions ViL can be used to perform trials with test subjects as early as in the model development stage.

At the end of the V process, when the target ECU has already been integrated in the vehicle, ViL may be used to achieve a very high degree of maturity of the ADAS functions prior to the commencement of actual road tests. The functionality of the systems can also be reproducibly tested under various boundary conditions with ViL so that only random tests under full real-world conditions are necessary. As a result, costly iteration loops in the approval process can be avoided.

The ViL tests can be automated in all development stages. In this case, the driver model IPGDriver assumes the role of the test driver and carries out the defined manoeuvre tasks. To do so, the virtual driver accesses the actuators of the real-world test vehicle in real time. The test vehicle is controlled by a driver model. This allows the driver's behaviour to be kept constant or specifically varied in order to investigate the influence of the driver (like his braking behaviour) on the functions of the assistance system. The test curves and results can be exactly reproduced and the automation leads to a significant reduction of time and costs.

CONCLUSION AND OUTLOOK

The proposed Vehicle-in-the-Loop (ViL) test concept offers maximum consistency in the model based development of driver assistance systems. Based on an identical model platform, MiL, SiL, HiL and ViL tests can be performed – with test scenarios that have to be configured only once and can be reused in all domains.

The ViL concept is not only suitable for validating the functional safety of electronic control units. In a virtual, augmented environment the driver, too, can be tested in conjunction with the future driver assistance functions. Particularly in the further development of today's assistance systems into partially and high automated or autonomous systems the ViL approach can provide substantial support.

After all, the success of autonomous functions crucially depends on the design of the interface between the driver and vehicle: For instance, what strategies are used to govern the handover of vehicle control from the driver to the assistance system and vice versa? How can it be assured that the driver of a vehicle being operated in autonomous mode can be brought back "in the loop" at any time? The proposed concept provides a safe, realistic and resource-saving test method to comprehensively investigate such questions.

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