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Functional Testing of ADAS/AD along the Vehicle Life Cycle

In order to ensure the functional safety and customer acceptance of increasingly complex Advanced Driver Assistance Systems and systems for Autonomous Driving (ADAS/AD) over the entire life cycle of a vehicle, virtual validation methods are essential in addition to real test drives. dSpace shows how vehicle-in-the-loop simulation with over-the-air sensor stimulation enables efficient, safe, and reproducible testing of ADAS/AD.

The German government has set itself the target of reducing the number of road deaths by 40 % between 2021 and 2030 [1]. Regulatory bodies and legislators see great potential in advanced driver assistance systems to improve road safety. Among other things, all newly type-approved passenger cars must be equipped with an Autonomous Emergency Braking System (AEBS) since July 6 2022 in accordance with EU Regulation No. 2019/2144 and all newly registered passenger cars from July 7 2024 [2].

NEED FOR END-TO-END VALIDATION

AEBS has a safety-critical relevance that requires the full functionality of the sensors involved. However, during the course of the vehicle product life

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cycle, the function of these sensors may be restricted due to internal and external influences. Possible consequences are:

- When the data from the radar, camera, ultrasonic, and lidar sensors is merged, the central control unit detects inconsistencies and switches off the assistance systems for safety reasons.
- Due to misinterpretations, audiovisual warnings are permanently issued by the vehicle.
- The vehicle misinterprets its environment based on incorrect data and actively intervenes in the driving process with potentially serious consequences.

These dangers make it clear that ADAS/AD functionalities require comprehensive and complex testing. In this context, the United Nations Economic Commission for Europe (UNECE) presented the New Assessment and Test Method (NATM) for automated driving [3]. The NATM is a multi-pillar approach that should be understood as a framework and potential pioneer for new test methods. In order to promote these methods, a comprehensive overview of the testing and standardization landscape has been created under the banner of the Association for Standardisation of Automation and Measuring Systems (ASAM). In the study group's report, experts from all areas of the automotive industry see "Requirements-based Vehicle-in-the-Loop (ViL) testing" as a valid way of testing the functionality of highly automated vehicles [4].

SENSOR-IN-THE-LOOP SIMULATION WITH OVER-THE-AIR STIMULATION

For many years, vehicle sensors have been stimulated without contact, that is Over-the-Air (OTA), in Hardware-in-the-Loop (HiL) simulation. The aim of HiL simulation is to be able to simulate and test a complete mechatronic system by pairing real control units or even a combination of sensors, control units, and actuators with virtual (simulated) components.

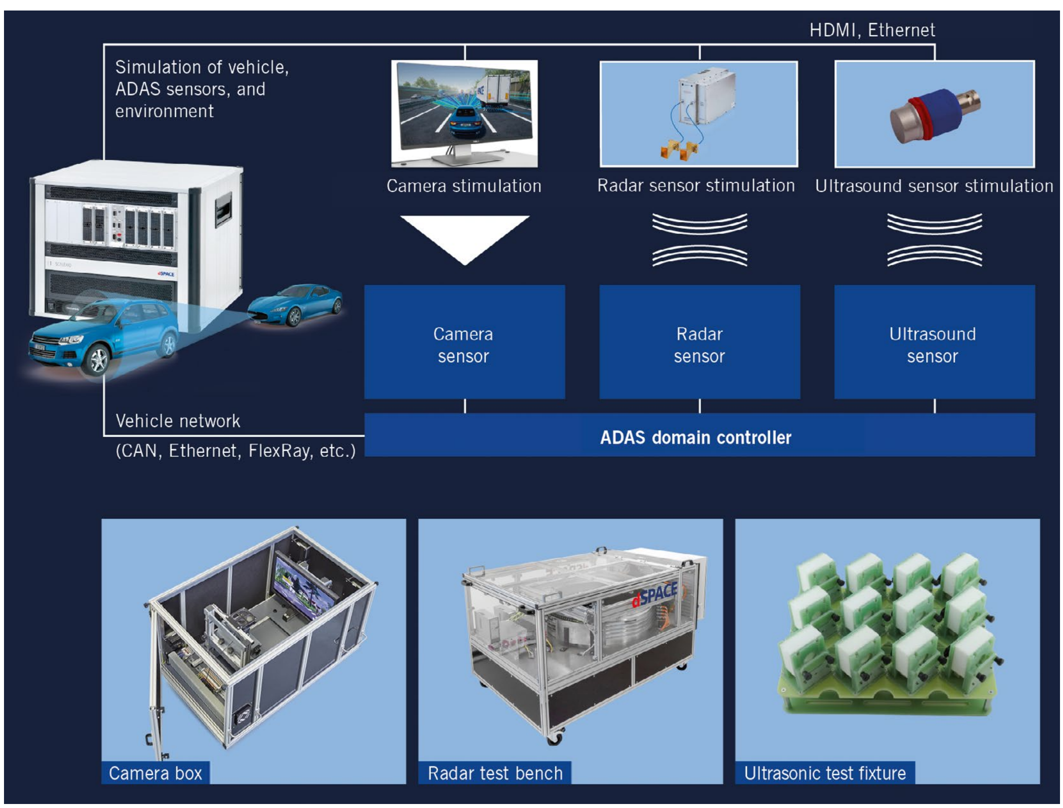

FIGURE 1 Functional principle – sensor-in-the-loop with OTA stimulation (© dSpace)

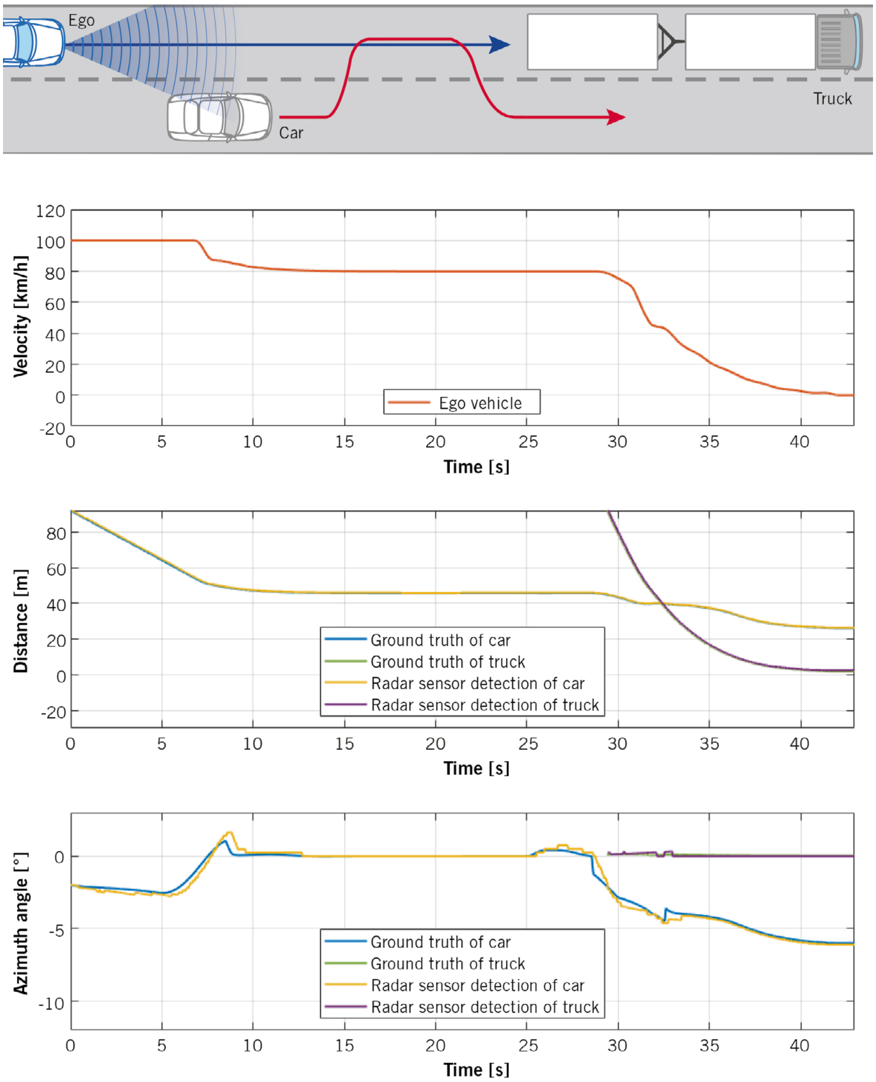

FIGURE 2 Schematic representation of the driving scenario (top) and radar OTA measurement results, which were corrected for sensor latency (bottom) (© dSpace)

A real-time simulation computer serves as the central unit, which simulates the vehicle together with the surrounding sensors, the traffic environment, and other road users. This ensures synchronous stimulation of all sensors. Cameras are stimulated OTA by presenting them with an image of a simulated environment. In order to excite radar and ultrasonic sensors, suitable echoes are generated that simulate objects in the sensor's field of view. The vehicle and environment model running on the real-time computer serves as the information basis for the simulation of these dynamic objects.

FIGURE 1 shows the components used for OTA stimulation of camera, radar, and ultrasonic sensors. Within the camera box, the camera is positioned in front of a high-resolution monitor, which displays a suitable perspective of a dynamic environment simulation. The simulated perspective is adapted to the real vehicle parameters, such as camera position and orientation. During operation, the box is closed and completely darkened to prevent disturbing light reflections and glare. The unmodified radar sensor is installed in a radar test bench and stimulated with real radar echoes using radar target simulators. The test bench essentially consists of a round absorber chamber made up of five stacked and individually rotatable rings. The rings are equipped with the transmitting/receiving antennas of the radar target simulators, whose concentric movements simulate the azimuth angle of the radar targets. The advantage of OTA stimulation is that it makes it possible to test the entire chain of effects from the sensor front end to data processing in the control unit.

To demonstrate the functional principle, the OTA sensor stimulation was paired with a camera and a radar sensor to simulate a driving scenario. The information of the detected objects processed by the sensor control unit is compared with the ideal object information (ground truth data). For a meaningful comparison, the radar sensor data was corrected for the processing and communication latency of the sensor. The example scenario is a cut-in/cut-out scenario. The ego-vehicle drives at 100 km/h in the left lane of a two-lane highway. A second car traveling at 80 km/h changes from the right lane to the left lane, slowing the ego-vehicle down to 80 km/h in the process. The driver of the car in front then notices too late that there is a truck in the left lane. He brakes, swerves into the right-hand lane, and comes to a halt next to the truck. The ego vehicle can stay in the left lane because it brakes in good time.

FIGURE 2 contains the resulting simulation values. The first graph shows the velocity of the ego vehicle. The second graph shows that the automotive radar sensor in the radar test bench detects the two other vehicles according to the simulation, as illustrated by the comparison with the ground truth data for the distances of the vehicles. The azimuth angles to be simulated and those actually detected by the radar sensor also show good correlation in the third graph. **FIGURE 3** shows the raw camera image with the results of the environment detection, displayed using bounding boxes and object types. The camera demo algorithm of the Nvidia Drive AGX development platform used here only differentiates between the vehicle and road sign object classes. These are reliably detected throughout the entire scenario.

VIL SIMULATION ON THE TEST BENCH WITH OTA STIMULATION

The technology of ViL simulation has its origins in HiL simulation. Many years of experience from numerous HiL projects have been incorporated into the develop-

FIGURE 3 Visualization of the camera OTA stimulation (© dSpace)

ment of the ViL test bench. The same established technologies are used to stimulate the sensors of the unmodified vehicle without interfering with the E/E architecture and without access to the bus systems.

The Vehicle under Test (VUT) is positioned on a steerable chassis dynamometer to check the correct functioning of the environment sensors and advanced driver assistance systems. The advantage of ViL testing with OTA stimulation is that the vehicle does not have to be manipulated in any way. No data is fed directly into the control units and there is also no communication with the vehicle via the OBD interface. Depending on the test scenario, the driver can accelerate, brake, and also steer the vehicle thanks to the special chassis dynamometer used. The data from the steerable chassis dynamometer (wheel speeds, steering angles, etc.) is transmitted to the simulation via interfaces so that the behavior of the VUT can be virtualized with its real physical movements. This digital image of the vehicle and its surroundings is calculated in real time and displayed synchronously. The simulation feeds a monitor and radar target simulator for the OTA stimulation of the camera and radar sensors. A monitor and radar antennas attached to a dynamic gantry system are integrated into the test line and directly in front of the vehicle to be

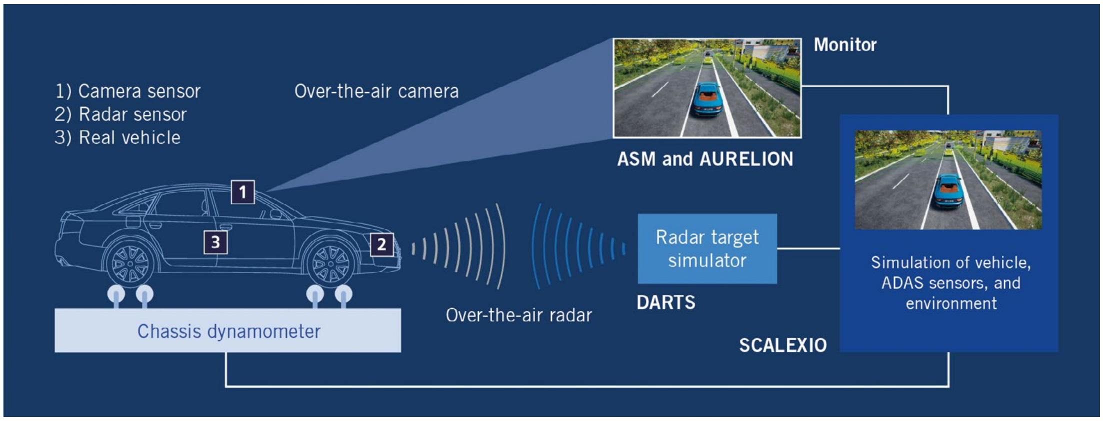

FIGURE 4 Functional principle – ViL with OTA stimulation (© dSpace)

tested. The monitor stimulates the vehicle's camera with environment and road scenarios animated by the sensor-realistic simulation solution in the form of a 3D world. This serves to check whether the camera sensor of the VUT recognizes the relevant objects correctly, **FIGURE 4**.

This solution can be used to test advanced driver assistance functions such as adaptive cruise control, front collision warning, autonomous emergency braking, lane keep assistant system, lane departure warning system, highway driving assist, blind-spot detection, rear cross traffic alert or safe exit assistant.

Together with its development partner Dürr Assembly Products and the technical inspection organization KÜS, dSpace has developed a solution that enables precise and reproducible testing of ADAS functionalities in a safe test hall environment, **FIGURE 5**.

This form of validation can be used in Periodical Technical Inspection (PTI), for End-of-Line (EoL) tests in automotive production, for the type approval/homologation of ADAS/AD, and for Research and Development (R&D) purposes.

While only non-invasive test methods (like OTA stimulation) can be considered for the specific use cases of EoL testing and PTI, another form of feeding simulation data to the vehicle can be used in R&D and, to some extent, in homologation. This invasive sensor data feed includes, for example, an intervention in the vehicle's communication network. A combination of the two techniques is also possible.

Ultrasonic-based near-field sensor technology as well was stimulated in customer projects on a real vehicle in dynamic driving mode. When driving slowly, for example, during parking maneuvers, objects are defined in any virtual scenario and object distances are calculated at run time in the simulation environment. These distances are the target values of the ultrasonic stimulators for the ultrasonic sensors installed on the vehicle. The user can manipulate the echo signal generated for the stimulation in real time. In addition to the time-of-flight, the amplitude, frequency, and number of signal oscillations can be adjusted. In addition, both direct echoes and indirect echoes can be generated. This setup enables the validation of all parking assistance functions (parking assistant, automatic or autonomous parking) and their validation in accordance with ISO 17386 regulations on a real vehicle.

SUMMARY

ViL simulation with OTA sensor stimulation on a chassis dynamometer enables black-box tests of ADAS/AD functions of an unmodified vehicle. Even critical test scenarios can be carried out reliably and reproducibly. This approach now provides an additional validation, certification, and verification tool for the entire vehicle life cycle.

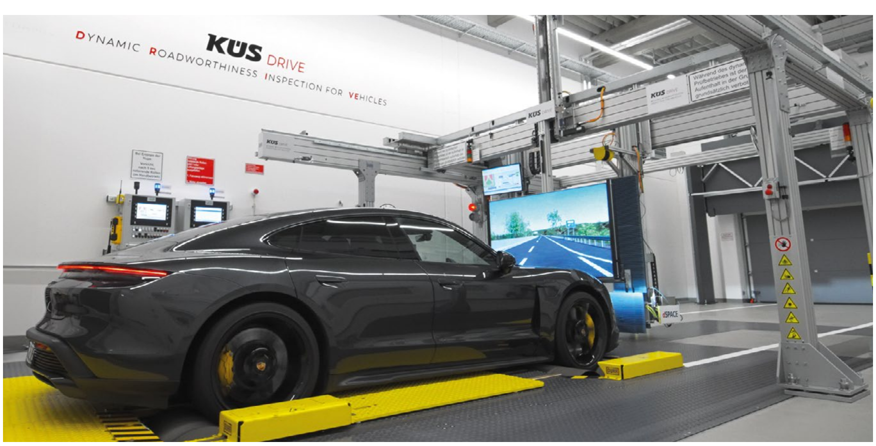

FIGURE 5 ViL on the chassis dynamometer with camera and radar OTA stimulation (© KÜS)

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