

Lab-Based Testing of ADAS Applications for Commercial Vehicles

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ABSTRACT

Advanced driver assistance systems (ADAS) are becoming increasingly important for today's commercial vehicles. It is therefore crucial that different ADAS functionalities interact seamlessly with existing electronic control unit (ECU) networks. For example, autonomous emergency braking (AEB) systems directly influence the brake ECU and engine control. It has already become impossible to reliably validate this growing interconnectedness of control interventions in vehicle behavior with prototype vehicles alone. The relevant tests must be brought into the lab at an earlier development stage to evaluate ECU interaction automatically.

This paper presents an approach for using hardware-in-the-loop (HIL) simulation to validate ECU networks for extremely diverse ADAS scenarios, while taking into account real sensor data. In a laboratory environment, the sensor systems based on radars, cameras, and maps are stimulated realistically with a combination of simulation and animation. This makes it possible to validate ADAS functionalities, such as lane departure warning (LDW) systems, AEB and predictive cruise control (PCC), already in the lab.

The project described in this paper is a cooperation of MAN Truck & Bus AG and dSPACE GmbH. To simulate realistic driving environment scenarios, several dSPACE Automotive Simulation Model (ASM) components with special enhancements are combined to create a virtual truck. By using various real sensors simultaneously, new possibilities for investigating sensor data fusion are offered even before a real prototype exists. Specially designed automatic monitoring of the real cockpit instrumentation provides additional validation options, further increasing test maturity. In the final development phase, the laboratory results for driver assistance systems are validated by performing actual test drives.

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INTRODUCTION

HIL systems have become the state-of-the-art technology for developing and testing ECUs in the automotive field [1]. Testing of controller functionality in a virtual environment is rapidly becoming more important, especially for applications for commercial vehicles. Due to higher numbers of axles, gear types, suspension systems, and trailer combinations, the number of possible vehicle variants is nearly unlimited [2]. Today, over 90 ECUs are connected to network simulators at the same time and are used closed-loop with dynamic plant models [3]. Eight years ago, only just over 20 ECUs were integrated in parallel [4].

In addition to the validation of the many vehicle-specific variants, ever stricter laws on safety further increase the test effort [5].

Some examples of concrete steps toward these goals in Europe are the mandatory installation of emergency brake assistants and lane keeping assistants in all new truck models from November 2013 and in all newly registered trucks from 2015. These European and

international laws also specify the requirements for the lane guard system (LGS) [9] and the emergency brake assistant (EBA) [10]: The LGS has to issue a warning if the outer wheel edge is at least 30cm outside of the lane marking and the vehicle speed is above 60 km/h. The system has to work reliably at curve radii above 250 m, a lateral speed below 0.8 m/s and a lane width above 3.5 m. For moving targets, which can move at a speed of up to 30 km/h, the EBA has to decrease the truck's speed by 50 km/h. If the target vehicle does not move and the truck moves with up to 80 km/h, the EBA has to begin to reduce the truck's speed not later than 30m after the obstacle has been detected.

These typically radar- and video-based systems (EBA and LGS) particularly address the two main causes of accidents: driving into the rear of another vehicle and unintentionally leaving the road [11].

New requirements in the ADAS field increase the complexity of validating networked functions. In addition to accident-free driving, the areas of energy efficiency and digital networking also offer great innovation potential for vehicle manufacturers and suppliers. This

increases the range of functionalities that the ECUs have to provide. These functionalities are now usually implemented in ECU networks and no longer assigned to dedicated ECUs [11].

LAB-BASED TESTING

Until now, ADAS functionalities usually have been significantly less interconnected and were limited to particular ECUs. As these functionalities now become more interconnected and certain functions are distributed across the ECU network, an end-to-end test is necessary to ensure the operational reliability of the system within the virtual vehicle. Thus, in addition to common component and integration tests on the HIL simulator that use dynamic plant models for sensors as well, integrating real sensors and actuators is especially important for ADAS applications.

On the other hand, the real human being has to be replaced with a validation system, to come to fully automated end-to-end tests. Thus, one major advantage of HIL simulation for ADAS functionalities is the possibility to test and calibrate the driver warnings of the actuators fully automatically. No real person has to be subjected to the continuous sounds and acoustic alerts of the driver assistance system.

One goal of the lab-based testing is to reach the highest possible driver acceptance for the different ADAS functionalities, like LGS, via maximum system availability and equipment quality. Error messages are to be reduced without limiting the use cases. This means that lane detection must be robust and that warnings should not be issued when the lane markings have to be crossed.

With repetitive tests in the Lab and later on the real driving scenarios MAN Truck & Bus AG has proved that it exceeds the legislative requirements for advanced driver assistance systems by far.

System Overview

The HIL simulator described below was designed for testing the following ADAS functionalities in a virtual vehicle in the laboratory:

- Lane guard system (LGS): A video camera behind the windscreen records the lane markings. Acoustic signals from the left or right speaker in the vehicle doors issue warnings for the driver.
- Emergency brake assistant (EBA): As a component of MAN BrakeMatic®, the EBA aims to prevent or at least reduce rear-end collisions at the tail ends of traffic jams on highways.
- Adaptive cruise control (ACC): The ACC system automatically adjusts the driving speed and the distance to the vehicle ahead according to the specified settings.
- MAN EfficientCruise®: A GPS-controlled cruise control that uses saved map material to take upward and downward gradients in the route ahead into account and to adapt the vehicle's speed strategy accordingly. Thus, the fuel consumption can be optimized.

The following requirements were defined in the concept phase of the test system:

- Large-scale ECU network tests and realistic simulation of the vehicle environment
- Development and test of ADAS functionalities simultaneously to prototype development
- Automated closed-loop tests, particularly end-to-end tests from the real sensor to the real actuator
- Efficient reproduction of complex scenarios
- Coverage of a wide range of tests, including ambiguous traffic situations
- Testing the robustness and response behavior of the ADAS functionalities
- Support for the MAN EfficientCruise® functions, and validation of fuel consumption

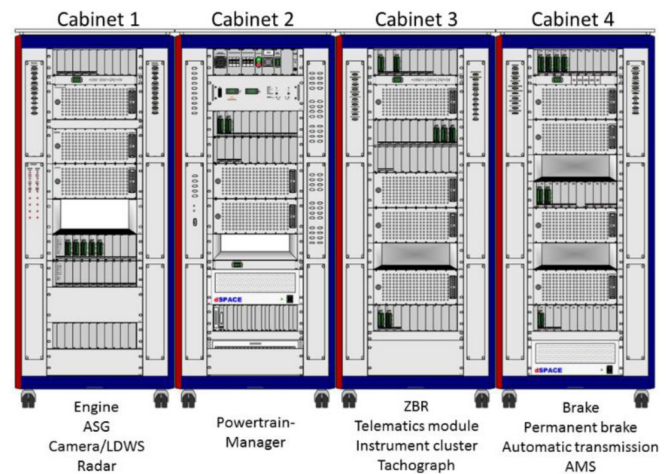


Figure 1. ECU distribution of the multitrack HIL simulator.

The presented test system simulates the complete chain of effects, starting with detecting the precarious situation up to supervising the acoustic or visual warnings in the driver's cabin. For this purpose, a real time capable dynamic model is used with the following components:

- Engine-related components, such as the engine itself, the exhaust system, the air path, the cooling system, and the exhaust brake
- Drivetrain-related components, such as the starter, the crankshaft, the clutch, and the gearbox
- Components for simulating the vehicle dynamics and the environment, such as tires, brakes, the suspension and steering system, the trailer, the road, and traffic

The four cabinets shown in Figure 1 are an essential part of the HIL simulator. Three PX20 Expansion Boxes from dSPACE are distributed across these four cabinets. The PX20 Expansion Boxes contain the real-time hardware of the system: Four DS1006 Processor Boards are connected to dSPACE I/O hardware, including two DS2202 and four DS2211 HIL I/O Boards, four DS4302 CAN Interface Boards, four DS4004 HIL Digital I/O Boards and two

DS2004 High-Speed A/D Boards. Due to its modular setup, the system is highly scalable and can be modified flexibly if further ECU functionalities have to be covered in later development stages. The HIL simulator contains a total of 26 CAN controllers. Twenty of them are being used for establishing a 'main-local' principle in which local enforcement of bus errors for individual ECUs is possible, while the remaining ECUs in the cluster or network are not affected by the manipulated bus signal. Figure 2 shows the CAN network of the simulator distributed across the four cabinets.

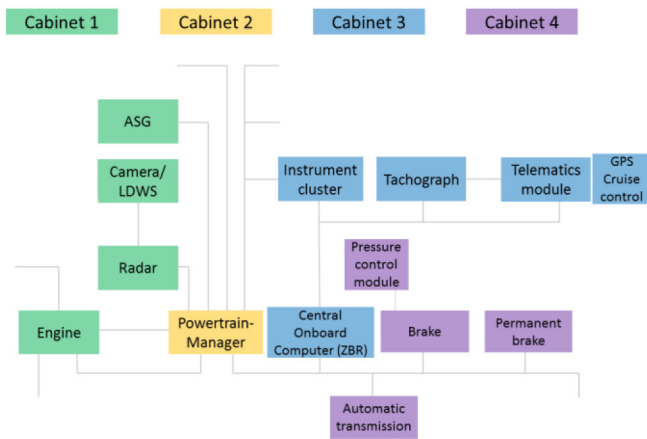


Figure 2. ECU network of the HIL simulator.

The ECU network of the simulator is necessary to test distributed ECU functions. For example, during a brake maneuver of the antilock brake system (ABS), the electronic brake system (EBS), the engine ECU and the transmission ECU communicate with each other. Tests of the EBA, as a further example, involve data exchange between cabinet one, which contains the connection to the camera-in-the-loop subsystem, and cabinet four, which contains the EBS.

Camera-in-the-Loop Tests

As described earlier, one focus of the test rig is end-to-end testing, i.e., from the first sensor in the signal chain up to the last actuator that executes an action. Hence, it was necessary to develop the camera-in-the-loop subsystem shown in Figure 3. A separate box contains the vehicle camera, which faces the computer screen. In order to simulate the perspective from the driver's cabin realistically with the 2-D image on the screen, a special optical lens has to be mounted in front of the camera in the test arrangement.

The scene view of the driver cab is projected on the screen via the animation software MotionDesk. Thus, the simulated road environment including moving/non-moving objects, different lanes and traffic signs are visualized. To get a realistic animated view from the driver's perspective, the nodding movements of the driver cab are also simulated - a novelty that was first introduced with dSPACE ASM. For details on the enhancements in the simulation model, see section Special Model Enhancements for Camera-Based Systems.

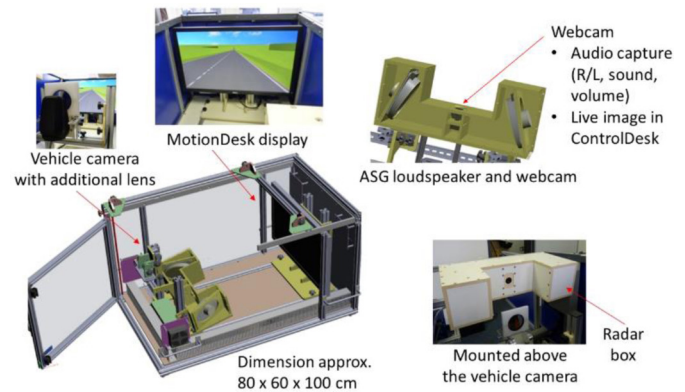


Figure 3. Camera box with MotionDesk display, webcam, loudspeaker setup and radar box.

An additional webcam in the box is used to send live images of the screen to the operator interface in ControlDesk. This way, the operator obtains visual access to the current state of the MotionDesk scene view within the sealed box shown in Figure 3. The stream of the webcam can also be saved to a video file for later analysis.

Testing the Acoustic and Visual Signals in the Driver Cab

The camera box shown in Figure 3 also contains a set of vehicle loudspeakers, which in a real truck are integrated in the driver's cab. The loudspeakers are embedded in a soundproof casing together with a two-channel microphone.

The camera box is also necessary because the HIL simulator is used for calibrating the LGS. A well-calibrated driver assistance system increases acceptance by truck drivers. MAN Truck & Bus AG therefore aim at minimizing false alerts while maintaining high system availability especially in ambiguous traffic situations. For example, the LGS should not intervene in the following cases:

- If crossing the lane marking is inevitable at a highway exit or during an overtaking maneuver
- At the beginning or at the end of curves
- During lane changing maneuvers for navigational purposes at highway junctions

The system also has to be able to cope with various weather conditions, where lanes can be covered with snow or leaves, and faded lane markings or lane markings in different colors. The robustness of the control system is tested by utilizing a virtual driver with typical behavior patterns, as well as special vehicle model sequences for emulating standard maneuvers.

Another test field that involves the camera box is the response time of the LGS. According to the European and international laws described in the Introduction section, the acoustic warning has to occur within a certain time period: