Seamless Tool Chain for Testing Camera-based Advanced Driver Assistance Systems

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The increasing use of camera-based driver assistance systems results in a higher development effort for vehicle manufacturers and automotive suppliers. To control time and costs in the development and validation process, the use of virtual test driving and suitable tools offers the possibility of seamless in-process work with a simulation environment in order to virtually test all the required vehicle components at an early stage. Particularly camera-based advanced driver assistance systems lead to new test specifications to be considered in the development process as a result of the cameras' characteristics. IPG demonstrates how a suitable method for efficient testing of camera-based driver assistance systems is available for every development stage.

MOTIVATION

By now, advanced driver assistance systems (ADAS) are playing a central role as they provide the basis for automated or autonomous driving on its various levels of automation. The aim of ADAS is to assist or ease the driver's burden in diverse driving situations or, in the case of highly automated or autonomous driving, to fully take over all driving tasks. This presupposes perfect functionality in any situation, which leads to high testing requirements in the development process. How these requirements can be mastered will be shown here based on an open and innovative tool chain.

Particularly in the area of ADAS the validation requirements have enormously increased for the following reasons:

- Many systems in the vehicle access data from several sensors which, to some extent, is fused prior to being used.
- The systems are increasingly interlinked.
- The test scenarios are becoming more complex as the surroundings play a significant role in defining them.

As a result, it soon becomes evident that the testing requirements rise to such levels that test cases can no longer be economically run in the real world [1] or that feasibility becomes questionable because many test scenarios, in reality, cannot simply be reproduced due to the large number of objects involved. To meet these challenges, virtual test driving is used in all stages of the development process. As a result, it is possible to optimise and extensively validate functions at an early stage even without real-world prototypes. This is typically referred to as frontloading.

In addition, the reusability and reproducibility of the test cases across the entire process are major advantages of virtual test driving that lead to significant cost benefits. Test scenarios that have been created once can be used in the Model-(MiL), Software-(SiL), Hardware-(HiL) and Vehicle-in-the-Loop (ViL) stages. In the MiL and SiL stages the scenarios can be calculated in multiple real time which results in major efficiency improvements of the development process. Modifications can be made very easily as well: by hand, by test automation or by means of DoE (Design of Experiments). This makes it possible to validate advanced driver assistance systems at an early stage at a high level of testing depth, in spite of the myriad of complex test cases.

REQUIREMENTS IN A MODERN SIMULATION ENVIRONMENT

For efficient testing of advanced driver assistance systems, the various scenarios must be easy to implement. Briefly summarised, this results in the follow-

FIGURE 1 Virtual parking scenario with different camera perspectives (© IPG Automotive)

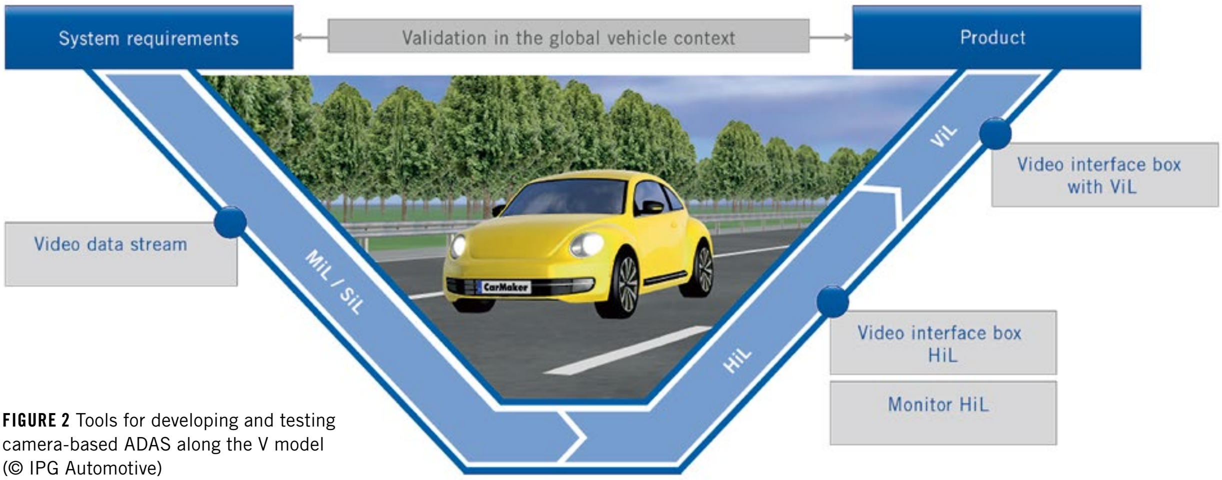

FIGURE 2 Tools for developing and testing camera-based ADAS along the V model (© IPG Automotive)

ing requirements to be met by an appropriate testing tool:

- openness in order to allow the user's own models to be integrated into a full virtual vehicle and to subsequently operate this vehicle in complex traffic scenarios
- integration of software or hardware controllers and sensor fusion algorithms
- easy possibility to set up complex testing scenarios
- reusability of test cases and associated evaluation criteria
- sensor models such as Radar, Lidar, ultrasound and cameras including the modelling of the relevant properties
- data must be made available at the same time and place
- lean hardware architecture/test system set-up (i.e. short latency periods)
- utilisation of the test platform across the entire development process
- openness to accommodate various hardware platforms, e.g. IPG Automotive (Xpack4, Etas, NI, dSpace etc.).

To enable the efficient development and testing of camera-based ADAS across the entire development process as well, additional factors must be considered. Testing requirements in this area will increase as more and more ADAS such as AEB (Autonomous Emergency Braking) or steering-assist systems are starting to use cameras as a sensor source. Furthermore, cameras become more widely used as prices for them keep dropping.

REQUIREMENTS OF VIRTUAL TESTING OF CAMERA-BASED ADAS

The simulation of camera characteristics is important for virtual testing of camera-based assistance systems. It must be possible to consider and/or parameterise the following camera-relevant factors:

- lenses or lens types (e.g. fisheye)
- optical aberrations (e.g. distortion, chromatic aberration, dirt on the lens)
- number of lenses (e.g. for mono or stereo cameras or tricams, as well as for surround view systems with several cameras etc.)
- sensor characteristics (e.g. monochromatic, colour (incl. Bayer pattern), defective pixels, sensor noise).

For functions such as parking assistance systems with optimally large detection of the surroundings, even exceeding a 200° viewing angle with fisheye lenses (for example, with one camera each at the front and rear and in the left-hand and right-hand mirror) it must be possible to model the corresponding lenses (see parking scenario, **FIGURE 1**).

TESTING OF CAMERA-BASED ADAS

CarMaker and other solutions by IPG Automotive provide diverse tools for testing camera-based ADAS in the various stages of the development process, **FIGURE 2**. Thus, users can decide what approach makes the best sense in the respective development stage, depending on their systems. The test cases and evaluation scenarios created in CarMaker, as described above, can be used again – both in pure simulation and subsequently on camera HiL, in combination with the Video Interface Box (VIB) or by using the Vehicle-in-the-Loop method.

TESTING IN THE MIL/SIL STAGE

Virtual testing of camera-specific functions requires a camera model, **FIGURE 3** (part 1) by means of which various camera positions and characteristics can be configured (from resolution, to refresh rate, through to optical and sensor characteristics). The Video Data Stream (VDS) camera model, in addition to the aforementioned characteristics, is able to emulate other camera-specific effects in the simulation, i.e. the rolling shutter effect, motion blur or vignetting. Only in that way camera-based assistance systems can be checked and evaluated correctly, such as traffic sign recognition or the fusion of various camera perspectives when parking. In addition, diverse settings (e.g. aperture angles) can be parameterised in VDS and simulated video data in the RGB, intensity, depth map and filter pattern (RAW) formats can be made available at the same place and time. As a result, the data from VDS may be used for data fusion as well. Thus, the use of VDS allows closed-loop tests to be performed at an early development stage. This allows the entire software event chain of the camera from the control system through to the actuators in the whole vehicle to be validated.

VDS is typically used in the development and testing of image processing algorithms for object recognition (e.g. line, pedestrian, sign recognition, etc.). Subsequently, for instance Euro NCAP-relevant functions such as AEB are tested in the simulation environment – in fully automated mode. At the same time, an automated analysis and prediction of the Euro NCAP stars achieved can be made, which is subsequently documented in the corresponding test report.

TESTING IN HIL STAGE

Many camera functions are validated in a later development stage using Hardware-in-the-Loop. There are various methods to perform the test of camera-based assistance functions.

CAMERA HIL

This method provides for the real-world camera installed in the vehicle to film a monitor inside a black box, **FIGURE 3** (part 2). There are two available options: in the so-called open-loop technique a real-world recording of a scenario is played and filmed. In the event of a parameter change in the system (e.g. an AEB trigger threshold) the recorded scenario remains the same. This enables merely a vague perception, for instance of whether or not a pedestrian is being hit. In the closed-loop approach the current simulation scenario is always projected on the monitor, which means that the changed behaviour of the AEB based on a parameter modification is immediately obvious.

The ability to test an integrated assembly of the camera lens and ECU without access to camera-internal interfaces is a major advantage of this method. Furthermore, the installation of this testing system for the "mono camera" test case is relatively simple so that even without any specific knowledge of the communication between the image sensor and the camera control unit it is easy to set up, although orientation errors may obviously lead to inconsistent results. The camera HiL is a commonly used solution for testing mono camera systems but, with an additional expense, could be set up for stereo cameras as well. For many applications, for instance if no special cases such as night scenes have to be considered, this method is sufficient and provides a simple, uncomplicated solution.

However, this method also harbours a number of weak points which, depending on the use case, are of lesser or greater importance. For example, they include an occasional faulty synchronisation between image build-up in the monitor or in the DLP projector and image acquisition in the camera as a result of which the camera captures distorted images which are not valid for the analysis. In addition, the scope of contrast that can be displayed on monitors is smaller than that of modern image sensors (algorithms, however, use contrast as the key characteristic for object differentiation). In many cases the light intensity is insufficient to cause overexposure in the image sensor (e.g. to model glare by oncoming traffic or when exiting tunnels). The testing of stereo camera systems or cameras with "fisheye lenses" represents a particular difficulty. In this case the available image region of a conventional flat monitor is inadequate.

VIDEO INTERFACE BOX (VIB)

This system does not require a real-world camera. Instead, the data is fed directly into the ECU. The electrical connection between the camera and the ECU is separated in this case and the camera interface replaced with the newly developed hardware, **FIGURE 3** (part 3). It is fed via the DVI interface of the graphics board of the computer on which the simulated environment is generated. Via high-performance

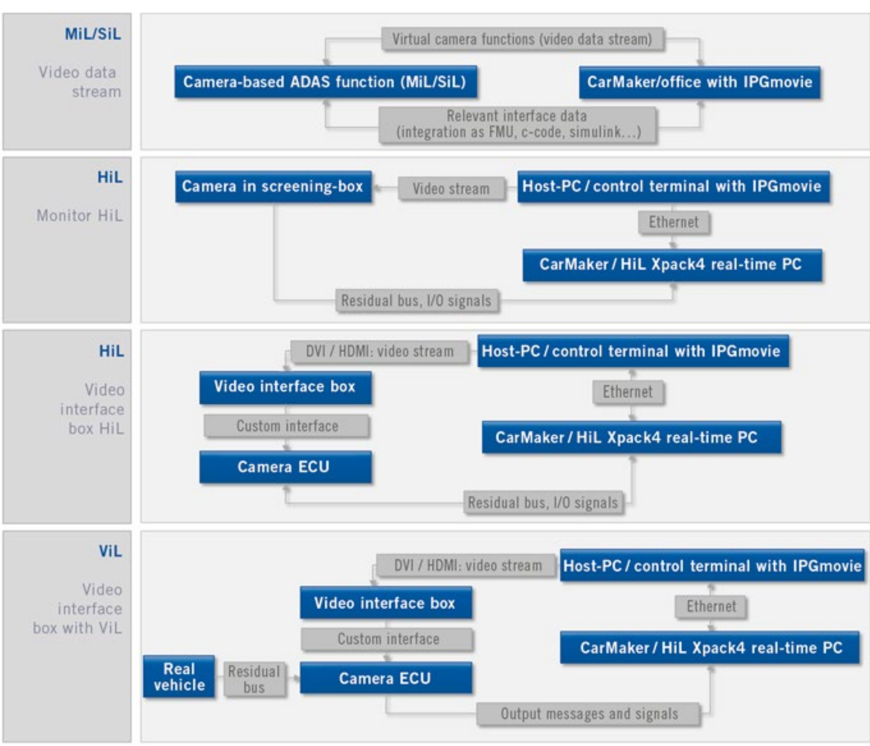

FIGURE 3 Overview of the functional principles of the single tools (© IPG Automotive)

hardware and a corresponding signal adjustment the video data can thus be converted into nearly any desired interface format and directly fed into the ECU with reliable timing and low latency. Feedback channels enable the synchronisation of the image output of the channels to the relevant exposure signals so that the emulation vis-á-vis the ECU behaves in a totally transparent manner. At the same time, an emulation of up to four cameras is possible for testing stereo camera, tricam or birds-eye-view systems. Due to the underlying concept all channels are ideally synchronised, while resolutions and frame rates remain configurable independently of each other.

With this testing system it is possible to check camera-based functions in the closed-loop HiL method and by integrating other electronic control units including their simulated environment sensors and to thus tap into the advantages of virtual test driving also in the context of sensor data fusion.

TESTING IN THE VIL STAGE

The ViL method is suitable for enhancing the transparency of test scenarios while including information of the surroundings without putting people or hardware at risk. By embedding a real-world vehicle in the virtual surroundings the virtual environment and/or the function under test can be experienced by means of augmented reality. This method enables time- and cost-efficient testing and validation of the systems.

Furthermore, the combined use of VIB and ViL is possible, **FIGURE 3** (part 4), for instance for Euro NCAP-relevant scenarios such as AEB for pedestrians that will be required from 2016 on in order to achieve the highest possible score. This way, virtual pedestrians can be displayed to the drivers using see-through technology while the functional capability of the advanced driver assistance system is checked by means of VIB.

REFERENCE

[1] Hakuli, S.; Krug, M.: Virtuelle Integration. In: Winner et al. (publisher): Handbuch Fahrerassistenzsysteme, 3rd edition, 2015. Springer Vieweg, p. 126