Autonomous Driving Supported by Simulations

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***Abstract*—The automotive industry is largely sensitive to the high quality of the products. This momentum results that huge amount of tests and analyses are required to achieve this goal. The emerged costs and time demand can be decreased by involving computer-based methodologies, like simulations. Simulations imitate the exact characteristics of vehicle parts in fully modeling form. If the whole vehicle stands in the focus of simulations, the system must be supported by highly accurate reality descriptions. The OpenDRIVE standard contains exact descriptors about the road environment (road segments, lanes, lane markings, etc.). Such models can be obtained by surveying and modeling reality. The paper gives an overview of the standard and current implementations in the various automotive simulators. The future perspective awaits massive growth of the importance of the standard.**

Keywords—simulation, autonomous driving, development, OpenDRIVE, digital map

I. INTRODUCTION

Self-driving vehicles are expected as one of the biggest changing factors in our near future life. The road transportation stands in front of a great revolution as the vehicles will be equipped with autonomy. These expectations are implicitly understood together with a very safe operation. The development of vehicles requires a huge amount of resources, manpower, time and money; these efforts are expressed in the price labels. The carmaker industry is therefore interested in effective techniques that can reduce the above-listed items; fewer efforts can establish higher profits at the end. The various computer-based solutions can be used well in this struggle.

Among the plenty of computer-based procedures, we focus on the simulations. “A simulation is an approximate imitation of the operation of a process or system, that represents its operation over time.” [1] after another definition “Simulation is the implementation of a model or models in a specific environment that allows the models’ execution or use over time.” [2] Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training, education, and video games.[1] Naturally the automotive world profit also from the advantages of the use of simulations in the different production scenarios.

Generally, the purpose of the simulation can be the verification or validation of a proof of concept, the analysis and/or the increase of complexity of a system (architecture) or the analysis and/or the increase of the level of quality (e.g. accuracy). The simulation acts advantageously in error detection, failure localization, effectivity, and performance increase, whereas considers the available resources, manpower and working process. Shortly, it has an excellent, i.e. high added value versus cost ratio. [3]

The modern vehicles contain more and more computing devices: computers, microcontrollers, etc. These hardware components own an adequate software environment, therefor software development has an increasing role in automotive development and production. Simulation can be discussed on various development levels: source code, software component, system component or system levels. These levels have methodologies with sophisticated testing procedures. Experts agree that such a complex development task cannot be managed without permanent feedbacks and continuous testing workflow is mostly desired. Beyond the software world, the hardware is similarly divided into hardware (as a whole), hardware components, etc. levels. All these simulation modules can have inputs and outputs, where the focus is on the System-under-Test (SuT) block.

II. AUTONOMOUS DRIVING DEVELOPMENTS IN GENERAL

The world of the carmakers has the feature of the above-mentioned process. The development of a vehicle starts with conceptual planning, continued by the elaboration of the details and the prototype, then intensive tests are executing with going back to certain planning phases and refining the elements. After long and hopefully overall tests the prototype can be accepted and the series production starts.

Within this process, more and more computers and their software require more and more software tests. Real vehicle testing is only allowed with high mature software. Simulation and the connected virtual testing have a consequently higher importance in nowadays production workflow.

Because software development is tightly coupled to the hardware environment, and this is more crucial in vehicle control, the methods in software development have to consider the hardware specialties. The current hardware components are therefore developed together with their software.

The most important element of a vehicle is its “brain”, the Electronic Control Unit (ECU). To be able to test it, a series of vehicle components: the engine, the brake system, the environmental sensors, the wipers, the lighting system, etc. must be connected. There are a series of such units: Engine Control Module (ECM), Powertrain Control Module (PCM), Transmission Control Module (TCM), Brake Control Module (BCM or EBCM), Central Control Module (CCM), Central Timing Module (CTM), General Electronic Module (GEM), Body Control Module (BCM), Suspension Control Module (SCM). Further modules are easy to be mentioned. Some modern motor vehicles have up to 80 ECUs. [4]

In the test procedure, these modules have to be connected to the relevant vehicular subunit, e.g. the engine. As was mentioned, the real tests are preceded by a virtual testing course, where the affected subunit must be substituted by a computational model. This simulation and testing is the Hardware-in-the-loop (HIL) simulation. This is a technique that is used in the development and test of complex real-time embedded systems. [1], [5]

When not only a single vehicular component is under tests, but the car as a whole, the Vehicle-in-the-Loop (ViL) is discussed. The Vehicle-in-the-Loop (ViL) concept, which is already in use, was directly developed to test ADAS functions. In this configuration the vehicle itself is real but all the other elements of traffic are simulated. DAS stands for Driver Assistance System, which is a collection of assistants, i.e. services helping in controlling the driving task. A known example for DAS service is the Cruise Control (CC), or another name “tempomat”, which is responsible to ensure a constant prior set cruising speed. ADAS is the abbreviation for Advanced Driving Assistance System. To continue the mentioned example, the Adaptive Cruise Control (“adaptive tempomat”) can be revealed, which extends the functionality by permanently measuring the distance to the vehicle driving in front of the ego-vehicle and controlling the speed with respect to a safe distance. The next step is using the Scenario-in-the-Loop (SciL) testing environment, where not just the physical attributes of the vehicle are tested but also its sensors via their virtual twin realization. In this case, the investigated scenario is simulated and fully or partly realized in parallel. [5], [6]

The ViL and mainly the SciL testing tasks have a strong demand for the digital representation of the real environment. The reality has to be captured and represented to support these systems. There several ways to solve that challenge, but the most widely used, nowadays standardized way is the OpenDRIVE representation.

OpenDRIVE is the leading open format and the de-facto standard for the description of road networks in driving simulation applications. The main contributors in designing and developing the standard are Audi Electronics Venture, BMW Group Research and Technology, Daimler, Deutsches Zentrum für Luft- und Raumfahrt, Fraunhofer IVI, Mercedes-Benz Technology, Realtime Technologies, TESIS DYNAware, Technische Universität München, VIRES Simulationstechnologie, VTI – Swedish National Road and Transport Research Institute. The OpenDRIVE standard has the following main components: road geometry (e.g. reference line, elevation, superelevation, lanes), signaling (e.g. signs, signals), road type and speed profile, simplified road surface (e.g. materials, patches), infrastructure (e.g. tunnels, bridges), arbitrary objects, variations (data sets), custom extensions (user data). [7], [8]

Obtaining acceptable results from the different levels of simulations, real-life tests can be conducted. The last phase of this quality control process is the testing with real vehicles on real public roads. Fig. 1 demonstrates the fundamental role of the simulation in the modern vehicle development procedure.

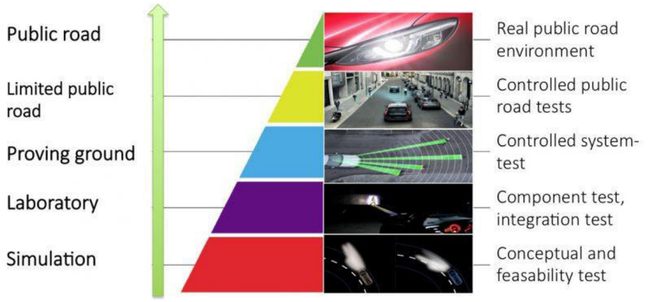

Figure 1. Levels of the tests during the automotive development

III. SIMULATOR ENVIRONMENTS FOR AD DEVELOPMENTS

The previous section might suggest the message, that simulation is a highly appreciated instrumentation in the vehicular development. This is intensively valid for autonomous vehicle development tasks. Because these computer-controlled vehicles are more complicated, have more complex architecture and logic, their software contains more easily bugs, which are also to be discovered and eliminated. The role of simulation gets higher importance.

Because the vehicles are complex systems, their simulators and test environments are similarly complex and various. A rapid survey of automotive simulators having the ability to manage environmental data with OpenDRIVE standard is presented in Fig. 2.

Figure 2. Result of rapid search for automotive simulators with OpenDRIVE – OpenCRG - OpenSCENARIO support [8]–[14]

The common of these solutions is that all of them can consider environmental information with the help of the tools standardized by OpenDRIVE. The simulators expression is building modeling scenario, where the road environment (together with important buildings, rivers, bridges, etc.) is described in a type of map, further elements like vehicles, cycles, pedestrians but other objects as road work components, disturbing elements (wracks, oil slicks, dropped cargo, tree leafs, etc.) extend the scenario. The scenario is then equipped by sensors and controllers and is ready to conduct the test cases (Fig. 3).

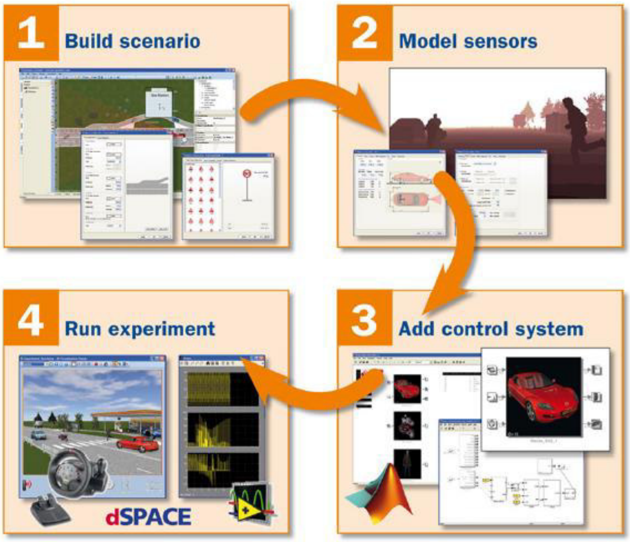

Figure 3. Simulation cycle with scenario definition, sensors and control system, and a running phase [10]

Relevant visualizations in the simulators present the current situation with roads, lanes, traffic signs and signals, as well as the vehicles, or even extended with incidents. The Virtual Test Drive (VTD) system from Vires can be seen in Fig. 4. Similar perspective road visualization is also in TASS PreScan available (Fig. 5) [10].

Figure 4. Vires VTD situation plot

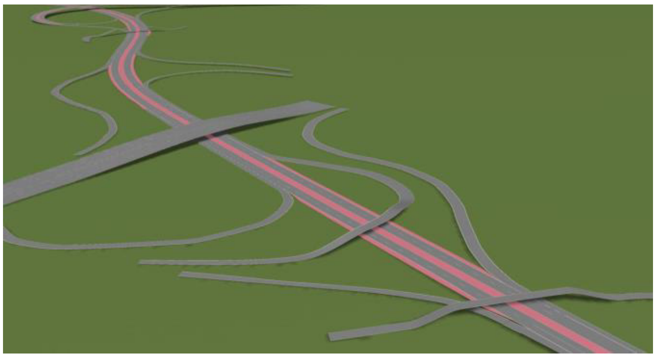

Figure 5. PreScan perspective 3D visualization for roads

Thanks to the achievements in computer graphics, all such simulators are prepared with (quasi) photorealistic environmental visualization power. The graphic engine of those systems can create textured scenarios, where the exact situations are easy to understand, evaluate – even by non-expert users (Fig. 6).

TASS PreScan

Vires VTD

Figure 6. Photorealistic scenario visualizations

The widely known mathematical software package Mathworks Matlab contains also a complete vehicular computation toolbox. Within this toolbox, the OpenDRIVE map models can be imported and for example, safety-critical traffic situations can be evaluated. Fig. 7 demonstrates how a four-arm road junction can be loaded as an OpenDRIVE model, then the behave of a vehicle and a parallel moving cyclist can be analyzed. The presented test case clearly shows also the viewing angle of the onboard camera. Other sensors, like lidars, radars, etc. can similarly be evaluated.

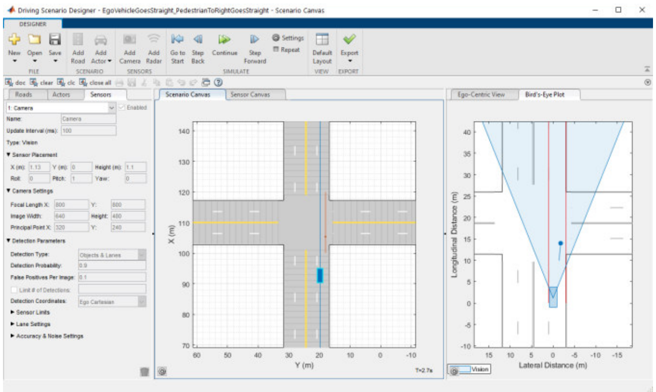

Figure 7. Driving Scenario Designer in Mathworks Matlab with a traffic scenario and vehicle with an onboard camera

IV. Conclusion and outlook

The long and costly development procedure in the vehicle industry welcomes all potential technologies, which can accelerate it and reduce the costs. This moment justifies the rapid increase of the simulations' use. Simulators are computer-based tools, which can imitate reality, in these cases the real components of a new vehicle. Computer simulations require exact models representing the very fine details of the features of the analyzed component. If not just any part of a vehicle is to be analyzed and tested, but the vehicle as a whole, the simulations describe and show the behave of the vehicle in a specific circumstance. The road environment is an elementary part of these simulations. The OpenDRIVE standard is capable to describe all important road elements, like lanes, lane markings, signs, and signals, road furniture etc. OpenDRIVE models can be obtained by surveying the reality and evaluating those measurements. Thanks to this character, OpenDRIVE is implemented in more and more simulators. The bottleneck of the use of OpenDRIVE models is the fact, that it requires exact lane-based road models, where consistency is crucial and the achievement of the necessary quality demands actually quite high efforts and human interactions. There are many improvements expected in the future containing automatic model generation and/or artificial intelligence.

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