A study on the transformation of virtual validation methods in the development of new mobility solutions

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Abstract

Increasing complexity of systems-of-systems and shortened development cycles of cyber-physical systems necessitate a change from the use of virtual validation methods. Whereas simulation was formerly used more for analysis and verification, virtual validation methods are now increasingly integrated deep into the product development process. Furthermore, it is intended to use them as an alternative to real-world tests for the certification of automated systems. To validate the results of virtual validation methods, a credibility framework must be established. Credibility depends not only on the quality of correlation between models and reality, but also, on the development process used, the skills of the stakeholders, and the traceability and reliability of models, parameters and results.

Key-words:

Credibility, Virtual Validation, X-in-the-Loop, Simulation, Autonomous Driving

Introduction

This contribution analyses the change in the use of virtual validation methods and simulation in the development process of cyber-physical systems. Credibility is identified as an essential characteristic for a reliable validation environment, which does not only describe model accuracy, but depends on many factors in the process. In the analysis of validation environments, particular focus is placed on advanced driver assistance systems (ADAS) and automated driving systems (ADS).

Methodology

Based on exploratory research this effort investigates the use of virtual validation methods in the development process of cyber-physical systems from a holistic product engineering perspective. For this purpose, it is first examined how complex systems-of-systems simulations are built from submodels and how these can be modeled in the context of the XiL framework according to (Albers et al., 2013) and (Riedmaier et al.). Furthermore, it is observed how the roles of the creators and users of the simulation models change and whether new roles emerge. (Düser, 2022) Furthermore, the cycle-oriented processes coming from software development such as CI/CD will be considered and the impact on the classic product development process will be elicited. Finally, new fields of application for simulation are identified.

Results and Findings

Increasing complexity and transformation to systems-of-systems

In the past, modelling and simulations were in general built, executed and evaluated by a simulation engineer with dedicated expert knowledge. The simulation engineer therefore had a very good understanding of the accuracy of the models and what statements could be made with the entire simulation. Today, this approach is no longer feasible due to the increasing complexity of the products towards systems-of-systems and the extended use of virtual methods. This can be illustrated by highly automated vehicles. Validation of the overall function of such a vehicle can only be achieved by holistically mapping the relevant subsystems. For this purpose, the subsystems involved can either be modeled virtually or integrated physically into the validation environment. This applies not only to the systems directly integrated into the vehicle (sensors, perception algorithms, motion control, drivetrain), but also to the systems surrounding as well as all the humans interacting with the vehicle. Especially the modelling and simulation of the environment and the human are major challenges for the validation of these cyber-physical systems. Due to the multi-layered interaction between humans and cyber-physical systems, it is becoming increasingly difficult to model humans realistically. These interactions include, for example, situations during the handover between vehicle and driver,

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pedestrians in traffic, or the effects of the automated vehicle on the well-being of the occupants. According to Taylor, the realistic representation of human behavior is the greatest challenge in modelling. Both the prediction and the representation of the behavior must be modeled. (Taylor et al., 2015) According to the required fidelity level the representation of humans can for example also be recorded by motion capture and replayed. The modeling of the environment must be carried out as required according to the validation goal. For example, if sensors are to be stimulated with virtual data and the subsequent perception is to be validated, a corresponding (high) model quality of the environment is necessary. In addition to a high resolution of the objects, the physical properties must also be represented. Wallace et al. propose a metric to compare the quality of a modeled environment to reality. (Wallace et al.) Otherwise, if the strategic planning of the ADS is validated, graphically simple environment models may suffice, but with special attention to the traffic model.

Specificities and modularity of validation environments

Traditionally, the XiL validation environments are divided into MiL, SiL, PiL, HiL, DiL and ViL, among others. ASAM e.V. has made a recommendation as to which environment is particularly suitable for which validation use case. (ASAM e.V., 2022) Nowadays the validation of systems-of-systems proves to be challenging, as the complex interactions between the systems have to be considered as well. However, as can be seen in (Dona et al., 2022), realistic modeling of these interactions often requires a combination of XiL environments, which requires a combination of skills and technologies. Therefore, it could be more purposeful to structure the environments according to the required skills of the users and the technologies used. A structuring into cloud, cyber-physical test bench and proving ground would be feasible. In the cloud cluster all test environments would be usable, which are purely virtual or at least virtualizable. This applies to MiL and SiL in general and can also be extended to PiL or HiL if virtualization or emulation is possible. In general, simulation in the cloud has several advantages over local execution. First and foremost is scalability, which is a basic requirement especially when CI/CD processes are used in development. Parallelization enables a very large number of simulations to be executed in parallel as a consequence. New business models such as simulation-as-a-service are also conceivable here. In contrast, applications that use a physical and virtual component can best be validated on a cyber-physical test bench. For example, validating vehicles equipped with ADAS or AD on a chassis dynamometer with sensor stimulation is a combination of ViL, HiL and a virtual environment component. Tests on a proving ground have the least abstraction but are associated with the greatest effort. The formerly clear separation of the use cases and therefore used test environment is becoming increasingly blurred. For this reason, we recommend a reorganization according to the underlying technology and skills of the stakeholders. Restructuring the test environments would also simplify the assessment of the team experience as mentioned in (United Nations Economic Comission for Europe, 2022).

Reliable process for simulation-based safety argumentation for approval and certification

A comprehensive validation concept is required for the certification and approval of ADAS and ADS. Up to now, virtual simulation environments have primarily served to gain knowledge for the developers and, with the exception of the release of the Electronic Stability Program (ESC) according to UN ECE R140 (R140, 2017), are only permitted to a certain degree for the use in certification. The release of the currently most advanced level 3 systems (e.g. ALKS) is therefore mainly based on proving ground tests and real-world driving. With the increasing degree of automation in the future, this procedure is no longer practical. In order to keep effort and costs low in the future and still achieve the maximum possible gain in knowledge, a combination of virtual tests, cyber-physical test benches, proving ground testing and real-world driving must be used. The challenge here is to use the optimal distribution across the different validation environments throughout the advancing development process. The further development of the system in development results in changing requirements for the validation environment, which must be counteracted by parallel development. At the beginning of the development process, there are often only simple models of the system in development, which can be covered by simple validation environments. It may also be that no physical systems are yet available, which requires purely virtual validation. If, on the other hand, the development process is advanced, the proportion of physical tests can be increased in order to obtain more robust validation results. The process of joint development of the system in development and the accompanying validation system must be designed in a comprehensible manner. This includes the exact validation environment including model and tool versions, input and output data, and scenarios performed. For this purpose, a simulation data management tool must be developed that stores this data in a central location and protects it from manipulation, for example by the use of blockchain technology. (Hildebrand & Driesten, 2020) Once validation results are used for safety argumentation of a system, it must first be shown that the simulation and underlying tool chain is validated. (e.g. in (Dona & Ciuffo, 2022)) Due to the complex nature of the system-of-systems being modeled, this process is associated with a lot of effort. The IAMTS process (International Alliance for Mobility Testing and Standardization [IAMTS], 2021) or the SET Level Credible Simulation process (Heinkel & Steinkirchner, 2022) can assist with this. Liu et al. propose some metrices to evaluate the credibility. (Liu & Yang, 2005)

Extending the range of applications for virtual validation

In the past, simulation models were used analytically and for verification purposes to confirm individual development increments. Today, new processes and technologies open up new application possibilities for simulations, ranging from immersive user experience tests to scenario screenings. Each individual application places special requirements on the simulation which must be fulfilled for credible results. For example, the ever-increasing amount of program code in a vehicle makes regression testing a much needed application for simulation. Furthermore, simulations can be used to determine and identify critical scenarios and edge cases. After virtual screening of a large number of scenarios, these selected scenarios can then be re-run with high credibility on a cyber-physical test bench or proving ground. Another new use case is generating training data for machine learning algorithms. Simulation can be used to specifically represent certain conditions in the data. However, when generating the data, care must be taken to ensure that there is no bias or gaps present (Black Swan Problem (Koopman & Wagner, 2016)) in the data. Furthermore, simulations can be used in combination with VR/AR headsets to test immersive human-machine interactions.

Use of virtual validation in the development process in transition

In the domain of software development, CI/CD or DevOps processes have become established in recent years. In order to be able to use these processes also in the development of cyber-physical systems, the validation environment including models and tool chain must be run in the background. When changes are made to requirements, software or hardware, a predefined set of scenarios can be simulated and evaluated automatically. If a change is made to the system in development, this must therefore also be implemented directly in the model or digital twin in the background. The CI/CD cycle therefore does not only exist for the system under development but also for the development of the validation environment and the set of scenarios and test cases. This approach scales particularly well when using purely virtual validation environments. However, advances in emulation are increasingly making it possible to virtualize HiL or PiL configurations and thus to run them on a scaled server farm. This approach allows the developer to focus on the results and less on the simulation itself.

Personas and roles in the process

Since simulations were formerly used on a much smaller scale in the product development process, it was possible for individual simulation engineers to build the models, run simulations and evaluate the results. This individual expert then had a deep understanding of the problem to be modeled and was therefore able to state very accurately in which areas the simulation had what validity. Today, the problem to be modeled is usually cross-domain and therefore much too complex for a single expert. Submodels of complex systems are therefore built and independently validated by different experts specialized in their respective domains. Still other developers assemble the individual submodels into an overall model and ensure that the interfaces of the models are accurately modeled. If the simulations are to be executed in the cloud, further specialists are required to ensure correct distribution to the nodes of the computing cluster. Creator (simulation engineer), user (validation engineer) and operator (IT administrator or test field operator) are therefore different groups of people, which requires very good coordination among them. Every single person only knows the unique properties or the Operational Design Domain (ODD) of his or her own segment. Nevertheless, they must be able to make clear to each other which requirements apply to the neighboring subsystems. In the end, it must be provable for the emergent overall model, including the implementation in the tool chain, what the simulation is capable of. This is a major challenge for the use of the model for certification.

Result Management

Especially in combination with the before mentioned CI/CD process, a huge number of simulation results are generated in a short period of time. In contrast to the past, it is no longer possible to manually check the large number of results for errors and plausibility. At this point, an automatism is needed that statistically evaluates the results, for example by cascading KPIs, and recognizes critical results. In addition, the results must be managed in a database together with the exact toolchain used. For example, previous results can be checked retroactively in case of model changes.

Conclusion

Product development cycles are becoming increasingly shorter and processes such as CI/CD from software development are also finding their way into the development of cyber-physical systems. This leads to the fact that virtual validation is integrated more and more deeply into the product development process. For this reason, it is essential that a framework is introduced that ensures consistent credibility throughout the entire process. This credibility framework therefore describes not only the correlation of models to reality, but many other factors that must be considered for a trustworthy validation result.

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