

DATABASE APPROACH FOR THE SIGN-OFF PROCESS OF HIGHLY AUTOMATED VEHICLES

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ABSTRACT

Objective

While the technical proof of concept for automated driving was shown in various projects, the existing methods and tools for the sign-off process are not suitable for the complexity of these systems and would be inefficient with regard to costs and time resources. Thus, the project PEGASUS aims to develop an effective and generally accepted procedure for the definition of design and quality criteria for highly automated vehicles. This paper focuses on a method to reduce the testing efforts for the sign-off process.

Methods

One element of the developed procedure is a database containing relevant traffic scenarios for the testing of highly automated vehicles. It is embedded in a circuit of recording and integrating scenarios from real-world traffic on the one hand and extracting and providing them to different suitable test environments on the other hand. This so-called circuit of relevant situations was already outlined in the 23rd ESV conference (Eckstein and Zlocki 2013), further elaborated in the meanwhile and is currently under development within PEGASUS.

Results

The process of recording and integrating relevant scenarios from real world measurements into the database has been implemented. Data from different sources (such as field operational test, accident databases etc.) were formatted into a standardized format to apply a common processing chain. This processing chain includes the calculation of derived signals and scenario likelihoods. Based on these steps it is possible to identify and cluster specific scenarios within bigger data sets. Afterwards, performance indicators can be calculated for characterization of scenario groups which enables to build distributions of scenario parameters (e.g. the criticality) and to derive test specifications for the database.

Conclusion

The dominating challenge for the implementation of automated driving is not the technical proof of concept, but the validation of these systems. Therefore, the PEGASUS project results will make a significant contribution implementation of this new technology due to the involvement of various OEMs in the project consortium and the foundation by the Federal Ministry for Economic Affairs and Energy. This paper describes the methodology and first implementation results for the database and the process chain from data collection, data storage to scenario parameterization and test specification derivation.

KEYWORDS

Database, traffic scenarios, highly automated vehicles, validation, testing methods

INTRODUCTION

Introducing driver assistance systems into the market is not a new challenge for the automotive industry. But since the automation levels for new systems under development increase, these have to deal with more and more complex scenarios within their specifications. Especially, for systems of automation level 3 and higher, according to the definition of the Society of Automotive Engineers (SAE Standard 2014), new challenges arise since the driver does not have to monitor the system and the driving environment anymore. Thus, the system has to be capable of solving even highly critical scenarios on its own due to the fact that these scenarios require solving strategies and actions within time frames that are outside the scope of the acceptable transition time between the automation levels, especially from the system to the driver (Petermann-Stock et al. 2015).

According to Eckstein and Zlocki (2014) the research questions that need to be solved to realize automated driving can be clustered to five aspects: Technical aspects, human factor aspects, legal aspects, economic aspects and societal aspects. The technical solutions for these challenges have been investigated in various projects (Fahrenkrog, Rösener and Zlocki 2016, Kotte 2016, Zlocki 2012, Hoeger, Zeng and Hoess 2011) and become more and more mature so that related products can be expected to be ready for market within a short time frame (Dokic, Müller and Meyer 2015, Ertrac 2015, Rupp and King 2010, VDA 2015). Also the human factor aspects are currently under research and the related challenges can be addressed by suitable design of the HMI to avoid phenomena like mode confusion. The legal framework which previously put systems that were not continuously supervised by the driver in conflict with existing law (UN 1969) has undergone an adaptation of the related paragraphs of the Vienna Convention enabling automated driving systems as long as they can be switched off by the driver (UNECE 2014).

The current achievements in paving the way for automated driving leave the societal aspects and the transformation of all five previously discussed aspects into technical standards as the remaining challenges. Both aspects are addressed in the

German research project PEGASUS (project for the establishment of generally accepted quality criteria, tools and methods as well as scenarios and situations for the release of highly-automated driving functions) striving to develop a commonly accepted methodology for the sign-off process of highly automated vehicles (Plättner 2016, Mazzega et al. 2016). The main research questions of the project are on the expected level of performance of an automated vehicle and how the verification that the desired performance is achieved consistently can be realized. In the following, this paper focuses on the discussion of the complexity of the verification in the first step and shows an elaborated solution in the second step.

METHODS

In the past, safety approval for driver assistance systems has mostly been achieved by driving a high amount of test kilometers to proof the maturity of the system. Statistical assumptions on the necessary test mileage for automated driving result in 240 million kilometers or even more (Winner 2016, Wachenfeld et al. 2015) depending on the reference for the safety approval (average mileage between accidents with injuries or fatal accidents etc.). In addition, functional changes would require a repetition of the hole testing procedure leading to enormous costs for the sign-off process. Thus, it is necessary to develop new approaches and methods for the validation of automated driving.

Besides real world testing there are different testing methods that are commonly used in the vehicle development. Figure 1 shows these methods and their related validity and cost levels. Starting with virtual testing methods (such as traffic simulations or dynamic driving simulators) the validity of the gathered results increase as well as the costs coming to real world testing - such as controlled test field and field tests. All of these test methods show their specific advantages at different stages in the development process and should therefore be combined to a holistic test approach as described in Eckstein and Zlocki 2013 and Zlocki, Fahrenkrog and Eckstein 2014. The basic idea of the so-called circle of relevant situations is to use a database a central element in

the associated V-model process to store relevant scenarios for automated driving systems which are recorded during real world driving (see Figure 2).

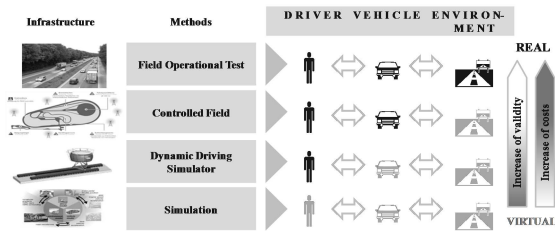


Figure 1: Test methods used for vehicle development and their level of validity and costs (Eckstein and Zlocki 2013)

The database of relevant traffic scenarios is fed by data from field operational tests, real-world traffic and accident databases (see R1 to R3 in Figure 2). Based on suitable criteria evaluating the criticality of the scenario and therefore the relevance to be considered for testing of automated vehicles these scenarios are integrated into the database by using a common scenario description format. The recorded scenarios do not require involving the use of an automated driving system, but are rather scenarios that occur in everyday driving and that an automated driving system has to be capable of solving when in operation. An additional data source (R4) may be data from driving simulator studies which can give insights on automation specific phenomena like automation risks (e.g. mode confusion). Due to new relevant scenarios caused by automation risks and the effects of increasing penetration rates of automated vehicles, it is necessary to keep the database constantly updated.

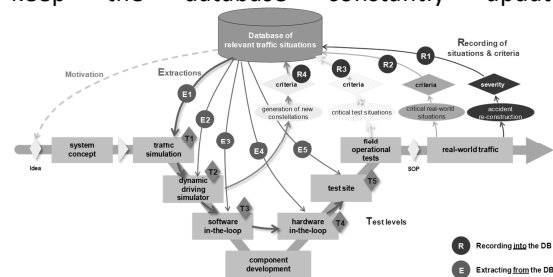


Figure 2: Circle of relevant situations (Themann et al. 2016)

One of the main benefits of the described approach is the extraction of relevant scenarios to the most suitable testing environments and at different stage in the development and validation process (E1 to E5). In a first step, all scenarios that are within the functional scope can be tested in traffic simulations showing that the system under test may be capable to handle the majority of the scenarios, e.g. by reacting faster than a human driver. Some scenarios however will require considering the interaction with the human driver to be able to evaluate the appropriateness of the system decision, e.g. transitions of the vehicle control from automation to the driver. Here, a driving simulator offers the best compromise between validity of results and spent efforts. But like for the traffic simulation some of the scenarios tested in the driving simulator will remain to be further investigated since vehicle dynamics are of importance. Hence, it is necessary to be able to extract scenarios also to controlled test fields reproducing these scenarios with driving robots, e.g. for surrounding traffic participants. If at this stage the “unresolved” scenarios are (close to) zero, the system under test can undergo a field operational test closing the circle of relevant scenarios by generating new data for the database.

By means of the described approach a shift of testing effort from real-world towards virtual testing methods is strived to increase the effectiveness of the used test methods for the validation of automated driving. In the PEGASUS project a similar approach is elaborated developing a framework for the sign-off process of highly automated vehicles (Plättner 2016). In the following, the concept and implementation of the database of relevant scenarios is presented by showing the data processing chain from recorded measurement data to test specifications for automated driving systems.

RESULTS

The database as it is implemented in PEGASUS contains different elements and interfaces. To give an overview on the different database modules and their content, the complete chain from input data over data processing to output data is described.

Input for the database

The diversity of the input data for the database requires the input interface to be able to deal with very different types of data. Input sources for the database are data from accident databases, field tests, field operational tests (FOT), naturalistic driving studies (NDS), controlled test fields, driving simulator, traffic simulation and expert knowledge. A first distinguishing characteristic is the level of detail. While database scenarios originated from traffic simulations can describe traffic scenarios in very much detail, scenarios generated by expert knowledge or accident databases might only be a rudimentary description of vehicle environment and the behavior of the surrounding traffic participants. The input interface enables therefore a scenario description as comprehensive as possible. Degradations from this best-case description determine for which use cases of the database the related data can be used. Besides the level of detail the data volume is another aspect to be considered: Data from accident databases are highly focused on the accident itself and a short period of time before and during the accident. Hence, the data volume is easily manageable. Data from field tests or naturalistic driving studies commonly have a high volume due to various sensor set-ups (image processing, Lidar scans, etc.) and no focus on a specific scenario. For this type of data it is necessary to process this high amount by automatic scenario filtering algorithms to identify the relevant scenarios.

Data processing chain

The database for the validation of automated driving is not intended to be a collection of recorded scenarios, but to provide test specifications which can be used in the sign-off process. Hence, it is necessary to transform the input data into scenarios that can be reproduced and tested with an automated driving system in the discussed test environments. To that end, the processing chain depicted in Figure 3 was developed and implemented.

In the first step ①, all data entering the data processing chain has to be formatted into a common environment and traffic description. This is provided by the data owner since it requires

individual converting of the raw data into harmonized signal names, data structure and coordinate systems. The first step within the data processing chain ② is to index the data and check them on format compliance. In addition, user rights for each uploaded data sets are assigned to create individual data sharing options.

After the two organizational steps (which still can be associated with the input interface), the substantial processing of the data is started by the generation of deduced signals ③ which are not found within the measurement data. Here, the common data processing chain shows a major benefit. Due to the fact that the algorithms for the processing chain are developed together by all consortium partners they provide a collective understanding of the data and enable a consistent evaluation basis. This is also of high importance for the next step ④ in which likelihoods of scenario affiliations are calculated. Common algorithms serve as the basis for a generally accepted understanding and agreement of what the relevant scenarios are and which parameters define their characteristics. As a result of this step time continuous scenario likelihoods are added to each data set. Based on the scenario likelihoods snippets with relevant scenarios can be extracted from bigger datasets in the next step ⑤. This step is not only applied to data from bigger datasets like FOT, NDS or field data. Also for other data sources like accident data or driving simulator which might already provided scenario snippets as raw data the calculation of scenario affiliation and the extraction of scenario snippets proves useful to ensure a uniform scenario evaluation and formatting. The calculation of performance indicators for each scenario helps to characterize the scenarios in a very compact manner.

As a result of the first five steps scenarios with relevance for automated driving are identified. In step ⑥ these scenarios are clustered to so-called logical scenarios (Baggschik et al. 2017). By assigning the extracted scenario snippets to logical scenarios their distributions for the scenario parameters are created and enhanced. The results are stored in a database entity combining the logical scenarios and the related parameter space. In the last step ⑦ the test specifications can be derived based on a selection

metric and are stored into the test specification database. By doing so, two tasks are fulfilled: Adding information on exposure (E), severity (S) and controllability (C) by the human driver as reference and selecting scenarios and parameter combinations for the test specifications. Here, the use case definition ④ has to be considered to match test scenarios and functional scope. All information is stored in the test specification database entity.

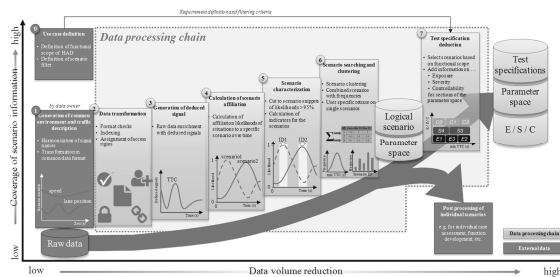


Figure 3: Concept of the data processing chain (Pütz, Zlocki and Eckstein 2017)

As it can be seen by the axes labels in Figure 3 the input data is reduced in their data volume by the processing chain. Raw input data normally contains a high amount of information. Even though there are also signals (e.g. Time-to-Collision) and information added to the inertial data sets, especially the later steps in the processing chain (⑤ to ⑦) condense and summarize the information contained in the (measured) scenarios relevant for automated driving. At the same time, the clustering to logical scenarios increases their information density. A single scenario snippet describes only a minimal subset of the related logical scenario. Thus, the logical scenario gives a better overview on the possible characteristics of the scenario type.

Output of the database

The main output of the data processing chain are the test specifications that are stored into the test specification database serving as a test catalogue for the sign-off process of automated driving systems. These test specifications are described in the OpenScenario format (Dupuis 2015), which can be used as a basis for the interfaces to the testing tools. While most traffic simulations tools will be able to directly use the OpenScenario as

input, for other test environments like controlled test fields conversions will be required for the scenario reproduction with robot vehicles.

An additional output option of the processing chain is the possibility to extract relevant scenarios for a individual case assessment or the system development. This might for example be useful to test a new developed system in highly critical scenarios or in scenarios with specific characteristics which are challenging for the chosen sensor set up. For both types of output it is important to transfer recorded data into a testable scenario description in which the system under test has the degree of freedom to change the outcome of the scenario. To that end, it is for example necessary to transform relative distances between traffic participants and the recording vehicle (assuming e.g. data from FOT or NDS) into absolute trajectories of the surrounding traffic.

DISCUSSION

The sign-off process of highly automated vehicles strongly depends on the verification of completeness. Hence, it is also necessary for the database approach to provide methods and algorithms showing that the functional scope is covered by the test specifications and that all relevant scenarios are considered. Even though this requires some efforts for the implementation, it is more reasonable to embed this verification of completeness in an effective concept than trying to proof it by the sheer size of the driven test mileage.

Despite the previously mentioned aspects, the described approach of making re-use of existing data shows two key benefits for the sign-off process of automated driving systems. First of all, the high efforts different stakeholders currently invest into individual validation processes are brought together by the project PEGASUS and merged to a more sustainable approach. Instead of generating new (expensive) data sets for every new system, existing data is used to reduce the necessary test mileage. The second major benefit is the fact that the data as well as the evaluation criteria are developed and used by all stakeholders providing a common evaluation basis. This is not only important for reducing test

resources, but to increase the societal trust and acceptance of automated driving.

CONCLUSION

The introduction of highly automated vehicles imposes the challenge of verifying the safety of these systems for the sign-off process. Traditional methods know from ADAS would cause enormous testing efforts leading to the necessity of new approaches for the sign-off process. With the circle of relevant scenarios an approach is established that is able to reduce these efforts by effectively combining existing testing methods. As one central element of this approach a database of relevant scenarios was implemented in the project PEGASUS. Describing input and output interface as well as the data processing chain for transforming data from different input sources into test specifications, two main benefits of this database approach could be elaborated. The reduction of testing efforts by a common usage of existing data and the harmonization of the data basis and evaluation criteria for the sign-off process providing a solid foundation for a sustainable and generally accepted system validation.

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