Automated Driving – How cloud infrastructure plays a vital role in future of validation for Automated Driving?

Large-scale data driven scenario-based validation on cloud

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Abstract
Development of Advanced Driver Assistance Systems (ADAS) and Automated Driving (AD) is safety critical. Ensuring that the ADAS/AD applications are safe requires rigorous testing for millions of kilometres [1] under varying environment and traffic conditions. Executing this testing of millions of kilometres physically (on road) will be extremely time consuming and expensive. Thus, ADAS/AD applications must be tested virtually, and scenario based virtual validation methods including Software in Loop (SIL) or Hardware in Loop (HIL) become the need of the hour. Traditional methods of in-premise SIL/HIL testing are extremely slow and expensive. With advances in Cloud Technologies like cost effective Graphic Processing Units (GPUs), Containerization, Global access to data; the traditional SIL/HIL testing can be migrated within the cloud environment. This offers scale to run millions of scenarios in a cost and time efficient manner.

This paper aims to explain how a combination of carefully designed database of traffic scenarios, cloud infrastructure, high performance simulators and automotive KPIs can help run millions of kilometres of virtual simulation for validation of ADAS/AD applications.

Proposed concept is designed and evaluated in commercial cloud provider for more than 10000 scenarios leading to millions of executions.

Introduction
Data driven scenario-based validation is critical to ensure the safety of the vehicle on road. The high-level activities required for validation of AD/ADAS functions are:

- Creation of scenarios based on regulatory standards and safety standards
- Executing the scenarios on scale to assure required coverage for homologation
Analysis of test results against defined KPIs (Key Performance Indicators) to validate AD/ADAS function performance in terms of maturity to perform against real traffic scenarios.

To perform above activities in scale and to achieve required performance, Cloud computing will play a vital role, along with cost saving and speed of execution benefits.

**Implementation Strategy**

To perform scenario based virtual validation of ADAS/AD applications in the cloud environment the following steps are required:

1. **Step 1**: Creation of Scenarios based on real road accidents/situations and standards prescribed by agencies like National Highway Traffic Safety Administration USA (NHTSA) [2], Functional Safety Standards ISO 26262 and New Car Assessment Program (NCAP)

2. **Step 2**: Upload these scenarios to database in Cloud infrastructure

3. **Step 3**: Create a scheduling, orchestration, and monitoring logic in Cloud infrastructure for effective execution of millions of scenarios in a containerized simulation environment

4. **Step 4**: Automate the test executions which is derived from the scenarios. The test runs are in thousands against one scenario. This adds up to millions of test runs

5. **Step 5**: Validate the System under test (SUT) against defined Key Performance Indicators (KPIs) for AD/ADAS functions

6. **Step 6**: Create reports as per defined format and provide analytical results on failed cases

Few key steps described above have been elaborated in this section:

1. **Extensive Scenario creation**

   As a first step, with extensive research and domain experience scenario database is created. The three data sources of scenarios mentioned below are used as an input to a ‘Validation Strategy’ [1] to help generate scenarios.
The Validation Strategy ensures that multiple facets of scenarios assuring coverage. That includes Operation Design Domain (ODD), Regional Regulations (NHTSA, NCAP, ISO), substantial number of parameters e.g., speed road type, object type etc.

i. Critical and Corner scenarios:
Various ADAS/AD use cases (Features/Functions) like Lane Change, Lane Merge, follow etc., are analysed to generate an extensive ODD (Operational Driving Domain) document. The ODD provides information about where, how and in what conditions these ADAS/AD uses case can operate. This ODD document also considers regional regulations in the countries or regions it will operate in e.g., US, EU, Universal etc. This analysis becomes the first data source for the Validation Strategy to create Critical and Corner scenario like sudden Cut-in of traffic, harsh weather, traffic occlusion detection etc.

ii. Safety, Security and Safety of The Intended Function (SOTIF) scenarios:
A detailed safety analysis of the entire AD/ADAS system is done e.g., Hazard Analysis Risk Analysis (HARA), Failure Mode Effects analysis (FMEA), ASIL level requirements etc to identify the Faults and Hazards that can happen to the system. This analysis is provided as an input to the Validation Strategy to ensure that the scenarios generated are safe and robust.

With the help of this data input to the Validation Strategy one can generate many scenarios with multiple combinations. It also allows to consider multiple parameters for a particular scenario such as parallel parking, perpendicular parking, sudden change in speed, size of parking space, other objects, time of day etc.

iii. Scenarios from real road data:
Real road data that are captured by host vehicles are mined and analysed to identify critical events such as absence of braking in Automatic Emergency Braking (AEB) feature when the braking was initiated, braking but did not happen at the right time or braking failed while a vehicle in front for Cut-in scenario or forward collision warning did not issue a warning. Vehicle data for such events is used to create a virtual scenario and this scenario can is used to test the algorithms to understand faults. Once the fault in the algorithm is identified and fixed it can again be tested in the same scenario to ensure that braking happens correctly since the real-world environment is already replicated in the simulation environment.
In addition to vehicle data, analysis of accident data from NHTSA, German in Depth Accident Study (GIDAS), Road Accident Sampling Study-India (RASSI) is also utilised to create scenarios.

Scenarios generated from the above sources help create a large quantum of database of ready scenarios that comply with ODDs (Operational Design Domains), standards (NCAP, ISO, NHTSA etc) and can help expedite validation of ADAS/AD features and functions. This huge database of scenarios will be uploaded to Cloud to run simulations on large scale.

2. Cloud infrastructure
An architecture to run millions of scenarios on cloud comprises of:

- **Database platform** consisting of database of scenarios, KPIs and analytical results of scenario run
- **Simulation platform** consisting of containerized Automotive Virtual Simulator integrated with AD/ADAS functions
- **Orchestration framework**: which contains Task manager and Scheduler.
  - Task manager is a single unit of process which manages the life cycle of the scenario deployment, executions, and post processing (collection and generating the KPIs)
  - Scheduler will initiate the execution of the selected scenarios as per the defined criteria
- **Containerization framework**: This is the heart of the architecture to assure the benefits of containerization. Scenarios run in Virtual Simulators inside docker containers. Task manager will initiate a request to create containers. Once these are created and configured in cloud, the necessary automated polling and agent services completes the responsibility of scenario execution in each container. Due to containerization in Cloud thousands of scenarios can run in parallel. Note: Virtual Machines can also be used instead of containers
- **Monitoring framework**: The executions are monitored continuously on real time by APM (Application Performance monitoring) which are also in distributed manner. Monitoring framework also helps in:
  - Checking simulation run times
  - Monitoring costs
  - Destroying container/VMs if required
• **Analysis framework:** Post scenario execution, the data generated are in terabytes and these scenario data are captured, processed, and stored in a structured database in Cloud. The following are key activities in this framework:
  
o. Transforming captured scenarios into a structured database
  
o. Data Maintenance and Asset creation (videos, graphs, stats)
  
o. Data filtering at point of collection. Large amount of data will require filter function quickly pull up relevant data
  
o. Creating meta data (Data Catalogue) for each set of data which allows for efficient search e.g., finding of a Scenario where it is raining heavily on a crowded street at night
  
o. Post processing and generating KPIs (e.g., Lateral, Longitudinal, Safety, manoeuvre). The method of defining KPIs and analysis of KPIs is mentioned in next section

Complete framework runs in the distributed computing mode, which is coordinating with each other to make sure that integrity and durability is maintained.

3. Analysis and Reporting

For any system to be validated, there needs to be a defined performance indicator [Figure 2] to be validated against. These indicators let developer know how the AD/ADAS functions are performed and needs to be extensively defined, automated for a large-scale validation.

KPIs (Key Performance Indicators) are defined [Figure 2] using AD/ADAS feature requirement document and industry standards (like ISO 26262). [Table 1] shows an example of KPI definition for an AD/ADAS function and its threshold.

KPIs developed are stored in Data Platform on Cloud and executed against every scenario run in Cloud using the Analysis framework. [Figure 3] shows as example plot of an output generated from a scenario run where a performance of the function is beyond defined threshold and KPI will be deemed failed. These failed KPIs can be run again after updating required AD/ADAS functions.

**Conclusion**

Using well architected Cloud based infrastructure it is now possible to achieve large scale scenario-based validation for AD/ADAS in highly cost and time efficient manner. Scenario runs
can be visualized, analysed and re-run multiple times. In this manner, thousands of kilometres of simulations and millions of scenario runs can be easily achieved.

For example, to execute 1 scenario of Traffic Jam Assist (TJA) on a local machine (computer) it takes 72 seconds which is 1000 runs in a day, thus, to execute 1 million scenarios one would need 1000 days, which is a cycle of a complete SOP (Start of Production) program.

Alternatively, if we execute the same using cloud infrastructure defined above with 50 GPU (Graphics Processing Unit) based instances then 1 million scenarios can be executed in less than 20 days.
Figures and tables

Fig. 1: Data Driven validation in cloud involves above high-level components

Fig. 2: Workflow of KPI definition and Scripting
Fig. 3: Plots for Lateral offset, Steering wheel angle and Lateral Acceleration.
Table 1: Sample KPI with Threshold for AD/ADAS function

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<th>KPI Name</th>
<th>Threshold</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Longitudinal Acceleration (moving average over 2 second)</td>
<td></td>
<td>ISO 22178</td>
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<tr>
<td>Longitudinal Deceleration (moving average over 2 second)</td>
<td></td>
<td>ISO 22178</td>
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<tr>
<td>Brake Jerk (moving average over 1 second)</td>
<td></td>
<td>ISO 22178</td>
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References

