Validation of Advanced Driving Assistance Systems

Authors: Gérard Yahiaoui [NEXYAD], Nicolas DU LAC [INTEMPORA],

Contributors: Laurent RAFAELLI [ALL4TEC], Roman KATZ [Ibeo Automotive Systems GmbH], Philippe DE SOUZA [CIVITEC]

Table of contents

INTRODUCTION

Advanced Driving Assistance Systems (ADAS) will soon be a rule in the automotive domain:

- Drivers are now used to advanced interaction with computers, smartphones and tablets. They more and more expect to get the same evolutions in the interactive services provided by their cars.
- The EURO NCAP organization rates the vehicles from 0 to 5 stars depending on the safety level they offer. From now, no vehicle will be granted 5 stars without ADAS such as pedestrian detection.
- Technologies (such as shape recognition software, cameras, laserscanners, radars and ultrasonic sensors) become more and more robust, integrated and affordable.

Car manufacturers have worked since the 90s on research programs aimed at automating some driving functions and/or relieving the driver in repetitive, tedious, or dangerous tasks (automated parking or cruise control). But these functions are subject to the following issues:

- Difficulty to monetize ADAS services: the driver finds it "normal and common" to be equipped with ADAS innovations and he is not willing to pay more for such functions when purchasing his vehicle. He already uses such advanced features such as voice recognition and other technologies on his smartphone so he expects the same kind of applications in his vehicle.
- Cost and dimensions for the equipment were not compatible with the automotive domain (for which advanced technology is on the market for 4 €/kg!)
- Computation and storage resources were not good enough so far to support complex applications in embedded systems.
- The responsibility is transferred from the driver to the car manufacturer in case of accidents when the vehicle operates in automated mode.

This last point implicitly raises the issue of the comprehensive validation of ADAS: in terms of performance, robustness, and downgraded operation mode when sensors might fail.

Regulation and norms on the one hand, technological progress on the other hand, have (or are about to) overcome the three first issues. The topic of ADAS validation from a legal point of view remains.

It seems pretty obvious that this point is crucial for car makers when they engage their legal responsibility, but also the image of their brand, in case of malfunction.

The ADAS Group from the MOV'EO cluster has developed an original approach providing altogether methodology, software and hardware technologies in order to provide car makers and suppliers efficient tools for the ADAS validation process.

This approach particularly allows to:

- Drastically reduce the number of kilometers to drive for testing purposes and so the costs and duration of the test procedures for ADAS validation
- Maintain and even increase the coverage of tested situations in order to obtain faster a more reliable validation
- Automate the tests executions

WORKFLOW AND PROPOSED TOOLING

The proposed workflow is as follows:

1. Definition and generation of relevant test cases (**AGENDA** methodology and **MATELO** tool)
2. Simulation of test cases (**ProSIVIC** tool) & Real sensors data recordings (**RTMaps** tool)
3. Generation of reference labeled objects and maps of lane markings, with event detection and scene analysis functionalities (**Ibeo's Evaluation Suite**)
4. Integration of software functions for perception and decision making (**RTMaps** tool + technologies to be validated)
5. Automated execution of test cases and reports generation (**I-DEEP** tool)

These tools are mostly being integrated in the frame of the COVADEC project (FUI 15) – (Conception et Validation des Systèmes Embarqués d'Aide à la Conduite). http://www.covadec.org and [Raf14]

Let's go more in details in each of these steps:

Definition and generation of relevant test cases

The AGENDA methodology

For illustration purposes, let's consider a driving assistance system making use of a HD (2 million pixels) color camera (8 bits per channel – 24 bits per pixel).

The number of images such a data matrix can create overpasses $I = 65\ 000^{2\ 000\ 000}$ [Yah14]

Among these images can be found your wedding picture, pictures of your last summer holiday, road pictures, etc. The number of possible inputs (in the sense of information theory [Shan xx]) is not infinite, but a very large number which also corresponds to a wide variety of scenes.

Therefore, it becomes obvious that it is impossible to randomly sample correctly the variance of such inputs. This would require to randomly take a very large number of images compared to I.

Also, we can consider that studying 1 000 000 km during normal driving situations does not allow to validate an image processing system. Indeed, at 100 km/h, this would correspond to 900 million images which remains very low compared to I.

It is therefore necessary to shift the problem into another space: an image description space, and particularly a road scenes and driving situations description space. In the end, the objective is to specify a driving situations database which can be considered "representative" of the usage of a vehicle during its lifecycle.

For this, we propose to use a methodology published in the 90s which objective was, among other things, to specify the learning databases and test cases of artificial neural networks: the AGENDA methodology [Yah92].

This methodology proposes to describe a processing system from its "variants" and "invariants" (example: variant by / sensitive to distance – for an obstacle detection system, invariant against global luminance, etc.)

We call "descriptive elements" the variability factors of road scenes, and qualifiers "varying by", "invariant by", the functional specification of the processing system.

In a V-cycle process, this specification is situated in the top-left area, and faces the validation in the top-right area: we can figure out that the setting-up of the validation database consists in sampling the variability factors of the scenes.

For this we propose to make use of orthogonal test plans.

NB: for 10 variability factors only (which is very low), if we consider they concern quantitative variables (road width, distance to obstacle, global luminosity level), and if we sample on three levels (low, medium, high) in order to maintain non-linear effects [tagxx], we figure out that this leads to 3^{10} combinations of variability factors for life situations. It is possible to reduce this number using the fractional orthogonal experience plans [Tag98].

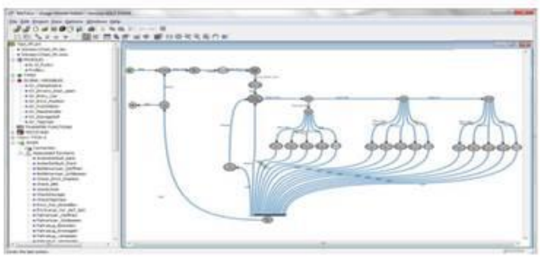
Note that this specification can be used with the aim of setting up the validation database with 3 techniques:

- Physically realize the tests corresponding to each factors combination (which is sometimes possible, sometimes not)
- Filter an existing road situation database taken on the fly in order to extract from there the said combinations (this assumes that algorithms and classification tools for driving situations are available)
- Numerically simulate the extracted combinations

Tooling

MATELO

MaTeLo (Markov Test Logic) is an MBT (Model Based Testing) tool, which makes it possible to build a model of the expected behavior of the system under test (SUT) and then to generate, from this model, a set of test cases suitable for particular needs (for instance, testing only the most frequently used functions of the system, or having 100% coverage of system requirements). MaTeLo is based on Markov chains. For non-deterministic generation of test cases, MaTeLo uses the Monte Carlo methods, associated with generation strategies adapted to user needs. Thanks to test acceleration techniques, MaTeLo also makes it possible to obtain a maximal coverage of system validation by using a minimum number of test cases. As a consequence, the number of kilometers to drive needed to validate an ADAS is reduced.



Simulation of test cases & In-car sensors data recordings

The proposal here is a joint approach making use in a complementary manner of simulation tools and of real sensors data taken from real equipped vehicles.

Simulation allows to:

- Automatically generate scenarios and simulations.

- Fine tuning of driving conditions (events, actors positions and speeds, climatic conditions, lighting…)
- Dangerous situations testing

Timestamped real sensors data recording and their use in playback mode allows to test each function to be validated against real situations in real environments and using the real sensors outputs with their defaults and latencies which simulation, as efficient as it may be, cannot replace.

Tooling

ProSIVIC

ProSIVIC is a simulation software environment specialized in the advanced rendering of ADAS sensors (cameras, lidars, radars, GPS, communication systems…). It offers complex sensor models as well as environments taking into account numerous physical and electronic characteristics (for a camera for instance, the point is to model distortion, noise, atmospheric and climatic conditions, lighting conditions…)

ProSIVIC also allows to integrate vehicle dynamics models, setup complex driving situations in complete environments, objects animation (such as pedestrians for example).

ProSIVIC can operate in real time or virtual time which allows addressing tests and validation use cases of ADAS functions with or without human in the loop.

High-performance data logging

The ADAS group can offer in-car recording solutions for multiple and heterogeneous ADAS sensors. Such recor

ders are scalable as they are based on the RTMaps software. These solutions allow real-time acquisition and accurate timestamping of each and every ADAS sensor sample (mono and stereovision cameras, lidars, radars, GPS, IMUs, CAN/LIN bus, XCP, analog and digital I/Os, audio, communication packets, eye trackers, biometrics sensors, motion capture sensors, etc.)

Available configurations are diverse and can be setup depending on the needs, in terms of number of sensors and I/Os, of bandwidth, of recordings duration…) and depending on constraints (power consumption, dimensions, installation procedure, cost)…

Recorded data are store in open and documented file formats, properly timestamped, and can then be used a posteriori in playback mode for offline validation of ADAS functions.

Real-time tagging functions allow to identifying particular situations and events from the driving session (voice tagging, automatic tagging based on measured signals, manual tagging with tactile interfaces).

Ground truth extraction & Semantic analysis of the scenarios

The capability to assess the performance and robustness of some perception or decision making function requires the availability of “reference information” (also called “Ground truth”): ego vehicle position and orientation, position orientation and speed of the various objects in the environment, geometry and various attributes of the environments such as road markings and traffic signs.

This information can be easily retrieved when working in a simulated environment as the simulator “knows” and can provide every piece of required information with a perfect accuracy and at each simulation step in parallel with data streams provided by virtual sensor models.

This becomes more complex when it comes to extracting the ground truth and providing semantic analysis of the situation from real sensors data as recorded on a vehicle equipped with ADAS sensors. Usual methods are based on manual or partially assisted labeling: operators are then in charge of processing each frame (most often video frames) one by one in order to crop each and every potential obstacle and object which future perception systems will have to detect and handle.

The cost and the duration for proceeding with such approach is a major issue considering the exponential amount of driving data to be tested in the context of ADAS validation.

Tooling

Ibeo's Evaluation Suite

The ibeo Evaluation Suite is a modular software to support the development process of automotive sensor and ADAS systems which provides object labeling tool in an automatic manner [Ibe15]. Evaluation Suite can be easily integrated in existing toolchains to assist in the development in the areas of DuT Evaluation, application testing and generation of reference data for training ADAS algorithms.

The functionalities currently available for Evaluation Suite include (i) automatic generation of labeled objects, (ii) post-processing of large test-drives, and (iii) generation of map of lane markings:

i. The automatic generation of labeled objects is based on cutting edge object detection and Forward-Backward Tracking (FBT) algorithms and Best Situation Classification (BSC) techniques for full and precise inference of objects' size based data provided by Ibeo's Reference Systems with multiple horizontal laserscanners.
ii. Post-processing of large test-drives is achieved through database processing, using offline optimization for automatic object labeling and full classification from the first moment of detection.
iii. Map of Lane Markings: through automatic road marking detection and mapping with rear scanner system, using scan-based processing of scan data provided by a down-looking laserscanner. Post-processed objects with lane marking maps can be combined with reference objects to provide a complete reference scenario that includes road users and the road information itself.

The following example below illustrates the application of Evaluation Suite for generating reference scenarios.

The top image shows the online results, which are improved in the offline stage using Evaluation Suite. The bottom image shows that all the labeled objects have the correct classification results, and their bounding boxes are consistent with the correct underlying class. Moreover, a map of lane markings has been built, and the labeled objects are now provided in combination with this map as the final output.

Integration of software functions to be validated

When it comes to validating a function (FUT – Function Under Test, or DUT – Device Under Test in an HIL bench), would it be a vision algorithm, a signal processing function, a data fusion module and would its purpose be for detection and classification, positioning, decision making… it then has to be integrated in an open an modular environment in order to be submitted to numerous test procedures, while still maintaining the capability of easily integrating it in a real vehicle prototype for real-time operation in real life (for demonstrators or real system testing).

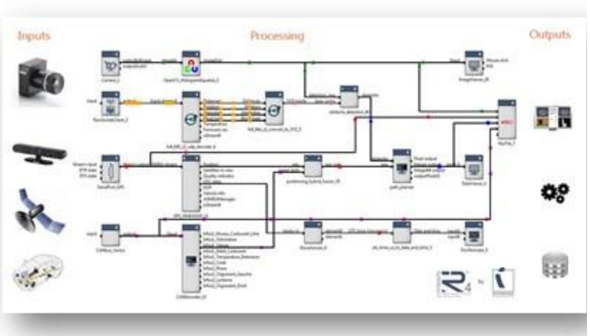
Tooling

RTMaps

RTMaps is a modular (component-based) software framework for rapid development and optimized execution of real-time applications having to manage, process and fuse numerous high-bandwidth, asynchronous and heterogeneous, sensors data streams such as cameras, lidars, radars, CAN bus, GPS, IMUs, V2V and V2I communications, etc.)

RTMaps also offers data recording of any kind of ADAS sensors, then synchronized playback, in real-time or virtual time, in order to allow offline developments for perception, data fusion, communications, decision making and command-control (developments, tests, validation and benchmarking).

RTMaps can also be connected to simulation and/or command control tools such as ProSIVIC and Matlab/Simulink. It can be ported to number of computing targets in order to integrate inside comprehensive development process, from upstream R&D down to industrialization and allowing simple porting from the offline environments (MIL, SIL) to the real systems (HIL and prototype vehicles).



Automated tests execution and reports generation

At this stage, we addressed the following functions:

- Constitution of test scenarios (as simulation scenarios or recorded data sets)
- Associated ground truth and situations (semantic analysis) retrieval
- Integration of functions under test in the software suite

It is now necessary to be able to execute the numerous test cases dedicated to validation (or invalidation) of the correct operation of such functions under all situations.

The automation of test cases execution on clusters of computers will be necessary here in order to obtain reliable results under limited time and efforts constraints.

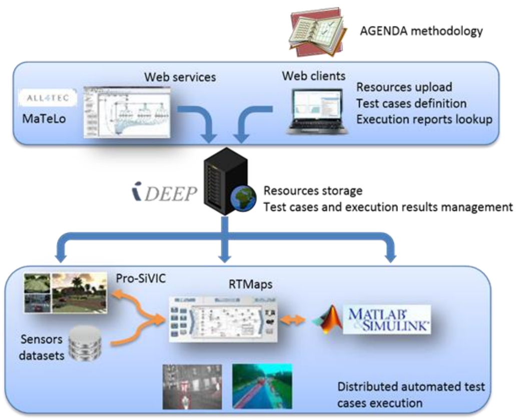
Tooling

I-DEEP

I-DEEP is a test execution automation server dedicated to validation of perception and decision making function for ADAS, particularly functions based on vision.

I-DEEP can store recorded sensors datasets and their associated ground-truth datasets and/or simulation scenarios resources, it can as well host image processing / signal processing / data fusion algorithms to be tested (as integrated into RTMaps plugins), and then allows to define and execute automatically the numerous test cases on cluster of calculators.

I-DEEP also offers a dual approach for validation of ADAS functions making use of simulation on the one hand and real datasets playback on the other hand. These two approaches are very complementary, simulation offering a comprehensive control of the scenario and its environmental conditions as well as the capability to test dangerous situations, whereas taking advantage of real data playback capabilities allow extension of the tests under maximum realism conditions.



CONCLUSION

Methodology, tooling and expertise for ADAS validation towards autonomous driving functions are now available. The companies which develop and provide such tools have grouped under the “ADAS Group” from the MOV’EO cluster and represent a dozen of high-technology SMEs.

We believe that setting up such competencies and tools in an interoperable manner will allow to leverage most of the issues relative to ADAS validation issues, and pave the way to massive adoption in the automotive market.

REFERENCES

[Shan48] C. E. Shannon « A Mathematical Theory of Communication », sur L'Institut d'électronique et d'informatique Gaspard-Monge (Reprinted with corrections from The Bell System Technical Journal, Vol. 27, p. 379–423, 623–656, July, October, 1948

[Yah14] methodology for ADAS validation ; potential contribution of other scientific fields which have already answered the same question, Gérard Yahiaoui, Pierre Da Silva Dias, Congress CESA 2014, session validation of ADAS, dec 2014.

[Yah92] "Un cadre méthodologique dédié à la conception de solutions neuronales : la méthode AGENDA", G. Yahiaoui, Colloque "les réseaux neuromimétiques et leurs applications, Neuronîmes92, Nîmes, 1992

[Tag92] Nair, V N (ed.) (1992) Taguchi's parameter design: a panel discussion, Technometrics vol34, pp. 127–161

[Tag98] Robust engineering - Genichi Taguchi ; Subir Chowdhury; Shin Taguchi - Dunod - 1998

[Raf14] MBT and Test Automation for ADAS validation – Laurent Raffaelli; Xavier Rouah – UCAAT 2014 conference: http://ucaat.etsi.org/2014/presentations/S3P4_MBT_and_Test_automation_for_ADAS_validation_L_Raffaelli.pdf

[Ibe15] http://www.ibeo-as.com/, Ibeo Automotive Systems GmbH, 2015

CONTACT (to know more):

groupements@pole-moveo.org