Attribute-based development of driver assistance systems

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1 Introduction

Advanced Driver Assistance Systems (ADAS) and Highly Automated Driving Systems (HAD) are among the most important megatrends in the automotive development. Accompanying this one big question arises: do all assisted and automated driving cars drive the same or will vehicle manufacturers be able to differentiate themselves with DNA of their own? And - especially for a sportscar-manufacturer like Porsche - how can ADAS and HAD impart typical attributes like driving fun and sportiness, Figure 1?

Figure 1: Porsche typical driving characteristics of ADAS and HAD.

In order to achieve this, clear driving characteristic goals (from a customer's point of view) must be defined and the system requirements for ADAS and HAD (including all components like sensors, ECU's and actors) shall be derived from this. However, what are driving and brand characteristics in the context of assisted and automated driving? And how can those be realized in the development? Porsche has addressed this question together with the University of Applied Sciences Kempten and MdynamiX. The main questions are: "How can an attributed-based development be achieved? How can Porsche effectively design brand-typical characteristics for ADAS and HAD? And how can Porsche establish this in the ADAS- and HAD-development?"

2 Motivation

Today, ADAS-development is mostly sensor-based compared to the classic chassis systems, which are attribute-based. The evaluation of those is commonly done individually on a subjective basis and not systematically. Various studies with over 160 test persons regarding longitudinal and lateral control assisted systems in current benchmark vehicles have shown that the functional and driving characteristics of the actual systems still offer a great potential upward. The customer acceptance is – in all benchmark vehicles – unsatisfactory [1] [2] [3]. The challenge for vehicle manufacturers is also the optimization of the systems and the difficulty of differentiating themselves regarding the brand-DNA. The brand-specific characteristics and the brand position of the vehicle have hardly been taken into account in the ADAS/HAD development so far. For Porsche with its sports- and luxury DNA it is very important to transfer the product and the brand to the age of ADAS and HAD, so that they can be experienced by their customers. Those should experience special emotions, sportiness and everyday practicability, distinguishable from other brands and products.

Using a lane keeping system (LKS) as a first example, a generic procedure model should be developed to translate subjective customer experiences into subjective expert evaluations and finally into objective measurable key performance indicators (KPIs) with defined manoeuvres [4]. Afterwards this method is applied to other systems – for example the Adaptive Cruise Control (ACC). Using those KPIs it is possible to define objective attribute targets for a Porsche typical characteristic and to validate them at any time in all phases of the development – from simulation, software-, hardware- and vehice-in-the-loop tests up to road tests. Furthermore it can be used for an objective benchmark comparison, especially in vehicles without BUS-access. As the next step this procedure model can be transferred to evaluate other ADAS and functions of higher automation levels.

3 Porsche typical characteristics of Advanced Driver Assistance Systems

As a sports car manufacturer, Porsche offered its customers only a few safety functions and a cruise control system when the first Panamera was launched in 2009. In the following years, Porsche pursued a late-follower strategy in the expansion of ADAS, focusing primarily on the Panamera and the SUV models. Since the introduction of the 2nd generation of the Panamera 2016, a trend reversal has been initiated. With predictive longitudinal control functions such as Porsche InnoDrive, for the first time Porsche introduced an in-house developed ADAS function and optimizes existing functions by means of Porsche typical extensions, such as sportiness recognition [5]. With the 3rd generation of the Cayenne, Porsche launched its first level 2-function with the Adaptive Cruise Assist, a combined lateral- and longitudinal function, Figure 2.

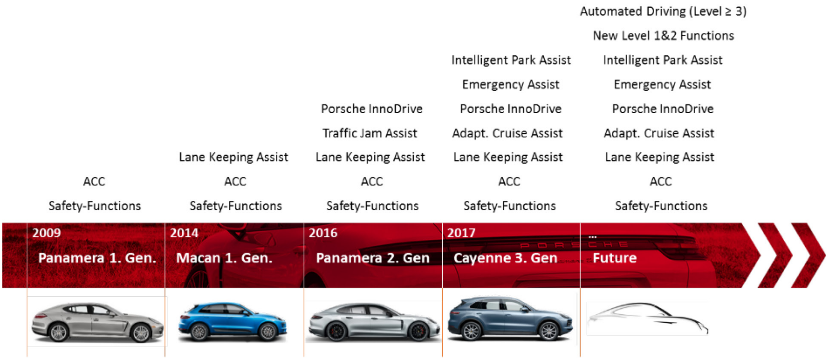

Figure 2: Evaluation of ADAS at Porsche.

Porsche pursues the approach of offering driver assistance functions with their own DNA by complying brand-typical attributes such as reliability, sovereignty, performance, intelligence and trustworthiness. In order to address this claim for future assisted and highly automated driving functions, professional methods are required for an attribute-based development.

4 Method

By applying principles and approaches of classic vehicle dynamics and chassis development [6], a generic procedure model is developed using the example of the LKS. This procedure model is afterwards transferred to the ACC-system.

4.1 Evaluation Level Model

In numerous expert workshops, benchmark tests, subjects-studies and measurement campaigns, the relevant evaluation-attributes were systematically developed and verified. These subjective characteristics are transferred to a so-called level model.

Using a suitable linkage between subjective criteria and measurement signals (e.g. lateral acceleration) the objective level results, Figure 3 [4].

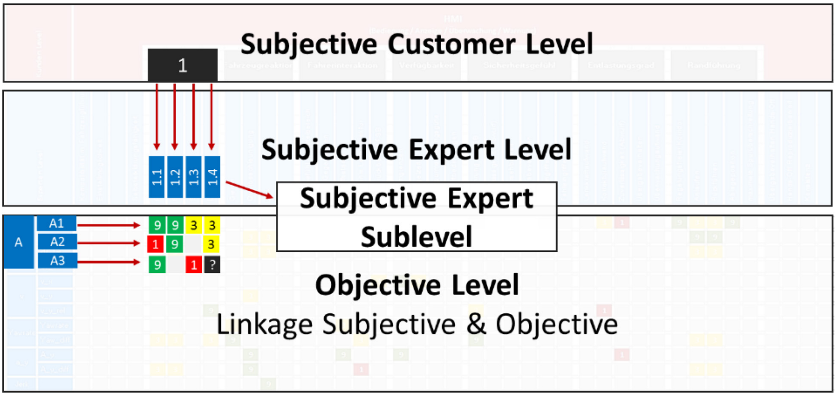

Figure 3: Evaluation level model with customer-, expert and objective level.

The model consists of the subjective customer evaluation, subjective expert evaluation, measurement signals and objective characteristic values (KPI) which are collected in defined driving manoeuvres/driving scenarios. At the highest customer level, there are key criteria such as track guidance quality, vehicle reaction, driver-vehicle interaction, availability, degree of relief, sense of safety and HMI (operation, display, monitoring and warning). At the expert level, the main criteria are broken down into sub-criteria. In the next step, all relevant and measurable vehicle signals are identified in expert workshops, in which the subjective expert criteria are expected to be clearly visible. Based on the expert knowledge, subjective and measurable are linked afterwards. The experts rate the degree of visibility to be expected as high (9), moderate (3), low (1), none (0) or unknown (?). Therefrom, KPIs for the relevant signals are developed according to the individual expert criteria in analogy to characteristic values of vehicle dynamics. It is possible to subdivide the second level into one more sub-level to consider much more detailed facets, like steering feel. In this case, steering feel can be evaluated during assistance guiding with common subjective steering feel criteria and special, new criteria such as the steering torque gradient.

4.2 Ground Truth measurement method

For the objective evaluation of the driving characteristics of ADAS and HAD a new measurement and test method need to be developed. This method must be unattached of BUS-access. In the assessment of driving dynamics, it is a common procedure that the driver – vehicle – environment control loop should be considered in the global vehicle evaluation. Therefore, driver input as well as road and traffic input, control intervention and the resulting vehicle reaction/movement should be evaluated in its six degrees of freedom. Derived from the automated and assisted lateral control, it is necessary to acquire a high level of knowledge of the road excitation, essentially road markings, surface geometry etc. as well as the driver input in order to be able to evaluate the resulting vehicle reaction caused by the system. In the case of ACC it is necessary to know all about the surrounding traffic, especially the preceding car.

Like all sensors, ADAS- and HAD sensors (camera, radar, lidar) are faulty and not available or sufficiently accurate at all time and in all situations. This can have a significant impact on the system behaviour and its driving characteristics. For example, the camera may not be able to reproduce the curvature of the road accurately, which can cause difficulties for the lane-keeping controller. This repeatedly leads to uncertainties if the experienced driving characteristics are a result of the poor performance of sensors, trajectories, controllers, actuators or the poor response of the vehicle influenced by steering, axles, tires and chassis control systems.

In order to investigate this cause and effect chain, a much more accurate reference measurement should be used as a “Ground Truth”. For the LKS an approach was chosen which integrates a highly accurate measured vehicle position and movement into highly accurate Ground Truth maps (Figure 4). For this maps the company Atlatec has generated a digital high accurate 3D-map of tracks around the cities of Weissach and Kempten, which can also be used as a digital twin in simulation environment. Using an Inertia Measurement Unit (IMU) with fiber optic gyroscope, Kalman filter, RTK-DGPS and SAOPS correction service the vehicle position and motion was measured (Figure 5a) [7]. Great efforts have been made to achieve the objective of a relative accuracy between both absolute measurements (digital map and vehicle position) of less than +/-5cm. For measuring the steering wheel torque and angle a measurement steering wheel from Kistler has been used. It is important to keep the original steering wheel installed in order not to influence the haptics, control functions, hands-off detection and airbag function. The LKS state-icon in the head unit was recorded by a special camera (AVAD) and converted into a measurement signal (Figure 5b).

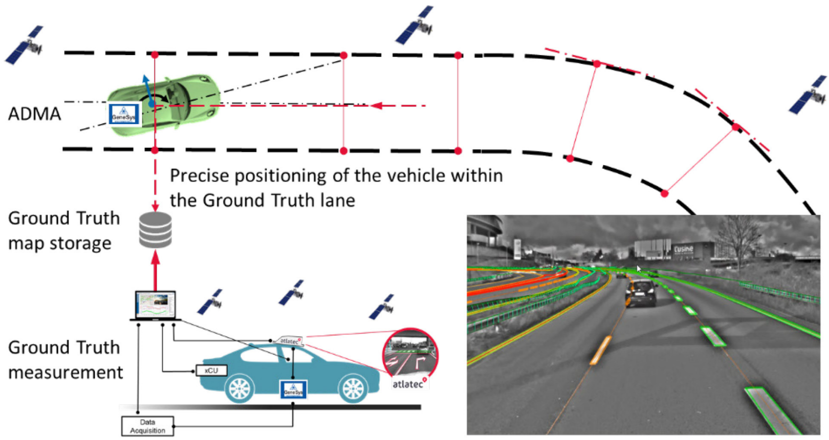

Figure 4: Measuring Ground Truth maps.

Figure 5a: Measurement Setup: IMU; 5b: measurement steering wheel and AVAD.

With this measurement setup it is possible to identify driver-interventions, to measure all relevant signals for the objective evaluation and to evaluate the on board sensors. The setup is designed to be used in all benchmark vehicles, however it is also possible to use the on board signals from the vehicle BUS. This allows a quality evaluation of the sensors, trajectory, controller and the vehicle response. It is also an enabler to investigate the effect chain of the system and the requirements of all individual components.

For the ACC measurement a second DGPS-unit and IMU on the preceding car are used for an exact measurement of distance, differential velocity and transverse offset instead of the Ground Truth map, Figure 6. All other measurement equipment remains identical.

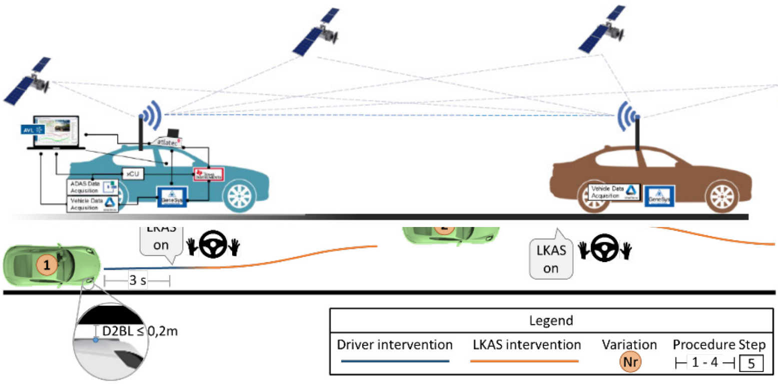

Figure 6: Measurement Setup for ACC with two cars.

4.3 Route and maneuver catalogue

For a comparable subjective and objective evaluation of ADAS and HAD it is important to test it in identical situations. To be able to evaluate the driving characteristics in comprehensive driving situations, the previous standard procedures such as EuroNCAP [8] are not sufficient. The variance in possible real road events (road types, curvature, road markings, cross slopes etc. for LKS and distance, velocity, acceleration, driving behaviour etc. for ACC) is far too great. For this purpose, a comprehensive route and manoeuvre catalogue with detailed driving manoeuvres was developed. In this catalogue, the routes, sections, areas and events are listed as well as the relevant measurement signals and the resulting objective criteria. Each manoeuvre is precisely defined and described with a trace of the driving situation (figure 7 & 8).

For LKS the manoeuvres are for example a so called free ride, lane change test, transient test, drop-off-tests, step-steer-tests, on-center handling test, etc. The free ride test includes test drives with different drivers and at different times and serves the recording of lane accuracy and availability. Most of the manoeuvres should be driven on open roads. For special KPIs like the sublevel of steering feel it is much easier to drive on a test track.

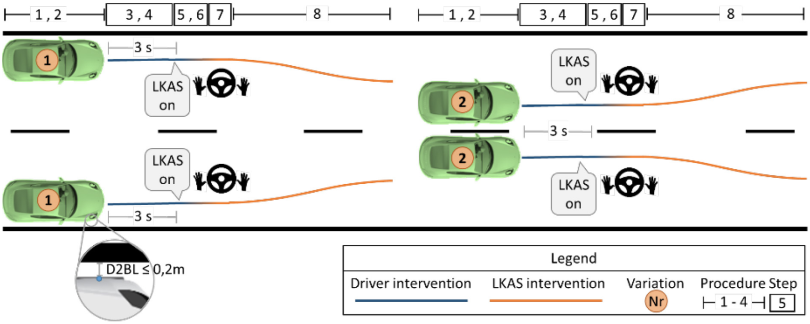

Figure 7: Driving manoeuvre for LKS.

In case of ACC the manoeuvres are for example braking and accelerating target vehicles, cut-in and cut-out situations, lane-change manoeuvres and stop-and-go-situations. In comparison to the LKS a free run is not intended and it is favourable to perform the tests on a proving ground.

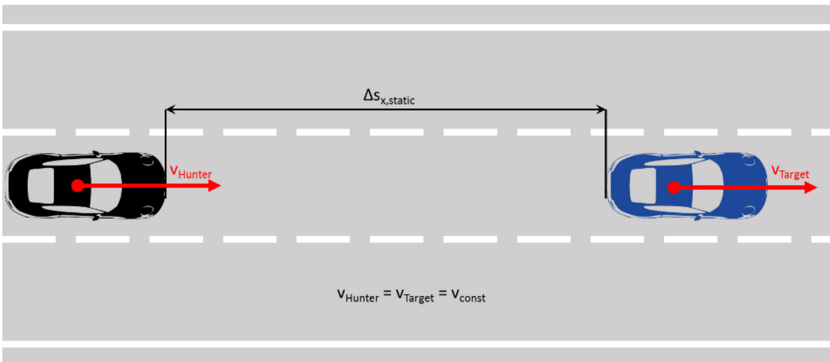

Figure 8: Driving manoeuvre for ACC.

4.4 Objective evaluation of driving characteristics using KPI's

By using suitable algorithms, the KPI's can be generated automatically from the measurement data. For this purpose e.g. reference signals of yaw rate and lateral acceleration, based on the "Ground Truth" curvature, are generated as target and the deviation from the actual measurement is evaluated. For free travel, statistical distributions or counting methods are used, such as the availability measurement, tracking precision measurement or jerk measurement, as well as finding specific states and events using an event finder. For example the stationary states can be identified by comparing the stationary lateral position to the lateral acceleration. The following chart, Figure 9, provides information on how the vehicle is carried outwards (negative curve cutting gradient) or on how it cuts curves slightly (positive curve cutting gradient). In addition, the chart shows the center position when driving straight ahead (offset at ay=0).

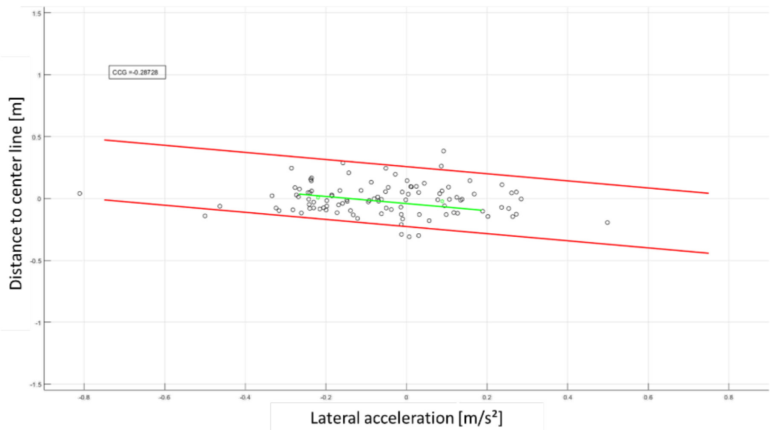

Figure 9: Side offset for curved and straight driving.

Furthermore, the lateral acceleration limits, steering torque limits, dropout limits, response, lock-in and lock-in times, steering torque gradients, steering hysteresis and drift speed are determined. In this scheme, over 80% of the subjective expert evaluations can be objectified, Figure 10.

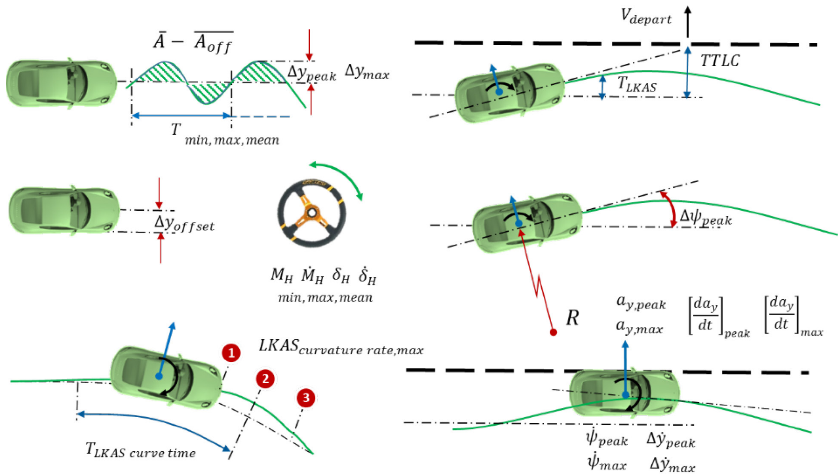

Figure 10: Concept of objective criteria.

4.5 On-Board evaluation

With the presented method it is possible to evaluate and benchmark LKS and ACC systems with a high accuracy, but it is associated with a high expenditure. For the usage during vehicle development in test- and calibration-drives, it is required to have a quick and easy evaluation system. For this special use case a so-called online-evaluation-system is developed, which evaluates for example the last calibration parameter set or two different vehicles with the same KPIs. The evaluation system uses on on-board signals including the track recognition of the vehicle camera. As a result, the score is not as precise as using the Ground Truth method, but it helps to compare different calibration sets quickly and easily during test drives.

5 Driving characteristic evaluation and KPI usage in development

The ADAS and HAD evaluation method addresses various steps of development. In the beginning KPIs help to define system requirements, based on earlier projects, knowledge and benchmark studies. Then the evaluation algorithms can be used in simulation and during the system verification and calibration process. At last, the subjective evaluation on expert level and the objective evaluation are an important part of the approval process of ADAS and HAD.

5.1 Benchmark studies and target definition

Especially in the highly innovative environment of ADAS/HAD it is necessary to observe the performance and solution approaches of competitor vehicles to learn from the good and to avoid poor solutions. Even in the age of ADAS/HAD, it is important for Porsche to design the product in a way that it can be experienced as brand-typical and to differentiate itself from others. This requires clearly recognizable driving characteristics that are associated with the Porsche brand and can be compared to the benchmark. Familiar brand attributes such as driving pleasure, performance, precision, driver feedback, transparency and reliability are to be addressed here as well, with a high degree of suitability for everyday use. Customers would expect a Porsche, for example, to drive precisely in lane and always provide the driver with pleasant but not disturbing feedback on the driving condition. A Porsche typical ACC should accelerate and brake like a sports car. For this purpose, the desired brand attributes are linked to the criteria in the level model, Figure 3. This makes it possible to define objective targets for a typical Porsche characteristic and validate them at all times in all phases of development. Figure 11 shows an example of the benchmark evaluation of three vehicles for track precision, as sub-criteria of the track guidance quality based on the calculated distance to centreline measured in the free ride test.

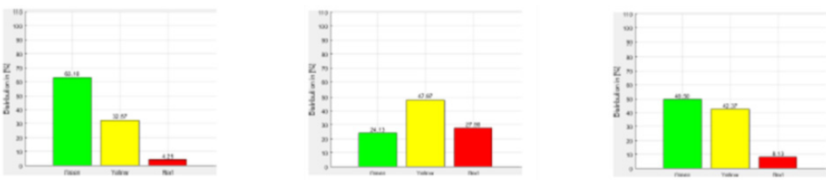

Figure 11: Lane precision distribution of three benchmark vehicles.

The green area is defined with ±20 cm, the yellow area with ±50 cm and the red area is more than 50 cm. For example a KPI-target can be more than 95% in the green corridor and 0% in the red area. Figure 12 shows the curve cutting coefficients of the three benchmark vehicles. The left vehicle possesses a relatively strong drift to the outside of the curve. In contrast the right car slightly cuts the curve, which would be desirable for a sports car. The bandwidth of the red lines represents the lane precision of the systems – for this aspect the left car posses the best properties.

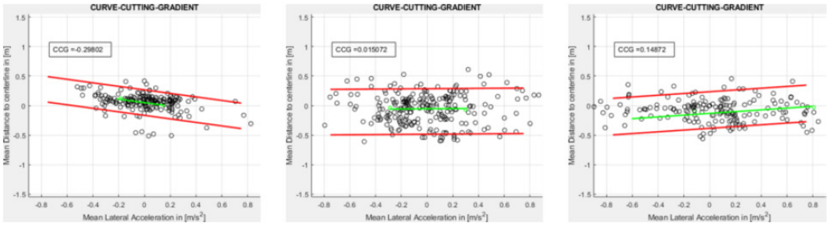

Figure 12: Curve Cutting Gradient of three benchmark vehicles.

5.2 Simulation-based development process

For using the objective evaluation in simulation (including model, software, hardware and vehicle in the loop) a modular simulation environment based on Vires VTD, Porsche driving dynamics model and a control system network including a LKS- and ACC-controller is developed. A real car model with a good steering, braking and acceleration behaviour is the premise for correct results. For this purpose, the Pfeffer steering model of MdynamiX was integrated into the Porsche driving dynamics model. Furthermore, the Ground Truth maps and the defined driving manoeuvres were implemented analogously to the real road tests, Figure 13.

Figure 13: Implementation of Ground Truth maps and manoeuvre catalogue.

6 Conclusion and outlook

ADAS and HAD functions are important to Porsche and should be developed with typical Porsche characteristics. Based on the examples Lane Keeping Systems (LKS) and Adaptive Cruise Control (ACC) a procedure model was successfully established to show how to evaluate different systems or calibrations and how typical Porsche characteristics can be effectively achieved in an attribute-based development. The procedure model can now be transferred to other assistance and automative driving systems. It also allows the definition of specific calibration goals for different regions e.g. China. In the future, Porsche customers will be able to experience brand-typical automated driving functions and the associated emotional driving pleasure.

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