Attribute-based Development of Advanced Driver Assistance Systems

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1 Abstract

Advanced Driver Assistance Systems and Automated Driving are a megatrend in the automotive industry. The following questions arise: Will vehicle manufacturers still be able to differentiate themselves "brand-specifically" in the future or will all vehicles be perceived the same when being driven? How can a brand DNA be implemented and how can the transfer of "fun to drive" to "fun to be driven" be achieved? In order to reach this, clear driving characteristic goals – in front of the customer – should be defined and the requirements for vehicle systems and components shall be derived from this. However, what are driving characteristics in the context of assisted and automated driving, **Figure 1**, and how can those specifically be achieved in the development? Porsche has addressed this question together with the University of Applied Sciences Kempten and MdynamiX. How can an attribute-based development look like and how can Porsche effectively design a brand-typical characteristic in this area?

Figure 1

Driving characteristics in the context of assisted and automated driving

2 Motivation

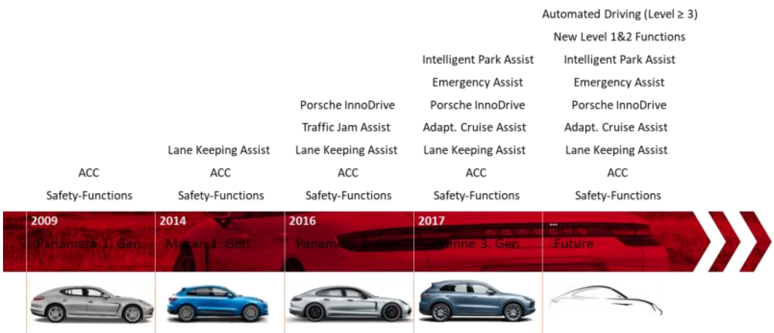
Previous studies with regard to automated lateral control with over 120 test persons and current benchmark vehicles of the University of Applied Sciences Kempten and MdynamiX have shown the following: The functional characteristics and driving characteristics, which are currently achieved, still offer a great upward potential and customer acceptance is still relatively poor [1] [2] [3]. Additionally the challenge for vehicle manufacturers in the development of Advanced Driver Assistance Systems and Highly

Automated Driving (ADAS/HAD) lies in the difficulty of differentiating themselves (brand typical). The brand-specific characteristics and the brand position of the vehicle brands have hardly been taken into account in the ADAS/HAD development. For Porsche, it is very important to design both the product and the brand in the age of ADAS/HAD so that they can be experienced according to their brand. Customers shall experience special emotions, differentiable from other brands and products. Using the example of assisted lateral guidance, a generic procedure model should be developed to translate subjective customer experiences into subjective expert evaluations and finally into objective key performance indicators (KPIs) with defined driving maneuvers [4]. This should make it possible to define objective attribute targets for a Porsche typical characteristic and to validate them at any time in all phases of development - from simulation up to road tests. The procedure model should then be transferable to the assisted longitudinal guidance and to driving functions of higher automation levels.

3 Evolution of Advanced Driver Assistance Systems at Porsche and Porsche typical character

As a sports car manufacturer, Porsche only offered its customers few safety functions and a cruise control system until 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 preview longitudinal control functions such as Porsche InnoDrive, Porsche introduces for the first time an in-house developed ADAS function and optimizes existing functions by means of Porsche typical extensions, such as sportiness recognition [5], **Figure 2**.

Figure 2



Evolution of Advanced Driver Assistance Systems 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 trust. 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

A generic procedure model was developed using the example of assisted lateral guidance. Principles and approaches of vehicle dynamics and chassis development were applied. [6].

4.1 Evaluation Level Model

In numerous expert workshops, benchmark tests and measurement campaigns, the relevant attributes for assisted lateral guidance were systematically developed. The defined subjective and objective characteristics were transferred to a so-called level model, **Figure 3**, and linked accordingly [4].

Figure 3

Evaluation Level Model

This model consists of the levels subjective customer evaluation, subjective expert evaluation, measurement signals and objective characteristic values (KPI - Key Performance Indicators) to be collected in defined driving maneuvers/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 were broken down in 4-6 sub-criteria. In the next step, all relevant and measurable vehicle signals were worked out in expert workshops, in which the subjective expert criteria were expected to be clearly visible. Based on the expert knowledge, subjective and measurable vehicle signals then were linked. The experts rated the degree of visibility to be expected as high (9), moderate (3), low (1), none (0) or unknown (?). Therefrom, KPIs for the relevant signals were developed according to the individual expert criteria in analogy to characteristic values of vehicle dynamics (chapter 4.3).

4.2 Ground Truth measurement method

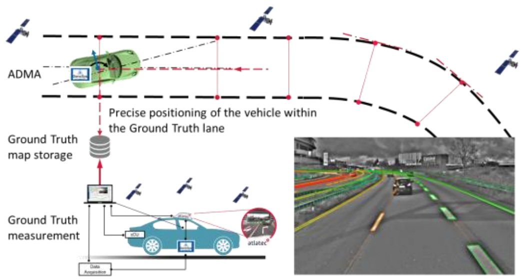
New measurement and test methods had to be developed for the objective evaluation of driving characteristics in the ADAS/AD context. In the assessment of driving dynamics, it is a common knowledge that the driver - vehicle - environment control loop should consider the global vehicle evaluation. Therefore, driver input as well as road and traffic input, control intervention and the resulting vehicle reaction/movement should be evaluated in its 6 degrees of freedom. Derived from the automated lateral control, it is necessary to obtain a high level of knowledge of the road excitation (essentially road markings and surface geometry) and the driver input in order to be able to evaluate the resulting vehicle reaction accordingly. In the case of assisted longitudinal guidance, a high-level knowledge of the surrounding traffic is required.

Like all sensors, environmental sensors such as camera, radar or lidar [7] are faulty and not available or sufficiently accurate in all situations. This can have a significant impact on the 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 method should be used as “Ground Truth". The chosen approach was to integrate both a highly accurate measured vehicle position and movement into highly accurate digital "Ground Truth" maps, **Figure 4**. Atlatec has developed a method to generate digital "Ground Truth" 3D maps with high accuracy, which can essentially be used in simulation. It was used to measure various country roads and motorways around Weissach and Kempten. An ADMA pro from Genesys (IMU - Inertia Measurement Unit) with fiber optic gyroscope technology, Kalman filter, RTK-DGPS and SAPOS correction service was used for vehicle position and motion measurement [8], **Figure 7**. The same "Ground Truth" 3D maps should be usable as digital twins in the simulation as well as for road testing, **Figure 6**.

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 +/-5 cm. Even in seemingly open terrain, satellite coverage by bridges, embankments or dips can be so poor that the IMU has to continue with pure coupled navigation and internal support. The longer the gaps in the GPS coverage, **Figure 5**, the greater the position errors. This depends on the drift quality of the IMU. By means of additional speed support methods and drift corrections or by forward/backward Kalman filters a sufficiently robust accuracy could be achieved [8].

Figure 4

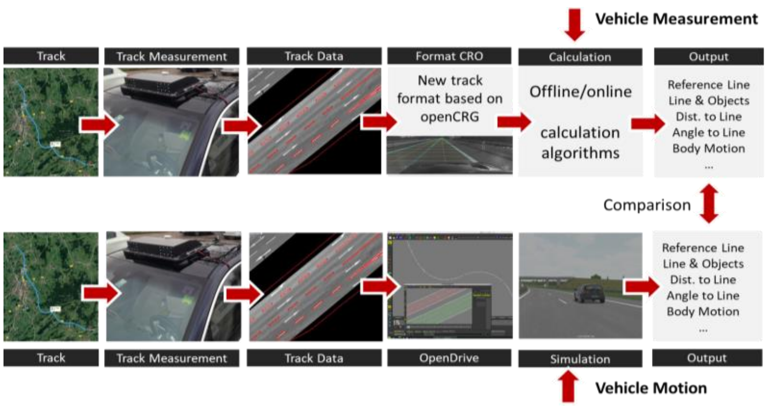


„Ground Truth“ measurement method”

Figure 5

GPS coverage

Figure 6



"Ground Truth" 3D maps usable for road testing and simulation

In order to locate the vehicle precisely in the track during data processing, a route description format (CRO, Curved Regular Objects), based on OpenCRG was developed and the Atlatec measurements were transferred accordingly, **Figure 6**. In different layers, an orthogonal regular grid can be generated in any resolution. Object types can precisely be assigned and extended at any time. Layer 1 describes the 3D road surface, layer 2 the road marking, layer 3 the barriers and signs, layer 4 the buildings. The data format additionally was enriched with information such as curvature, course angle and attributes as a lock-up table. Regular grids allow the computation-efficient calculation of jump marks, e.g. to the currently measured vehicle position/direction or forecast. Thus, localization and motion calculation in the digital maps are also possible in real time [8].

In addition, a Kistler measuring steering wheel, **Figure 7** right, was optimized and adapted to measure the real steering angle/speed and steering torque/gradient as a reference. It was important that the original steering wheel could be used to fully preserve haptics, control functions, hands-off detection and airbag function. The measurements can be characterized in terms of driver-vehicle interaction and allow an evaluation of the quality of the on-board sensors. The measurement concept was designed in such a way that the driving characteristics can be evaluated with all benchmark vehicles without bus connection, **Figure 7**. In order to be able to assign the availability and the system status of the LKAS to the driving status, the display in the instrument was converted into a measurement signal by means of a camera and image processing, **Figure 7** right.

Figure 7

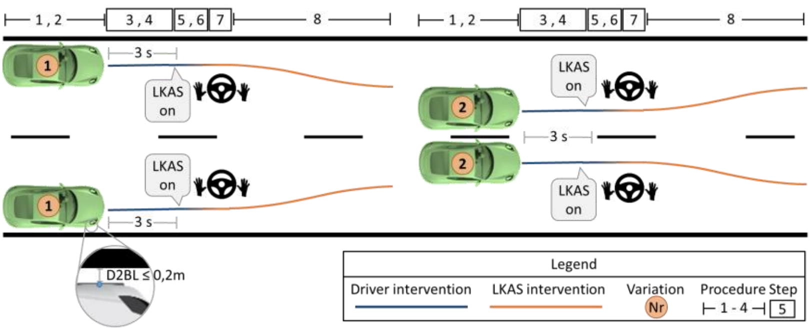
Vehicle measurement instrumentation

In addition, all bus signals, such as the object lists of the sensors, can be measured and precisely assigned. This allows the quality evaluation of the environmental sensors, trajectory, controller and the vehicle response to be examined throughout the entire cause and effect chain and the requirements of the individual components to be defined with regard to the overall vehicle characteristics.

4.3 Route and maneuver catalogue

In order to be able to evaluate the driving characteristics in comprehensive driving situations, the previous standard procedures such as EuroNCAP [9] or ISO (International Organization for Standardization) are by far not sufficient. The variance in possible real road events such as road types, curvature, road markings, cross slopes, road entanglement and other road excitations is far too great. For this purpose, a comprehensive route catalogue was developed which corresponds to the intended use of the functions and represents the required excitation variance. In a route catalogue the routes, sections, area and events were subdivided and typified. The waypoints and GPS positions were precisely documented and all routes were generated as reference routes for the driving test and the simulation as digital "Ground Truth" maps.

Figure 8



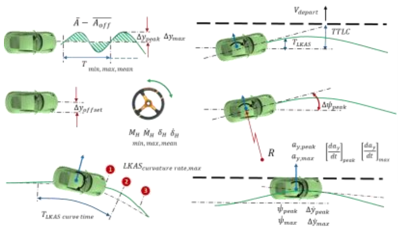
Example of a driving maneuver definition

In addition, a comprehensive maneuver catalogue was created, in which each individual maneuver was precisely defined, **Figure 8**. In the so-called free ride, defined operating points in the sections, areas and events with different drivers and times of day were tested using driving instructions. Furthermore, specific driving maneuvers such as lane change test (with and without turn signals), transient test, feedback test, stationary cornering as drop and performance test, on-center handling test, step steer test were developed and described exactly in one document analogous to an ISO.

4.4 Objective evaluation of driving characteristics using KPI's

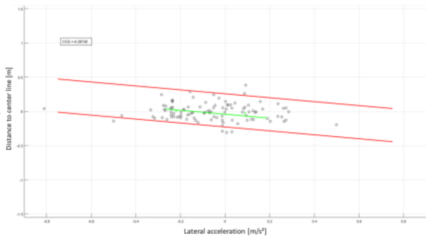
Using suitable algorithms, further signals could be calculated from the measurement data and then the KPI's could be generated automatically. For this purpose, e.g. reference signals of yaw rate and lateral acceleration, based on the "Ground Truth" curvature, were generated as target and the deviation from the actual measurement was 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 could be selected, from which the stationary lateral position above the lateral acceleration could be displayed. The following compressed chart, **Figure 10**, provides information, among other things, 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) and the dispersion as a measure of precision. 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 could be objectified, **Figure 9**.

Figure 9



Concept of objective criteria

Figure 10



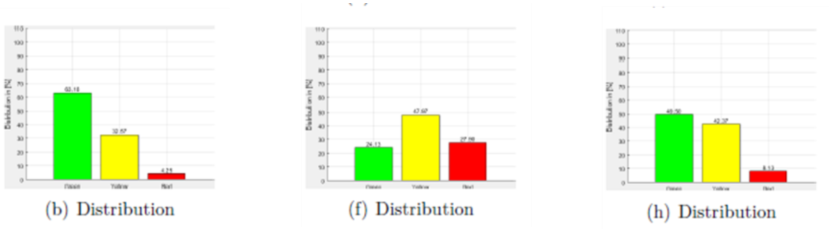
Side offset for straight and curved driving

5 Driving characteristic evaluations in development

5.1 Benchmark studies and target definition

Especially in the very 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 the bad. 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 typical of the brand 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 follow a fluid driving line very precisely and always provide the driver with pleasant but not disturbing feedback on the driving condition. For this purpose, the desired brand attributes were 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 - from simulation to road tests. **Figure 11** shows an example of the evaluation of track precision, as sub-criteria of the track guidance quality based on the calculated distance to centerline, of 3 benchmark vehicles, measured in the test free ride. The green area is defined with ±20 cm, the yellow area with ±50 cm and the red area is outside the yellow area. We would like to see more than 95% in the green corridor.

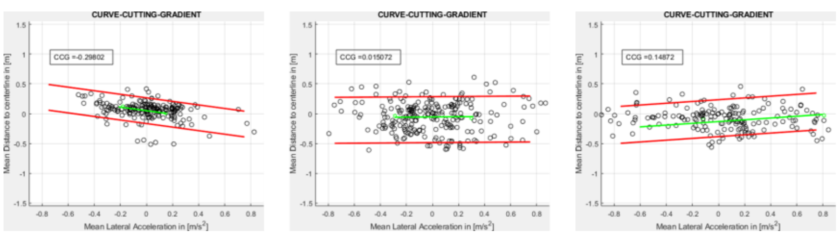
Figure 11



Lane precision distribution of 3 benchmark vehicles

Figure 12 shows the curve cutting coefficients of the 3 benchmark vehicles. The left vehicle is carried relatively and unnaturally to the outside of the curve.

Figure 12



Lane precision distribution of 3 benchmark vehicles

The middle vehicle shows a neutral curve-cutting coefficient and the right vehicle a positive curve-cutting coefficient – thus light curve cutting, which would be desirable for Porsche. The bandwidth also provides information about the lane precision.

5.2 Simulation-based development process

In order to be able to validate the characteristic objectives in all phases of the development at the overall vehicle level, a modular simulation environment consisting of the environment simulation Vires VTD, Porsche driving dynamics model and a control system network including lane keeping control was set up.

The co-simulation platform AVL Model.CONNECT represents the networking of the individual simulations/models and offers corresponding functions for their consistent use in MIL/SIL/HIL, **Figure 15**.

Figure 13

Implementation "Ground Truth" maps of the route

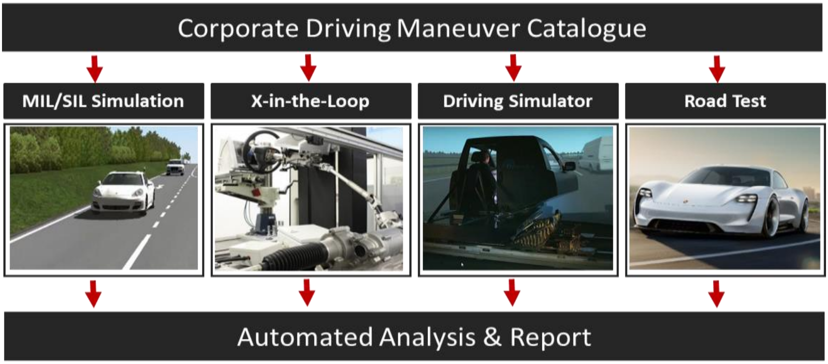
Figure 14

Implementation of maneuvers catalogue

A good steering model with effects in the on-center area is required in order to evaluate the track guidance quality, vehicle reaction and driver-vehicle interaction realistically. For this purpose, the Pfeffer steering model of MdynamiX was integrated into the Porsche driving dynamics model. The "Ground Truth" maps of the route and maneuvers catalogue were implemented analogously to the road tests.

In order to obtain comparable results for the evaluation of development progress in all phases, the evaluation and evaluation algorithms were integrated into the Porsche post-processing tool Veda Post. This can be used throughout, from the simulation to the road test, and always guarantees comparable results, **Figure 15**. Efficient calibrations for uniform driving characteristics across all model series and vehicle variants can thus be achieved.

Figure 15



Simulation-based development process

5 Conclusion and outlook

ADAS/HAD are becoming very important for the Porsche brand. Using the example of assisted lateral guidance, a procedure model was successfully established to show how a typical Porsche characteristic could be effectively achieved in an attribute-based development. The procedure model is currently being transferred to assisted longitudinal guidance and to driving functions with higher automation levels as well as to country-specific calibrations, e.g. China. In the future, Porsche customers will be able to experience automated driving functions and the associated emotional driving pleasure, typical of the brand.

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