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Automated simulation of scenarios to guide the development of a crosswind stabilization function

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Abstract: Mercedes-Benz has recently added a crosswind stabilization function to the Active Body Control (ABC) suspension for the 2009 S-Class. For this purpose the ABC uses the yaw rate, lateral acceleration, steering angle and velocity sensors of the Electronic Stability Program ESP to vary the wheel load distribution via the ABC spring struts, depending on the direction and intensity of the crosswind. This function has to distinguish between vehicle reactions caused by crosswind, by driver interaction, and by road unevenness. The effects of the crosswinds can be compensated in this way, or reduced to a minimum in the case of strong gusts. For developing this function Mercedes Benz used the test case generator TestWeaver to generate thousands of different driving and crosswind scenarios. The scenarios have been executed using a co-simulation of: (i) a dynamic vehicle model (based on the in-house tool CASCaDE), (ii) a road and crosswind model implemented in C and (iii) a MathWorks/Simulink model of the crosswind stabilization function. This simulation-based approach helped considerably to validate and iteratively improve the safeguarding algorithms of the stabilization function through all design phases.

Keywords: Rapid Control Prototyping; Systems for Vehicle Dynamics Control; Lanekeeping.

1. INTRODUCTION

Nowadays an increasing number of automotive functions is realized using software, resulting in a steadily growing

The CASCaDE vehicle model has been exported as DLL that implements the Silver API and uses a CASCaDE solver for numerical integration (shown as vehicle dll). A second sub-model was created to model crosswind and the road, called the environment dll in Figure 2. The wind stabilization function has been developed using MATLAB/Simulink and was included into the vehicle dll also comprising the CASCaDE vehicle model. A third sub-model called modifier

The vehicle dynamics behavior and especially the steering effect based on wheel load variation – the elastokinematic effect used here for crosswind stabilization – were validated from measurements. The aerodynamic characteristics were parameterized from extensive wind tunnel measurements and validated from bypass measurements at a crosswind test facility.

The ESP-algorithm is not included in the simulation model. Since crosswind impact is generally not strong enough to cause an ESP-intervention in the S-Class, a car featuring a strong directional stability, the influence of the ESP-system can be neglected in the study reported here. Only the ESP sensors used by the stabilization function are represented in the model. For other investigations the ESP could also be included.

This simulation model (including the stabilization function from 3.1) was converted into a dynamic link library (DLL) with an open interface implementing the communication with Silver. Driver inputs, current tire patches and wind is fed to the vehicle simulation. Vehicle and controller states are reported back to TestWeaver for scenario assessment and state coverage measurements (see Figure 2).

4. TEST OF THE STABILIZATION FUNCTION

It is not possible to test all possible driving situations in real life. Disregarding the great effort in time and expenses which make extended test drives undesirable, even on test tracks, only a limited number of road profiles is available, so all possible road excitations can never be covered. Furthermore, the possibilities to create different wind profiles for real life testing are very limited. In virtual test drives, however, every combination of road and wind excitation can be generated. Therefore, TestWeaver was chosen as a promising approach to cover the necessary test range with acceptable effort.

The main focus of the investigations was safeguarding against control impacts due to an erroneous crosswind detection. Since the observer bases the detection only on ESP-sensor data, and no direct wind-sensor is implemented, an asymmetric unevenness of the road, leading to lateral acceleration and yaw rate, could be interpreted as crosswind. To avoid the crosswind stabilization to respond to this excitation, other controller subsystems are designed to differentiate between vehicle reactions due to crosswind and reactions due to driver- and street-interaction or sensor faults.

The first focus was on trying to provoke the crosswind stabilization function to perform steering impacts due to driver and street interaction, thus detecting holes in the safeguarding mechanisms. Since basic features of safeguarding rules implemented were specified, and already sufficiently tested, the range of feasible driving- and environment situations in which the function had to be tested in this approach could be restricted to situations not already reliably and adequately covered. Thus scenarios not respecting these well-known limits set by the safeguarding mechanisms, for instance, on steering wheel angle or velocity, were not investigated and excluded in advance from the situations possibly chosen by TestWeaver. By taking into account this beforehand knowledge the design range TestWeaver had to cover to guarantee the reliability of the system was reduced to the regions not verified so far, allowing TestWeaver to work more efficiently.

Finding categories of suited street excitations was an iterative approach. Too high excitations were easily detected by the safeguard mechanisms implemented so far. Too small excitation did not lead to a relevant wind force estimation and, thus, to no reaction of the system. After choosing a promising range from evaluating the TestWeaver results, TestWeaver found several categories of impacts which the controller was not safeguarded against.

The mechanism included at the examined design stage only used the difference in spring travel between left and right wheel with the standard sensors being available in the ABC suspension system. The failure scenarios found with TestWeaver showed that a certain type of street unevenness did not lead to a high enough difference in spring travel. Reducing the critical limit of difference spring travel allowed was not an appropriate solution - this would reduce the percentage of time the system is active. The relevant scenarios were nonetheless marked by a high individual spring travel. From this observation a new safeguarding module was added, combining individual and difference spring travel.

After this element was included in the controller, a re-run of the critical scenarios showed that the unevenness was now detected. New runs with TestWeaver proved that the protection against false crosswind recognition was complete. The proportion of time the system was active was not reduced. Thus, this new criterion was implemented and approved in the test runs.

In a second approach TestWeaver was additionally used to create sensor faults of different classes: sudden offsets or linear drifts on the different sensor signals used by the observer and the safeguarding mechanism. Here TestWeaver was used during the design phase of the detection module inside the controller. Current versions were immediately exported, linked with the vehicle system simulation and tested with TestWeaver. The effectiveness of new measures or chosen limits was investigated before a first version was tested in the vehicle.