Figure 1: HIL test bench with a feedback steering wheel.

Innovations in Power Steering

Increasing demands on energy efficiency, comfort and safety are driving the development of mechatronic systems in motor vehicles. These demands are especially relevant for steering systems. In this field electromechanical power steering is gaining in popularity, and the functionality of these systems is extendable via software and steadily increasing. The system under development must fulfill both individual haptic requirements and specific safety-critical requirements.

In order to meet these challenges, DMecS GmbH & Co. KG has worked together with the Cologne Laboratory of Mechatronics (CLM) at the Cologne University of Applied Sciences to develop a feedback steering wheel (figure 1). This allows the front-loading of tests on prototypes to a hardware-in-the-loop (HIL) test bench.

Simulation Environment for the Feedback Steering Wheel

The test bench consists of several different real-time capable models. The simulation model for the steering system, consisting of the steering mechanics and the electric power steering (EPS) actuator with a controller, interacts with the models of vehicle, road and driver.

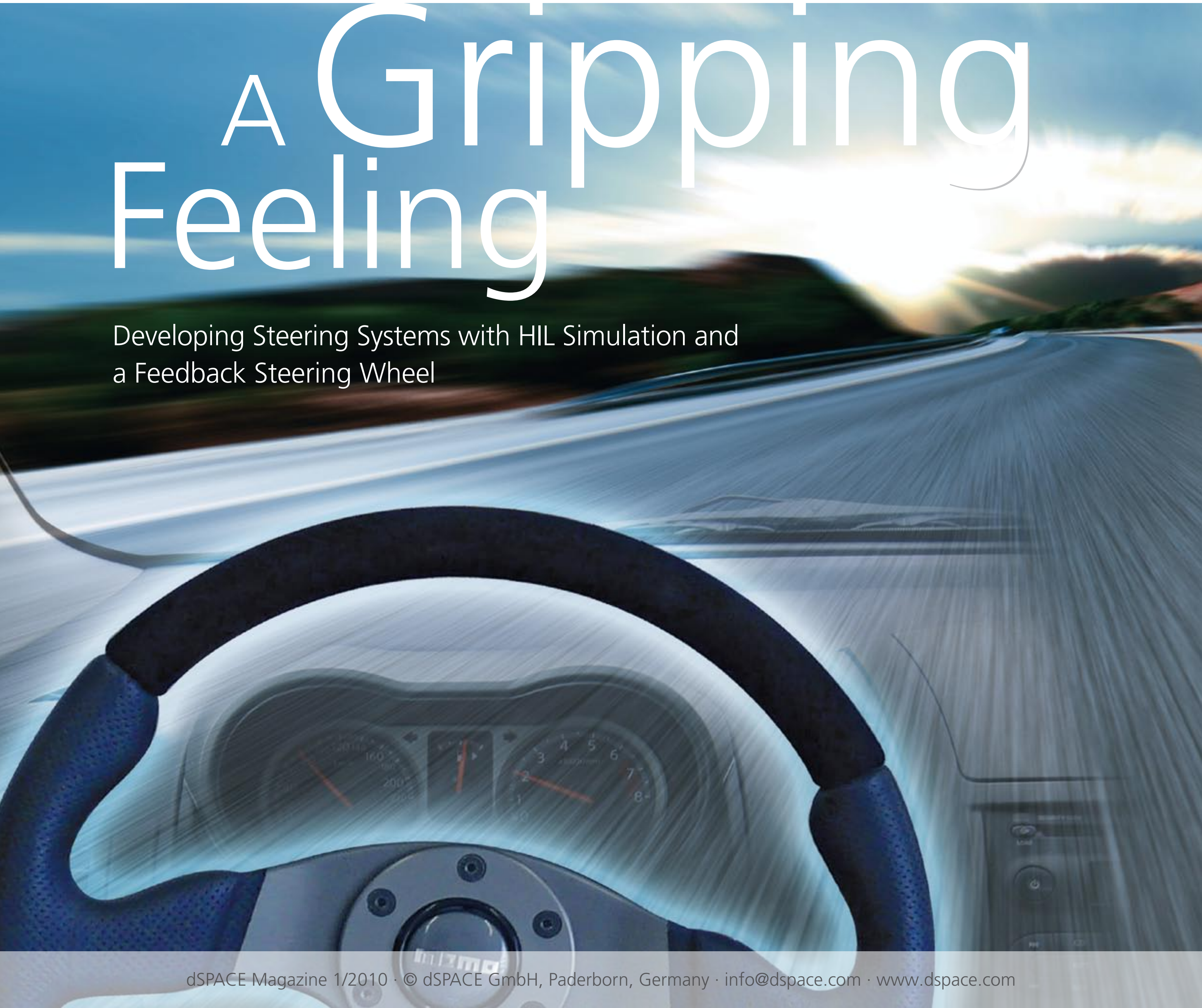
The Automotive Simulation Models (ASM) from dSPACE are used to simulate the vehicle and the road. The ASM Vehicle Dynamics Simulation Package is an open Simulink model for the real-time simulation of vehicle dynamics applications. This model allows a realistic simulation of the vehicle dynamics and the forces acting upon the steering system. The open structure of the ASM models made it easy for the developers to integrate their own EPS system models.

For the road, dSPACE ModelDesk was used to create individual road sections with special surface characteristics. This environment was used to develop and fine-tune the steering system with typical driving maneuvers, where the developer assumes the role of the driver through the use of the feedback steering wheel. For automated tests, the ASM driver models were used, which perform maneuvers repeatedly under identical conditions.

The engineering company DMecS is using a dSPACE Simulator to analyze the system behavior of steering systems. This allows testing at an early stage of development, before performing test drives. Innovative algorithms for generating steering characteristics and assistant systems are tested, evaluated and optimized realistically with regard to their acceptance by drivers through the use of a feedback steering wheel.

A Gripping Feeling

Developing Steering Systems with HIL Simulation and a Feedback Steering Wheel



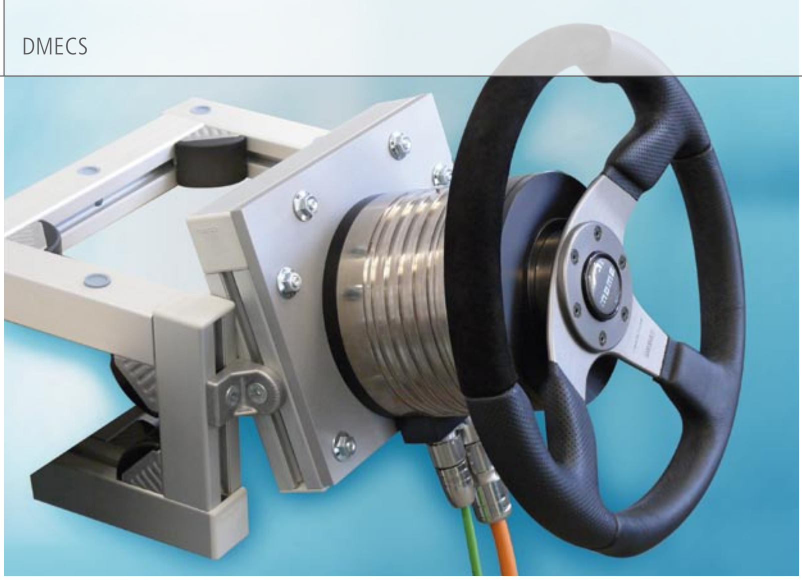


Figure 2: The feedback steering-wheel provides realistic haptic feedback.

> "The completely open Automotive Simulation Models (ASM) made it easy for us to implement our own steering models and new steering system algorithms."
>
> *Thorben Herfeld, DMecS GmbH & Co. KG*

Feedback Steering Wheel and HIL Test Bench

To provide a realistic steering feel, the mechanics and the electronics of the feedback steering wheel meet high demands. The careful design of the mechanical and electrical components minimizes undesired influences on the steering feel such as inertia, cogging, friction and signal propagation delays. The remaining deficiencies are reduced to an almost imperceptible level through suitable extensions of the HIL actuator control. The ASMs and the model of the steering system are implemented on a dSPACE Simulator in the HIL test bench. The simulator contains modular real-time hardware with a DS1006 Processor Board and the interface boards necessary for controlling the feedback steering wheel. Thus the available processing power is sufficient for the entire simulation model and any possible extensions.

Use Cases for the HIL Test Bench

For model-in-the-loop and software-in-the-loop simulation, the EPS controller and the ASM vehicle model run on a dSPACE Simulator. The feedback steering wheel is used to assess the steering feel and adjust it by modifying the controller structure, parameters and characteristic curves. In addition, by implementing control algorithms with TargetLink, the influence of fixed-point arithmetic can be analyzed and minimized appropriately. If the controller is run on a production-level ECU (figure 3), additional implementation issues (such as signal propagation delays and special interfaces) can be analyzed separately to minimize their impact on the steering feel.

Developing Algorithms for Steering Systems

The test bench was used to successfully develop various algorithms for generating steering feel. For example, the basic characteristic of one algorithm matches the steering feel conveyed by hydraulic power steering, and it also adjusts the steering assistance according to the current driving speed. This way the algorithm enables torque-free parking as well as increased centering at higher speeds.

Other algorithms use the tire forces to provide the driver with information on the traction potential of the tire contact patches. A special vehicle dynamics observer was used for these algorithms. In addition to the usual vehicle dynamics values, such as the slip angle or the yaw rate, this observer also estimates the tire forces without using tire models.

In addition to generating steering feel via software, an electromechanical steering system makes it possible to actively influence the current driving situation. For this purpose, assistance systems which stabilize the vehicle in critical situations were developed and tested.

Conclusion

- Development tasks for a steering system were front-loaded from the test drive phase to the simulation phase on a HIL test bench
- Innovative algorithms for steering characteristics and active steering intervention were tested realistically, analyzed and optimized with regard to driver's acceptance
- Efficient implementation supported by the open structure of the Automotive Simulation Models (ASM)

By using the HIL test bench with the feedback steering wheel during the development, it was possible to analyze and optimize the driver acceptance of these algorithms in advance.

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Cologne Laboratory of Mechatronics

Jan Guderjahn, research assistent *in the Cologne Laboratory of Mechatronics at the Cologne University of Applied Sciences.*

Thorben Herfeld, development engineer *of mechatronic systems at DMecS in Cologne.*

"dSPACE's seamless tool chain supported us when we were developing the HIL test bench. From parameterizing the ASM real-time simulation with ModelDesk, to analyzing and synthesizing the algorithms with ControlDesk, to setting up the HIL test bench and visualizing the vehicle model with MotionDesk."

Jan Guderjahn, Cologne Laboratory of Mechatronics

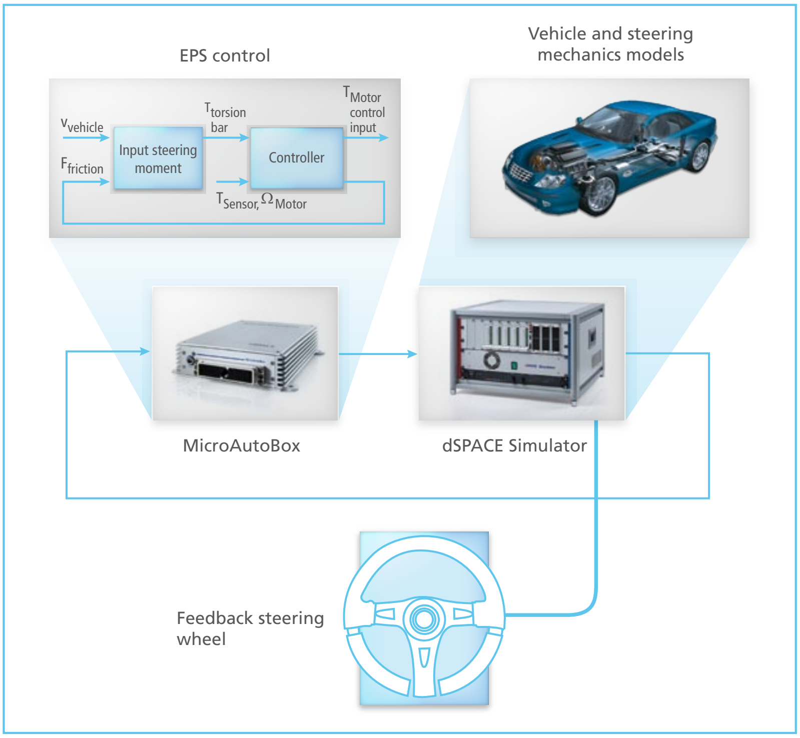

Figure 3: Test bench based on a HIL simulator, external prototyping system and the feedback steering wheel.

Summary and Outlook

The applications described above show that using a HIL test bench in the early stages of development can reduce the overall development time. Model-based system development that takes the haptic behavior of the steering into account makes it possible to fine-tune the entire system in the HIL simulation at an early stage. This reduces the amount of time and effort needed for fine-tuning and testing in test drives.

Besides the development of steering systems, the approach of using suitable HIL test benches can be applied to other systems with haptic feedback as well, such as braking systems or the sidesticks and pedals used in aviation.