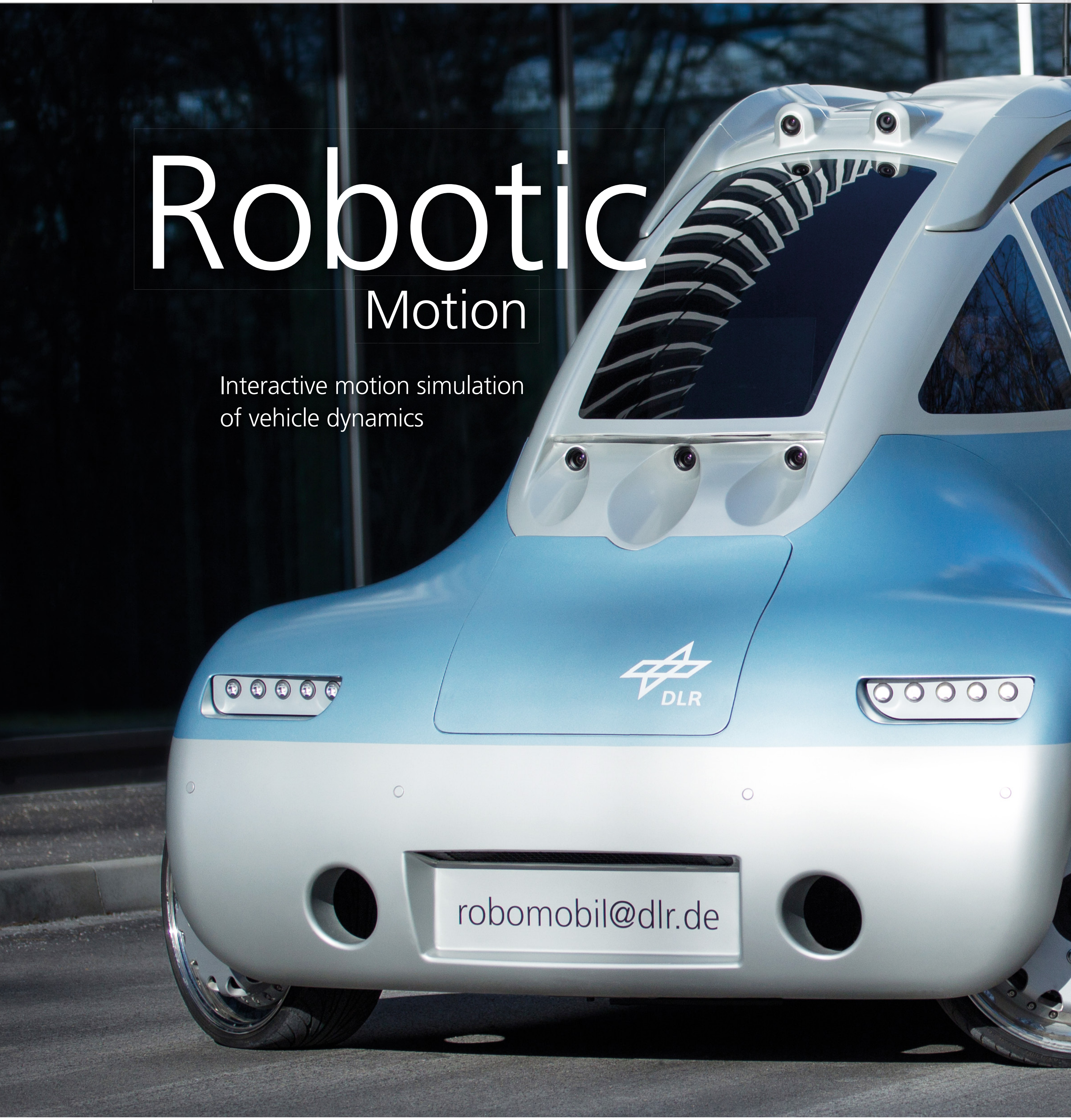
Robotic Motion

Interactive motion simulation of vehicle dynamics



How are we going to drive the cars of the future? To get a physically realistic impression, the German Aerospace Center (DLR) is using a robotic motion platform to develop and evaluate input devices for future automobiles.

Source: © DLR

X-by-wire technology creates new challenges, but the liberation from mechanical constraints also opens up new possibilities for designing modern automotive human-machine interfaces (HMI). ROboMObil – the German Aerospace Center's robotic x-by-wire research platform – takes advantage of these new freedoms to implement independent four-wheel steering and to help develop haptic input devices. An important step in the development of new HMI concepts is to evaluate the robustness under the physical coupling of vehicle accelerations through the driver's body onto the steering device, e.g., a joystick. To reproduce these disruptive effects in a hardware-in-the-loop (HIL)-based rapid control prototyping process, the DLR Robotic Motion Simulator (RMS) is operated in conjunction with a HIL system consisting of ROboMObil and a real-time vehicle dynamics simulation on dSPACE SCALEXIO®. This robotic HIL setup lets engineers not only perform pure component function tests but also investigate the interaction between the driver, vehicle behavior, and input device in realistic, interactive motion simulations. The goal of these studies is to reliably suppress the driver-induced physical disturbance through appropriate kinematically decoupled input devices, suitable generation of control variables, and force feedback strategies. >>

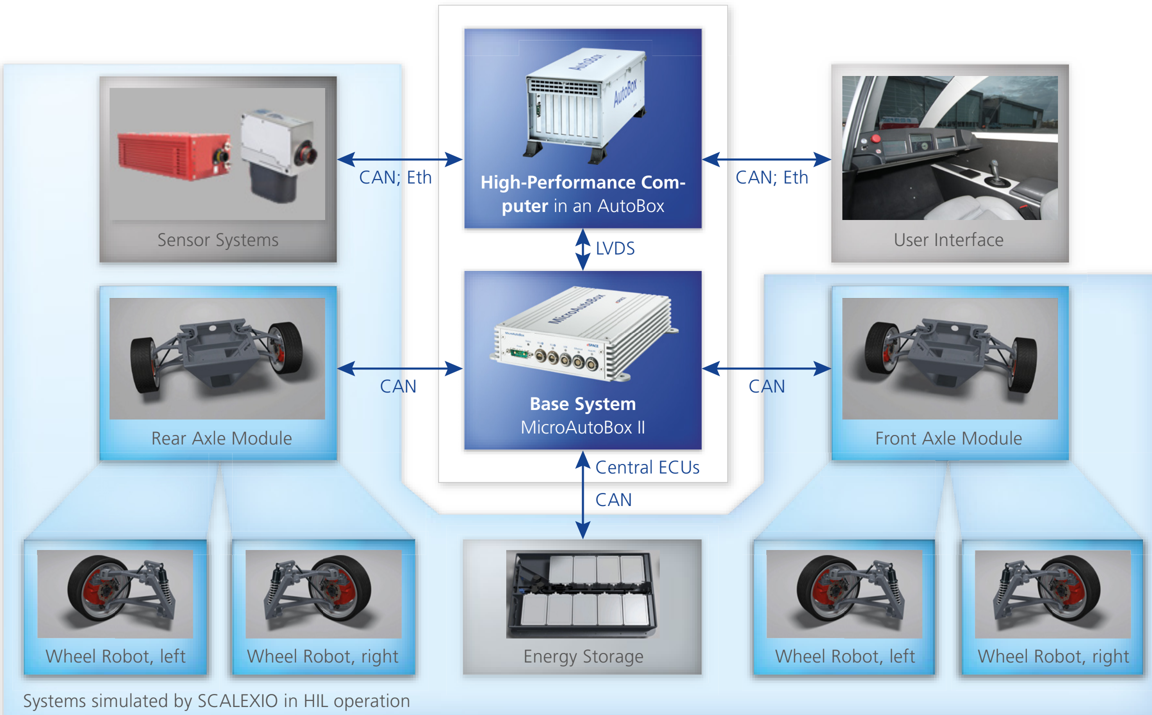


Figure 1: Setup of ROboMObil's computer network (Eth = Ethernet connection). The components represented virtually by the real-time vehicle dynamics simulation, i.e., simulated on SCALEXIO, are shaded in light blue.

ROboMObil Research Platform

Inspired by space robotics, DLR's ROboMObil is an x-by-wire research platform with an electric drivetrain. Thanks to its four highly-integrated, structurally identical "Wheel Robots", the platform has extraordinarily high maneuverability. Its x-by-wire architecture (figure 1), made possible by the Wheel Robots, enables a range of vehicle level applications. These include operating modes such as cockpit control, teleoperation control, and partial or full autonomous driving. This makes ROboMObil an excellent platform for a wide range of research tasks in areas such as vehicle dynamics control, autonomous driving, and the further development of human-machine interfaces. Its high maneuverability permits three fundamentally different modes of motion, namely longitudinal driving, lateral driving, and turning the vehicle around a center of rotation. Controlling each type of motion requires a specific HMI concept, which is analyzed within the robotic HIL setup. The current input device of ROboMObil is a force-feedback joystick with three degrees of freedom. The scientific challenge in developing this HMI is the realization of the ergonomic mapping of the joystick's one rotational and two translational degrees of freedom onto the control of the vehicle's three horizontal degrees of freedom, depending on the mode of motion.

Real-Time Vehicle Dynamics Simulation

At DLR, simulation tools play a central role for both the development and the validation of vehicle dynamics controls. For this purpose, DLR's virtual design and test environment contains detailed multibody dynamics models based on the object-ori-

> "The programmable interfaces provide the possibility to easily connect the SCALEXIO HIL system to non-dSPACE systems, such as the Robotic Motion Simulator, and integrate it into the interactive vehicle dynamics simulation as a motion simulator."
>
> *Peter Ritzer, DLR*

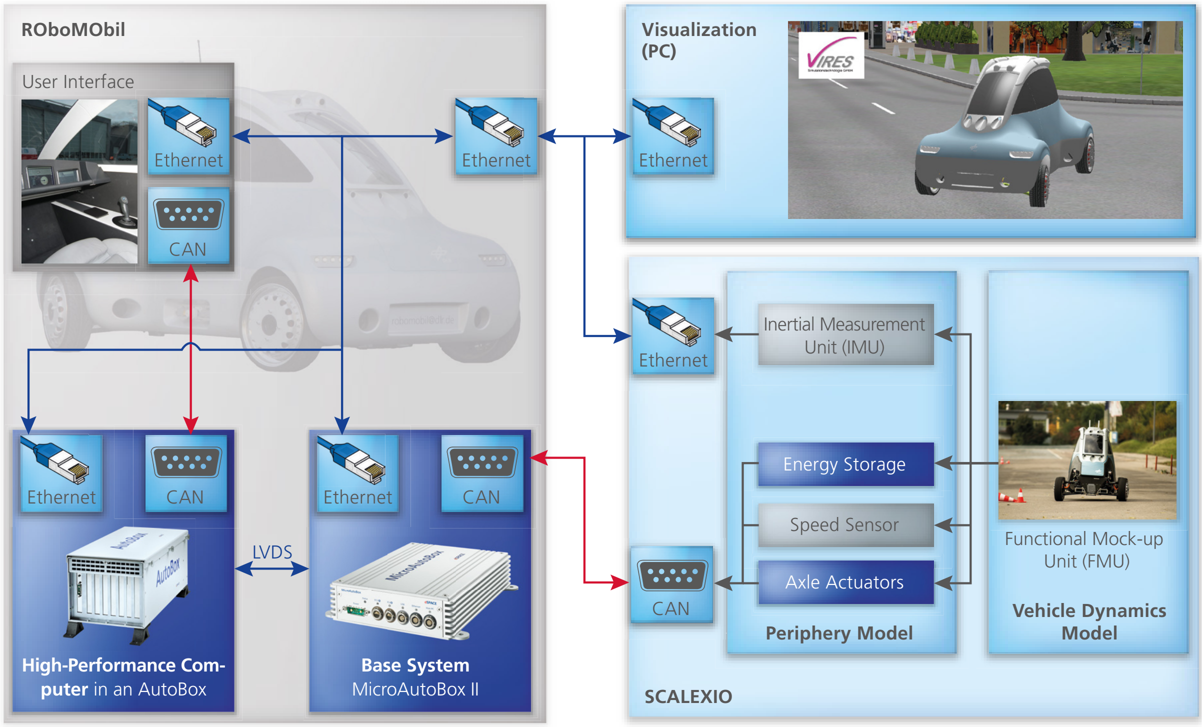


Figure 2: RObоMObil in motionless HIL operation to test the operating software and controls safely.

ented modeling language Modelica. In addition to multibody dynamics, these models also include sensors and electromechanical actuators to combine the various domains, such as the mechanics, electrics and hydraulics, into one model. To develop the new vehicle dynamics controls in Simulink®, the real-time-capable, full vehicle models are co-simulated using the Functional Mock-up Interface (FMI) standard. During the test phase, the algorithms implemented on RObоMObil's central electronic control units (ECUs), a network consisting of MicroAutoBox II and AutoBox, are validated on a SCALEXIO-based HIL system. This system performs real-time vehicle dynamics simulations that cover not only the multibody vehicle dynamics model and the tires, including their contact points, but also all of RObоMObil's peripheral devices, shown in figure 1 in light blue. The HIL architecture illustrated in figure 2 lets the engineers carry the methods of the FMI-based design process over to the validation process of the control software. Using the SCALEXIO system makes it possible to incorporate a Functional Mock-up Unit (FMU) from Dymola (a modeling and simulation environment for Modelica models). As a result, existing Modelica libraries from the DLR design and test environment can be utilized, which reduces the development effort necessary for real-time simulation of the vehicle dynamics.

Robotic Motion Simulator

In contrast to popular hexapod systems, the DLR Robotic Motion Simulator (figure 3) employs an industrial robot combined with a linear axis and therefore has a much larger, dynamically usable operational space, at comparatively lower costs. This improved operational space enables dynamic simulations of risky scenarios, such as dynamic driving maneuvers near the limit of adhesion. For such scenarios, DLR is currently developing real-time trajectory planning algorithms in order to generate realistic movement dynamically and interactively. One application of the RMS is to research human-machine interfaces for ground vehicles and aircraft. To keep the RMS flexible for different applications, it has a modular setup that facilitates an uncomplicated exchange of instruments or the entire cabin and, in turn, quick switches between different simulation scenarios, such as control via steering wheel and pedals or control via joystick.

Entire Robotic HIL System

Whereas conventional HIL concepts with driving simulation in a motionless cabin are fully sufficient for >>

Source: © DLR

Figure 3: To increase the operational space, a linear axis is used for the DLR Robotic Motion Simulator (RMS).

investigating the functionality of the software and hardware, evaluating the new haptic HMI requires more effort. In addition to pure function tests, this involves researching the interplay between the driver behavior and vehicle behavior. This is realized by the combination of the subsystems shown in figure 4. This setup makes it possible to account for the disturbances acting on the HMI, induced by the force coupling through the driver. During the experiment, the driver sits in the cabin of the RMS and drives the ROboMObil interactively through a virtual landscape. In this complex HIL system, in addition to the visual feedback (virtual reality) via in-cabin projectors, the vehicle motion simulated by the RMS also acts on the driver.

Outlook: User Studies

With the help of a robotic HIL, the DLR will conduct user studies in the future to compare the newly developed control interfaces to conventional systems involving a steering wheel and pedals. A great advantage of a robotic HIL for these scientific studies of HMI concepts is the comfortable exchange of the different HMI hardware and the ability to compare them in a consistent environment. In addition to user studies, the Robotics and Mechatronics Center (RMC) at the DLR is also concentrating on the further development of the ROboMObil HMI concept to meet the particular needs of this vehicle architecture. On the one hand, the control interface must be capable of addressing all of ROboMObil's three horizontal degrees of freedom; on the other hand, it must provide the required simple interface for future assistance systems, such as path-following control and platooning (driving in a convoy). This RMC research project on the interaction of the haptic channel with such semi-autonomous functions complements the developments achieved by the DLR Institute of Transportation Systems in automatic driving within the DLR project "Next Generation Car (NGC)". ■

Peter Ritzer, Michael Panzirsch, Jonathan Brembeck, German Aerospace Center (DLR)

> "We can transfer the FMI-based process used during the design phase directly into the validation phase. Integrating a Functional Mock-up Unit from Dymola into ConfigurationDesk significantly reduces the development effort necessary for emulating the physical environment in the HIL simulator."
>
> *Jonathan Brembeck, DLR*

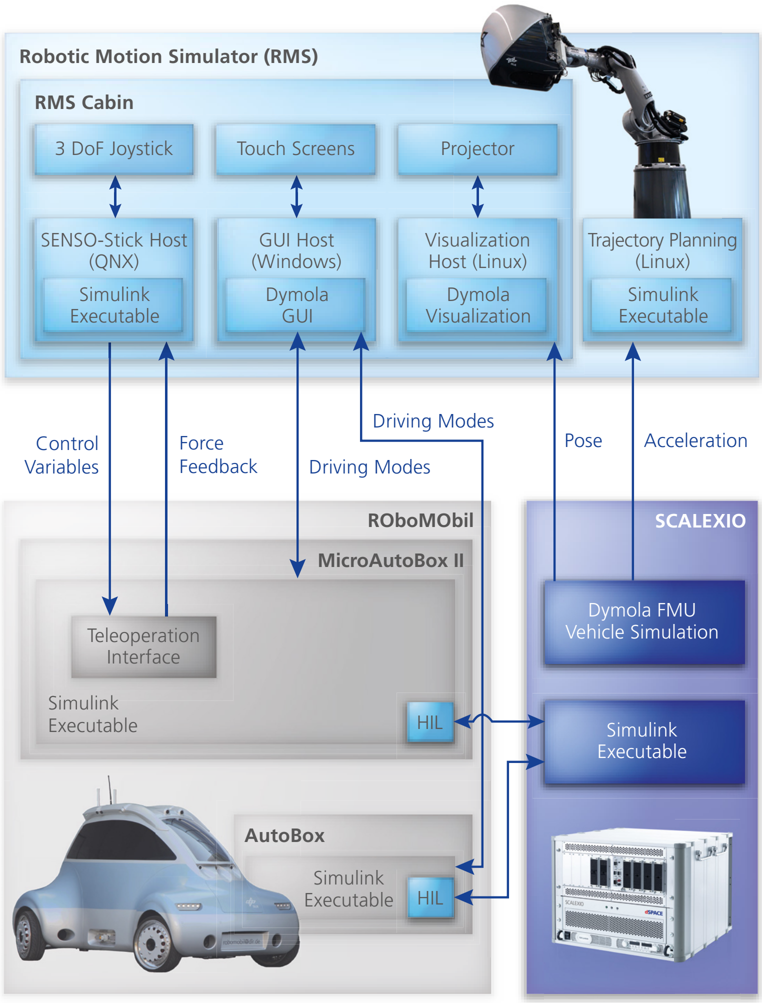


Figure 4: Entire system setup. The goal of this special HIL application is to evaluate innovative HMI concepts under real and known laboratory conditions.

Words of Thanks:

We thank the following persons for helping us set up the infrastructure of the mobile HIL. Tobias Bellmann, Andreas Seefried and Miguel Neves from the Robotic Motion Simulator Team, who were responsible for the integration and adaption of the motion simulator, and Christoph Winter from the ROboMObil Team, who was responsible for the 3-D visualization. We also thank Dr.-Ing. Tilman Bünte for his collaboration on this article.

See the ROboMObil in action: www.dspace.com/go/dMag_20161_DLR

More information on ROboMObil: http://www.dlr.de/rmc/sr/robomobil

Peter Ritzer
Peter Ritzer is a research associate at the Institute of System Dynamics and Control, Robotics and Mechatronics Center (RMC) of DLR in Oberpfaffenhofen, Germany.

Michael Panzirsch
Michael Panzirsch is a research associate at the Institute of Robotics and Mechatronics, Robotics and Mechatronics Center (RMC) of DLR in Oberpfaffenhofen, Germany.

Jonathan Brembeck
Jonathan Brembeck is the project manager of ROboMObil and head of the Vehicle Systems Dynamics department for automotives at the Institute of System Dynamics and Control (SR) at the DLR Robotics and Mechatronics Center (RMC) in Oberpfaffenhofen, Germany.