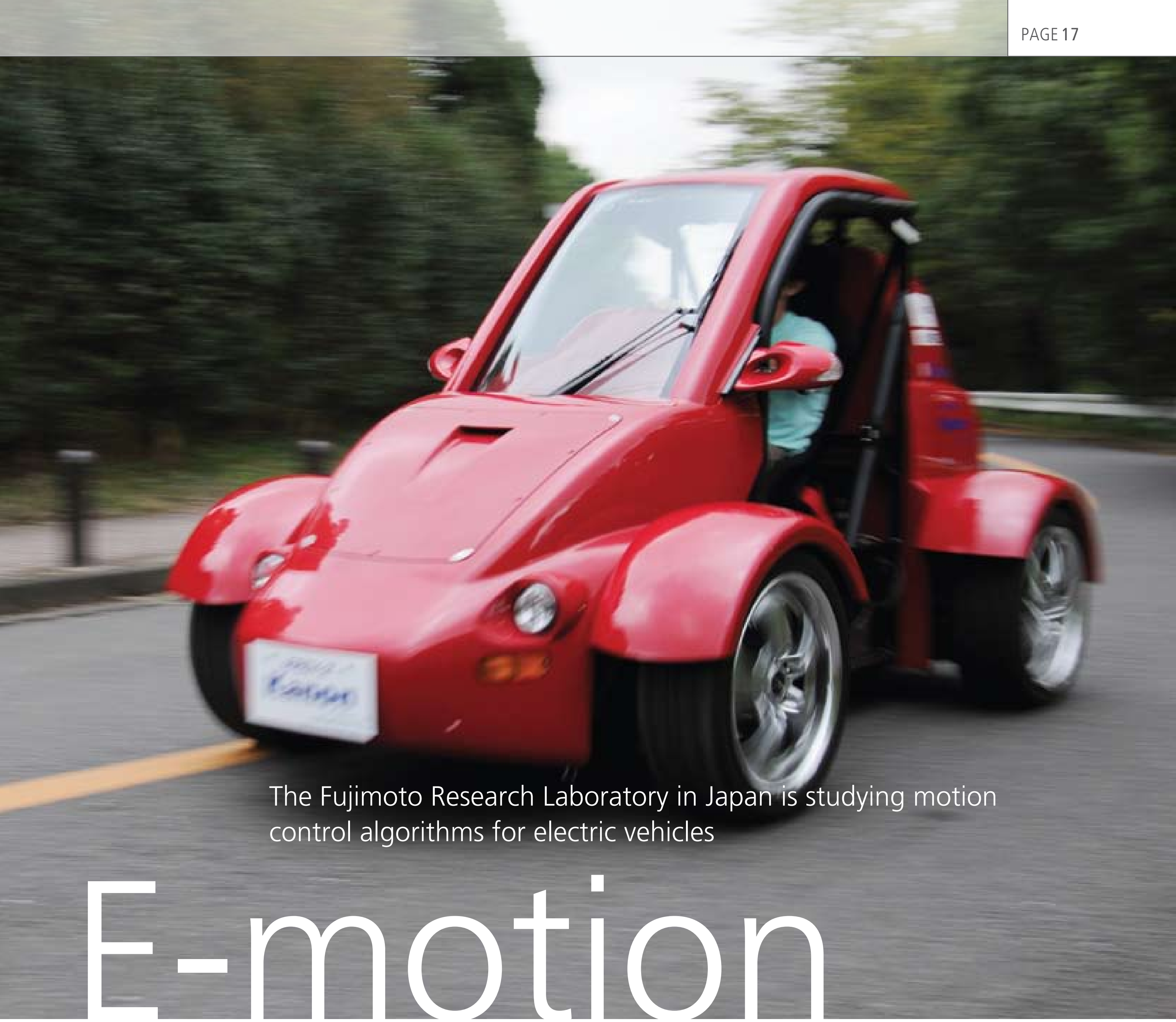
Research into developing electric vehicles has progressed over the last few years. These vehicles have the potential for completely new vehicle designs, and also different riding and handling characteristics. The in-wheel technology often used in this field requires dedicated control algorithms for convenient and efficient motion control.

Advantages of an EV

In recent years, heightened concern for energy and environmental issues has focused attention on electric vehicles (EVs), leading to a variety of research projects. The advantages of an EV are not restricted to problems such as CO_2 emissions, though. From the standpoint of vehicle motion control, an EV has three main advantages:

- Extremely fast torque response
- Accurate determination of generated torque
- Compact, lightweight motors can be incorporated inside each wheel to drive each one independently



The Fujimoto Research Laboratory in Japan is studying motion control algorithms for electric vehicles

E-motion

Research Focus at Fujimoto Research Laboratory

The Fujimoto Research Laboratory at Yokohama National University in Japan investigates electric vehicles, focusing particularly on methods of electric drive technology. The laboratory is working on a type of drive known as an in-wheel motor, and is also studying the safety aspects of electric vehicles on slippery road surfaces. Research is being conducted on attitude control methods that employ yaw rate control, using this yaw moment to prevent spinning and drifting when turning.

Development Objective: A Yaw-Stable Vehicle

An electric motor goes straight from zero to its maximum torque. Thus, uncontrolled torque requests can result in immediate loss of static friction, which results in vehicle oversteer during extreme cornering. To detect the beginnings of oversteer, the vehicle's yaw rate has to be determined. The yaw rate is the angular velocity with which a vehicle rotates around its vertical axis. If external effects push a yaw-stable vehicle off course, in the ideal case it returns to a straight path without the driver having to steer.

In-Wheel Motor Technology

The vehicle under investigation uses in-wheel motor technology, i.e., each wheel has its own electric motor and can be driven separately. A completely new type of yaw rate observer was developed especially

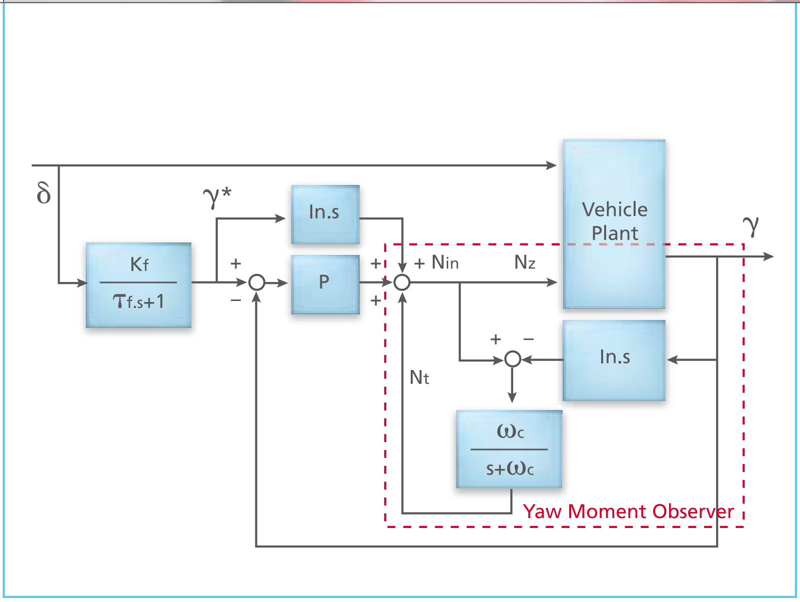


Figure 1: Block diagram of the vehicle stabilization control based on a yaw moment observer.

> "The dSPACE AutoBox is a very easy-to-handle control system, since it is extremely shock-proof and can be used in a voltage range from 8 to 60 V."

Shinsuke Sato, Graduate Student, Yokohama National University

for this kind of drive. The yaw moment can be derived from the difference in drive force between the right and the left wheel, and then used as a control input for stability control of the vehicle (called direct yaw control or DYC for short).
The electric motors require dedicated control algorithms for practical, efficient motion control.

Two-Dimensional Vehicle Control

To control the yaw rate, the lateral force and the actual wheel speed have to be known. The lateral force is a nonlinear variable that is difficult to measure or estimate. The effects of the lateral force can therefore be determined as a disturbing torque. For yaw-rate-controlled vehicles, the equation of motion is as follows:

$$I\dot{\gamma} = (2l_f Y_f - 2l_r Y_r) + N_z$$

where $\dot{\gamma}$ is the yaw rate, Y_f and Y_r are the lateral forces, and N_z is the yaw moment used as the control input of the controller. It is derived from the drive force difference between the in-wheel motors of the right and left front wheels. The proposed control methods are used to configure a yaw moment observer, so that the disturbance moment can be suppressed and the yaw rate can be controlled.
Simulation results show that without the control, the vehicle skids considerably during extreme cornering (figure 3), and its behavior is unstable. Vehicles with yaw rate control are stable.
The results of test runs also show that without control, the yaw rate varies considerably and the vehicle is unstable, but with the control, the yaw rate levels out to a fixed value (figure 2).

These results show clearly that the proposed control method is very effective on slippery road surfaces and increases vehicle safety.

Test Drive with dSPACE AutoBox

To test the control algorithms in practical test drives, the FPEV 2-Kanon test vehicle was equipped with a dSPACE AutoBox containing a DS1103 Controller Board that was responsible for computing the algorithms.
A control system modeled with MATLAB®/Simulink® was loaded to the AutoBox. The AutoBox drives the electric motors via converters. The angular velocity, the torque, the acceleration and the yaw rate are available as analog signals.

Effectiveness of the dSPACE AutoBox

To make full use of the advantages of electric motors, the control algorithms have to be calculated

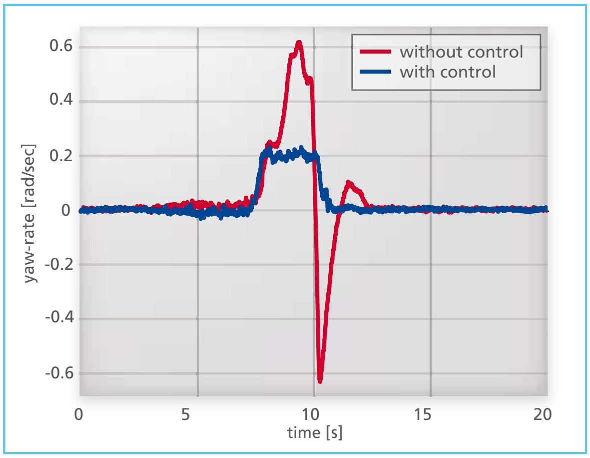


Figure 2: Test results on measured yaw rate. Without control, the yaw rate fluctuates strongly (red); with control, the yaw rate levels out to a fixed value (blue).

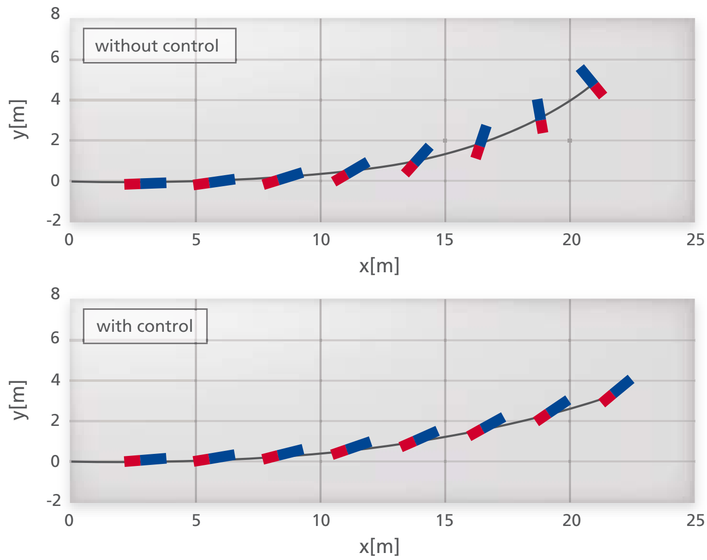


Figure 3: Simulated vehicle trajectories of a steering maneuver on a slippery surface. The vehicle rotates around its yaw axis (top). The vehicle is stable and does not skid (bottom).

Prof. Hiroshi Fujimoto in the development laboratory.

extremely fast. The short sample time of the DS1103 Controller Boards and its low latencies during I/O access meant that the algorithms could be executed in real time. Since the hardware has such extremely fast response times, the algorithms behaved as expected.

Conclusion and Outlook

The safety of an electric vehicle is greatly improved by the control methods that have been developed. They allow tires with low frictional losses to be used without compromising safety. The methods developed at the Fujimoto Research Laboratory result in lower electricity costs and a longer distance driven per battery charge.
The Fujimoto Research Laboratory is currently an active member of a research partnership between automobile manufacturers and suppliers, and will continue its research on powerful, reliable motion controls, including tests run under real-world conditions. The goal is to make these control methods available on the open market.

Prof. Hiroshi Fujimoto
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> "As a result of adopting a dSPACE system, the joint tests performed with a company that we do collaborative research with went smoothly. Even without an extremely convenient tool like the dSPACE system, as an educational organization we have to provide training that enables students to build control systems."

Prof. Hiroshi Fujimoto, Yokohama National University

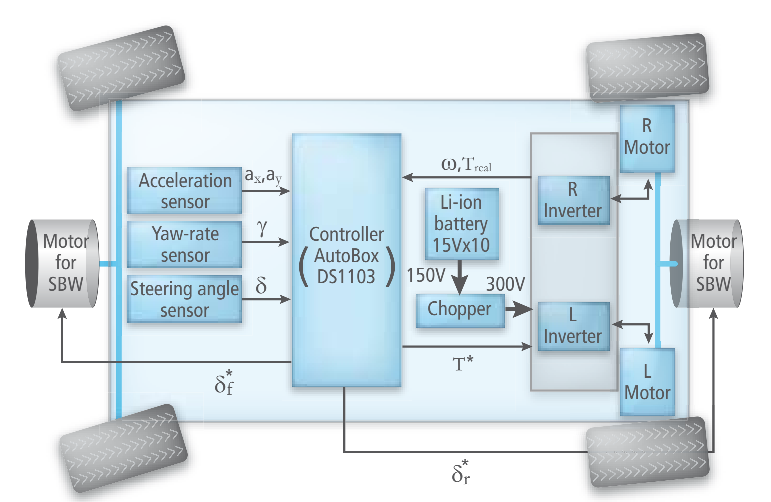

Figure 4: Configuration of the vehicle control system.