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dSPACE MAGAZINE

2/2012

Audi – Rethinking the Starter Battery

STIHL – Two-Stroke Engine with Electronically Controlled Injection

CIRA – Unmanned Space Plane Test Flight

It's great to see how many different fields our tools are used in. One of dSPACE's characteristics has always been that we are not fixated on just one sector or technology, as some of the applications in this dSPACE Magazine again demonstrate. Our diversity reflects our origins in mechatronics, which is a broad-based discipline itself.

Many people see dSPACE as being very automotive, though, and it is true that the automotive sector was and still is the main driving force behind our growth. It certainly keeps us busy fulfilling customers' requests and developing. So there are always plenty of new ideas and things to do. Consultants offering creativity seminars to find ideas for new products don't earn a cent from us: We're running at full load without them. And that won't change in the foreseeable future, since electronics and software are increasing, not decreasing. All the effort going into reducing the number of electronic control units in passenger cars does not mean that things will get easier. They'll just be different.

Ten years ago, I began to ask visionary managers in the car industry every now and then whether they thought there would soon be enough electronics in cars. The first answer I received back then was: "Not even in 30 years!" It wasn't the last time I heard that answer. We want accident-free, comfortable, and efficient driving? Then there's still a lot to be done, because without electronics and software, and without expanding the tools for developing and testing them, we'll never get there. And that's not the end of it. The more that is being and can be developed, and the more complex everything gets, the more attention has to be paid to supporting the development process. At dSPACE, we are working intensively on this very issue, and have just launched SYNECT, our data management platform.
This is one example of how dSPACE can and must grow. We already have over 1000 employees. And we're making room for more, expanding upwards by adding three stories to the first building on our Paderborn campus.

To get back to the idea of comfortable, accident-free driving: I find it interesting how the vision of autonomous vehicles is coming closer. Our first encounter with this concept came when we were still working at the university. The first practical outdoor test of our rapid control prototyping system with code generation for a special DSP chip – the original inspiration for founding dSPACE – was performed for the track guidance control in a Daimler-Benz bus 30 years ago. The test driver no longer had to steer. But he still needed one hand ready near the emergency button and near the steering wheel. Our confidence in driver assistance systems has grown a bit since then.

Dr. Herbert Hanselmann
President

Embedded Success dSPACE

IMPRINT

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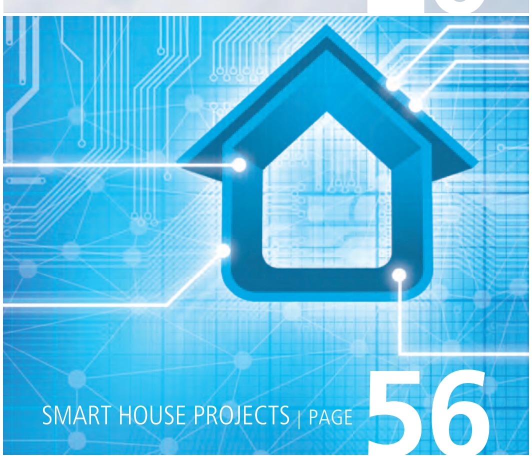
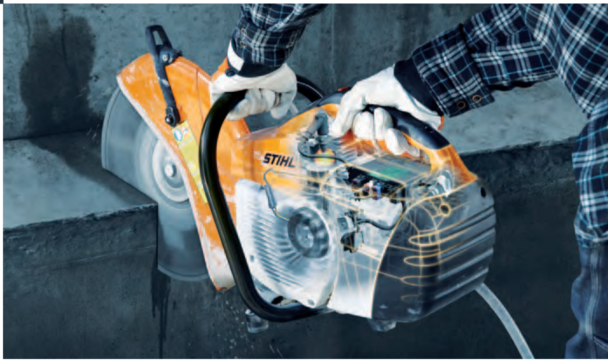


The Cutting Edge

The new TS500i cut-off machine with STIHL Injection is the first-ever battery-less, completely electronically controlled injection system for handheld power tools with a two-stroke engine on the market. STIHL used TargetLink and dSPACE real-time hardware to develop a flexible control unit that ensures easy startup and optimum engine control under rough conditions.

Completely electronically controlled injection for two-stroke engines



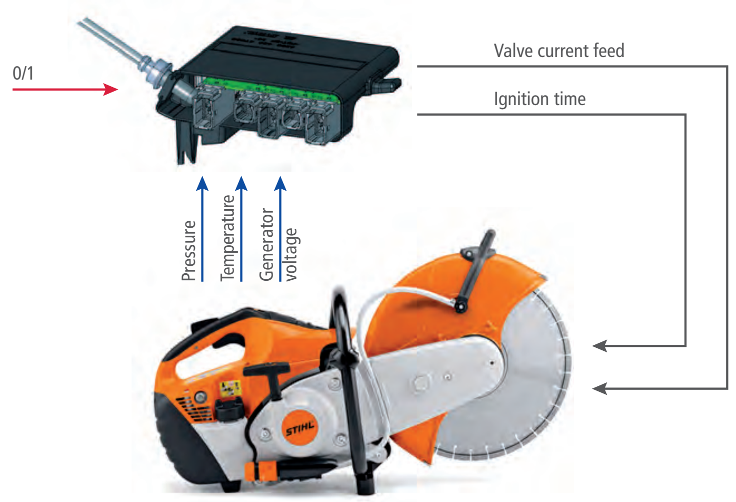


Figure 1: With STIHL Injection, the ignition timing is determined not only by engine speed, but for the first time ever by the load as well.

Coping with Extremes

Handheld engine-powered tools – like those used in construction, civil engineering and forestry – have to satisfy tough requirements. Robustness and safety are the top priorities, but comfort also plays a role in the endeavor to make working in rough conditions as convenient and efficient as possible. There are special requirements for integrating a completely electronic engine control, which makes things like a choke and manual settings unnecessary:

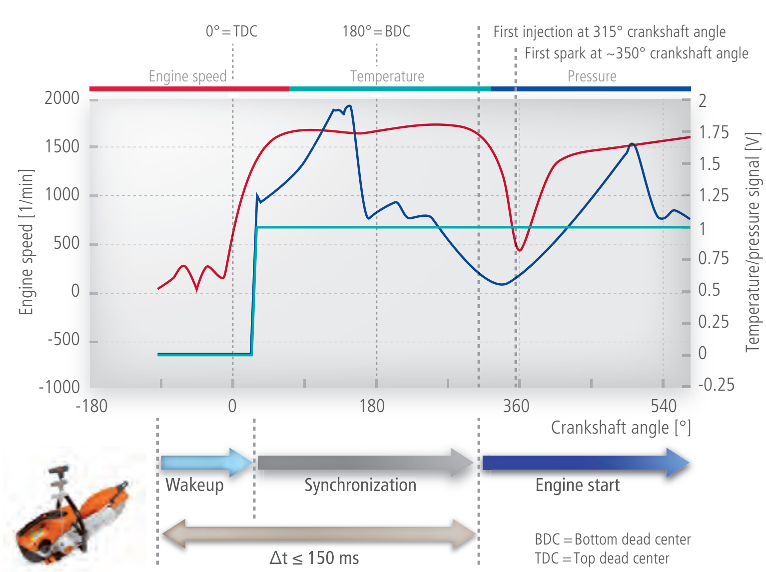
- The quality and constituents of the fuel used (e.g., biofuel/ethanol content) can vary enormously in practical use.
- The tool has only very limited space for system components – and where the ignition and the microcontroller are close together, interference is an additional concern.
- The performance and fuel consumption of the two-stroke engine must be optimal in all operating modes without manual intervention by the user.
- Compliance with the applicable emission standards is essential.
- The system has to be batteryless – which is ideal for startup when the tool has not been used for some time – and must also have automatic diagnostics.
- Maintenance effort has to be as low as possible.
- In addition, the tool frequently changes position during operation, and strong vibrations result. The engine must run smoothly despite this.

To meet all these requirements, STIHL used dSPACE tools to develop a completely electronically controlled injection system especially for handheld power tools with two-stroke engines. The new system first went into operation in the new TS500i cut-off machine. The ECU and software in STIHL Injection are generic in design so that they can be used in other STIHL products. The system was therefore designed for very high engine speeds of up to 16,000 rpm, which can occur in power saws.

System Design and Function

The components of the new STIHL Injection system are the power generator, the temperature and pressure sensors, the ECU, and the injection pump and injection valve. As soon as the crankshaft is started by the

Figure 2: Less than 150 ms are available for the batteryless startup.



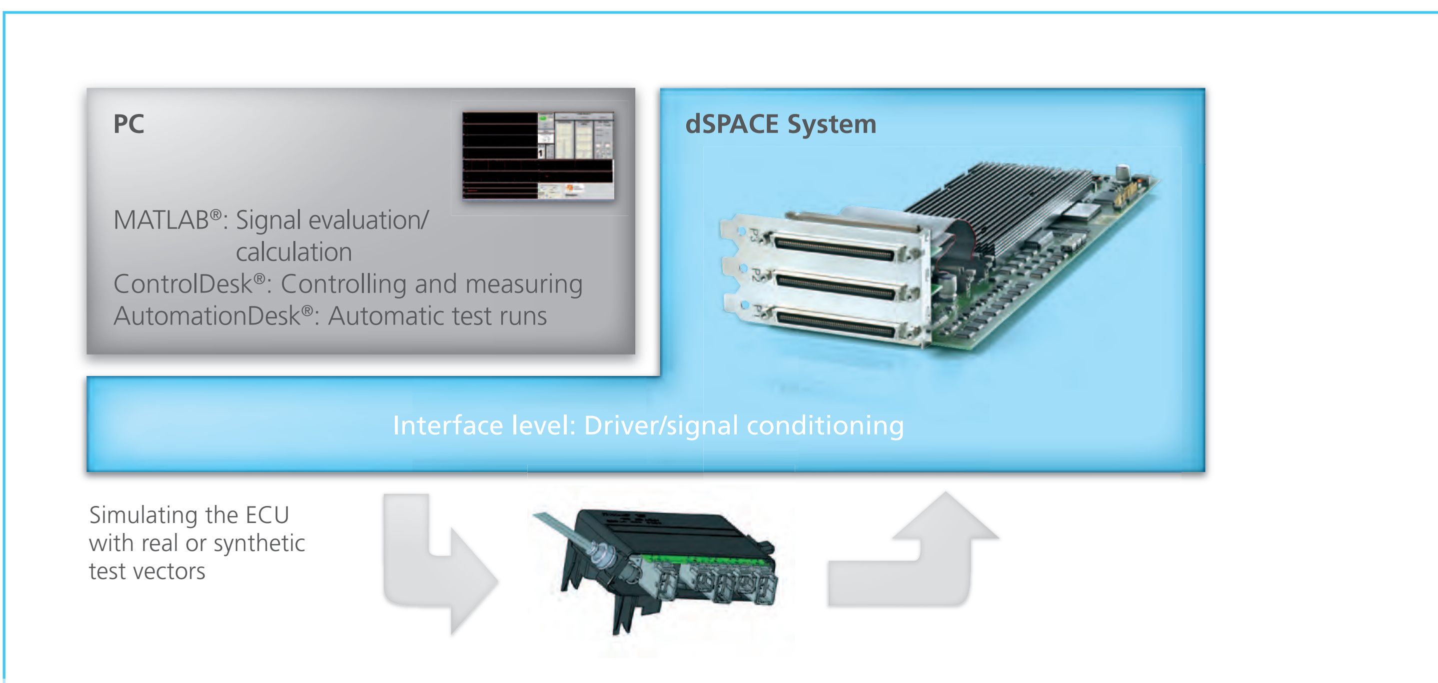
> "With TargetLink, we were able to perform fast iterations and try out changes in the model directly on the target."
>
> *Heiko Däschner, ANDREAS STIHL AG & Co. KG*

starter cord, the generator constantly supplies not only electricity but also the crankshaft position, and therefore the engine speed, to the ECU. The ECU is based on a 16-bit microcontroller with 64 KB flash ROM, 8 KB RAM and a 32 MHz clock rate, and uses the machine's load state to compute the required quantity of fuel, the injection duration and the ignition time. It also electronically controls the water supply for dust suppression. While the injection pump holds fuel pressure at a constant 100 mbar, the injection valve injects the optimum fuel amount directly into the crankcase synchronously to the cycle. The ECU has to perform complete engine management computation with each crankshaft rotation. The objective is to achieve a permanently high torque with minimum emissions. One particular challenge is the batteryless startup process initiated when the starter cord is pulled. The startup process must be completed within less than 150 ms, including powering up the ECU, synchronizing the system components, and performing injection.

Model-Based Development

For flexibility and fast iterations in the development of the software for STIHL Injection, STIHL used the model-based development approach throughout the entire project, combined with automatic production code generation. The mechatronic components were developed in parallel to the algorithms and the ECU. While the ECU and its operating system come from a supplier, STIHL itself developed the entire function model with the real-time concept for engine control, converted it to ECU code, performed system tests on the hardware and software, and calibrated and validated the control on the final device in parallel to development. The software was integrated on the ECU in close consultation with the ECU supplier. TargetLink was used to generate the ECU code from the function model and perform the associated SIL, MIL and PIL tests, supported by dSPACE Model

Figure 3: Error simulation for targeted debugging.



Compare for comparing different model variants. This let developers try out new ideas and changes quickly on the target processor. The final model of STIHL Injection comprises about 1500 TargetLink blocks. During development, STIHL reproduced the control deficiencies that were found, and performed targeted debugging by reproducing the error cases on a dSPACE real-time system (DS1103 plus ControlDesk) combined with extensive test automation via AutomationDesk. The system automatically compared the relevant parameters and checked the diagnostic functions. Static test vectors that had been recorded previously with the real machine were used for stimulation in the tests. Because the system has no battery, a special focus of the test runs was on close synchronization between the hardware and the software.

Objective Achieved

With this combination of model-based development, automatic ECU code generation and error simulation for targeted debugging, STIHL ensured both high software quality and a fast rate of development for the STIHL Injection innovation project, with fast iterations and immediate feedback on the target. Further development of the control will be based on the same development process and dSPACE tools to ensure that new functions can be implemented quickly while preserving maturity. Another STIHL control that will be further developed with the aid of the new development process is M-Tronic, which has been available since 2006. With the successful launch of the TS500i in early 2012, STIHL succeeded in implementing the world's first two-stroke injection engine for handheld power tools in large-scale production. The technology facilitates handling while at the same time boosting performance, and setting new technological standards. ■

Dipl.-Ing. (FH) Heiko Däschner
Dr.-Ing. Georg Maier
Dipl.-Ing. Robert Böker
ANDREAS STIHL AG & Co. KG

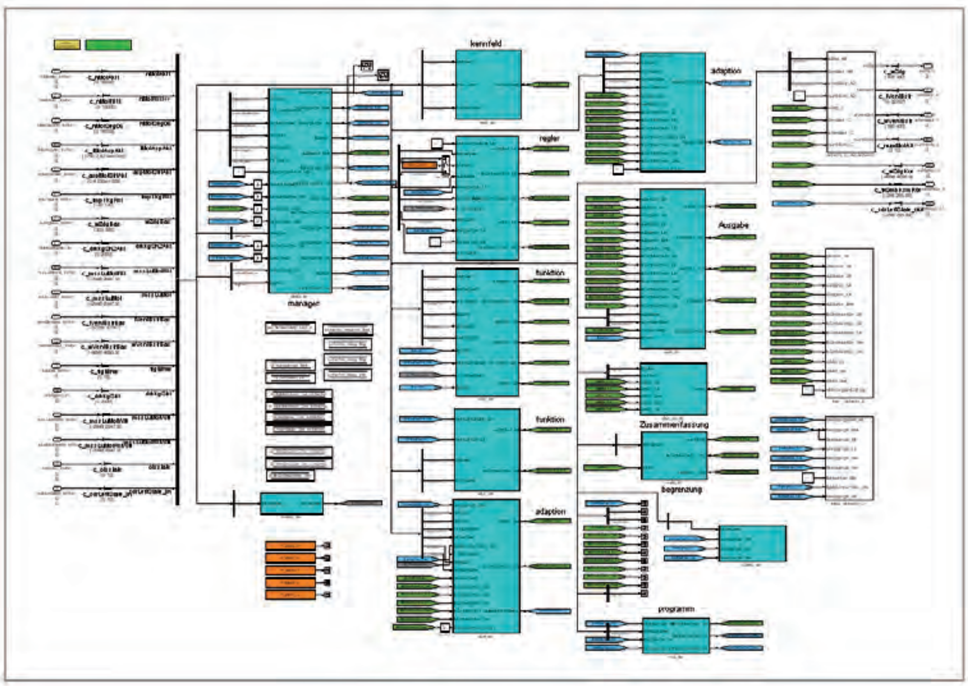


Figure 4: The ECU code from the function model was generated with TargetLink.

Dipl.-Ing. (FH) Heiko Däschner
Dipl.-Ing. (FH) Heiko Däschner heads up the group developing integrated electronic systems at STIHL in Waiblingen, Germany.

Dr.-Ing. Georg Maier
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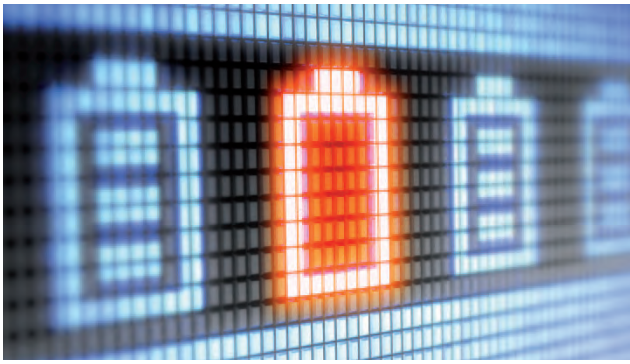
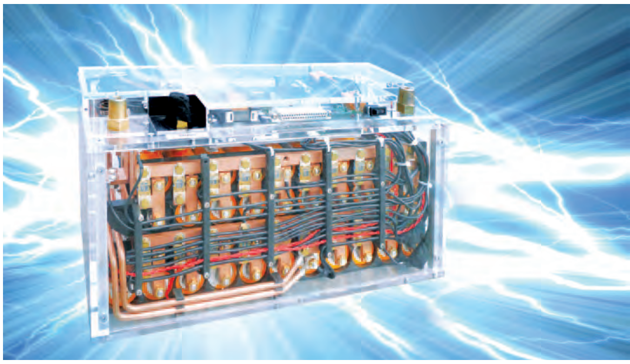
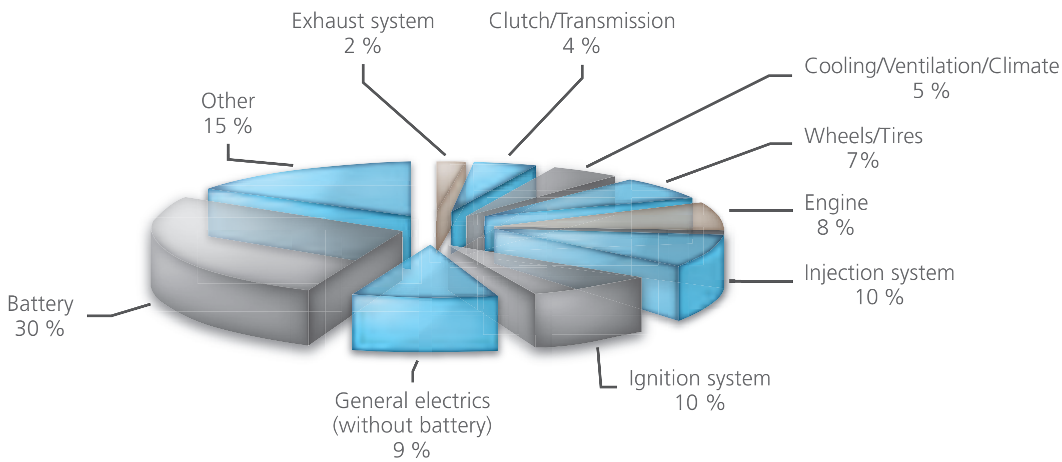
Ions at the Start

Building a demonstrator for a 12-volt lithium-ion starter battery

The 12-volt lead-acid starter batteries used in conventional vehicles are reaching their performance limits. Modern start/stop systems, more electrical equipment, and the increasing electrification of mechanically driven components are pushing up the demands made on energy storage. But at the same time, the need for lightweight construction imposes tight constraints. Developing a lithium-ion starter battery is a very promising approach here.







In 2011, around 30 % of vehicle breakdowns were caused by the 12-volt starter battery. Source: ADAC's Analysis of Assemblies in 2011.

Requirements for the Starter Battery

Two of the current hot topics in automotive development are the continued improvement of overall energy efficiency and reduction of vehicles' CO_2 footprints. Uncompromisingly lightweight construction is required, while at the same time, more and more electric power is needed – due to safety and comfort functions, the electrification of components that used to be driven mechanically, new functions like automatic start/stop, and so on. It all adds up to a high load on the battery. Moreover, the battery also has to meet requirements concerning weight reduction and cycle stability (charge/discharge in start/stop operation) or durability. It is also interesting to look at the causes of vehicle breakdowns in this context. An analysis of breakdown statistics by the German automobile association ADAC in 2009 showed that around 27 % of all vehicle breakdowns were caused by the battery. In 2011, the battery was involved in about 30 % of all recorded breakdowns. In short: conventional batteries have reached their performance limits.

Alternative Battery Solutions

One way to ensure high vehicle availability is to use two-battery electrical systems, plus double-layer capacitors or other battery technologies. Lithium-ion (Li-ion) batteries have especially attractive properties as 12-volt vehicle starter batteries. They currently possess one of the highest energy densities of all the available rechargeable energy storage systems. Their maximum possible charge/discharge cycles are several times those of lead-acid batteries, so they meet the requirement profile's criteria of low weight and cycle stability. For example, a lead-acid battery with a capacity of 92 ampere-hours weighs around 26 kg and reaches approx. 400 charge/discharge cycles at a discharge depth of 20 %. A comparable Li-ion battery weighs only 16 kg and reaches approx. 15,000 charge/discharge cycles at the same discharge depth. The achievable weight reduction of approx. 10 kg improves the vehicle's CO_2 footprint by around 0.85 g.

Challenges: Charge and Temperature

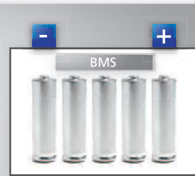
The disadvantages of Li-ion batteries are their extreme sensitivity to deep discharge and overcharging, and their restricted working temperature range. On top of that, the charging requirements vary according to temperature and driving behavior. For example, the highest demand on the energy storage is during short journeys in winter, when chargeability is restricted. These disadvantages can be counteracted by the right operating strategies, working points and other measures. This is a perfect job for electronic battery management systems (BMSs), which also perform numerous monitoring and controlling tasks, such as charge- and temperature-dependent control of the charge and discharge currents. A BMS also performs cell balancing to equalize the charge states in all the cells. Because a battery consists

Lithium-ion Batteries as Replacements for Lead-Acid Batteries

Lead-Acid

- Life cycle: ~ 4 years
- Cycles at 20 % discharge depth:
  - Lead-acid battery: ~ 400
  - AGM (Absorbent Glass Mat): ~ 1000
- Energy density: ~ 40 Wh/kg
- Price: Low
- Complexity: Low

Li-Ion



- Life cycle: ~ 15 years
- Cycles at 20 % discharge depth: 15,000
- Energy density: 50 - 100 Wh/kg
- Price: Currently five times higher than lead-acid batteries
- Complexity: High (requires a battery management system).

Comparison of lead-acid and Li-ion battery systems used as starter batteries in vehicles.

of several cells connected in series, cell balancing must always hold their charge states at the same level to prevent overcharging or deep discharge in individual cell groups.

Starter Battery vs. Traction Battery

The requirements for a 12-volt starter battery are not the same as for a high-voltage battery (traction battery) in an electric or hybrid vehicle. A starter battery has to support recuperation, but does not normally have to supply high currents for long periods, except during the startup process in the combustion engine. It also feeds comparatively low currents into the vehicle electrical system. In normal operation, a starter battery never usually discharges completely. Its charge state is typically in a range around 95 %.

Predevelopments for a Li-ion Starter Battery System

To develop various components in a Li-ion-based battery system efficiently, Audi ran several parallel subprojects. These included a battery demonstrator including battery electronics, thermal and electrical battery simulation models, a control algorithm (integrated in the BMS) for the charge current, and a tool chain for in-vehicle rapid control prototyping (RCP). The aim of this predevelopment project is to investigate and test possible approaches and methods for production use before actual production development kicks off. The experiment setup is designed for trying out and evaluating as many ideas as possible. This was achieved by constructing a battery demonstrator with electronics components and running all the algorithms on an RCP system.

Concept for Battery and BMS Algorithms

Initially, the battery demonstrator must match the form factor for conventional lead-acid starter batteries, which it has to replace in conventional vehicles. For future production use, more individualized shapes could be designed and implemented. In addition to the terminal voltage poles, the demonstrator has an interface to the RCP system with the BMS

Glossary

Electrochemical impedance spectroscopy – Method of disturbance-free analysis and characterization of materials. The system's impedance spectrum is obtained by evaluating excitation signals of different frequencies and the system responses.

Finite element method (FEM) – Numeric method for solving partial differential equations: for example, ones used as mathematical descriptions of physical processes.

Serial Peripheral Interface (SPI) – A bus system for synchronous, serial data transmission, with which digital circuits can be connected according to the master-slave principle.

Inter-Integrated Circuit (I²C) – A serial data bus that is used mainly for communication between different circuit parts within one device: for example, between a controller and peripheral control circuits.

algorithms. The RCP system can be installed in close proximity to the battery and connected to it via a bus system. In actual production, a solution would be integrated into the battery itself. The battery case contains the Li-ion cells and the electronics that measure the voltages and currents of the cell groups and the temperatures of selected cells. The electronics also enable cell balancing and serve as an actuator for controlling the charge currents. The battery demonstrator's internal structure has to take both thermal and electrical aspects into account. This includes the spatial arrangement of the cells and the electronics, and also the electrical connection of cell groups to current rails. Simulation was used with various test specimens to optimize the structure and topology of all cell connections.

Model of a Li-ion Starter Battery

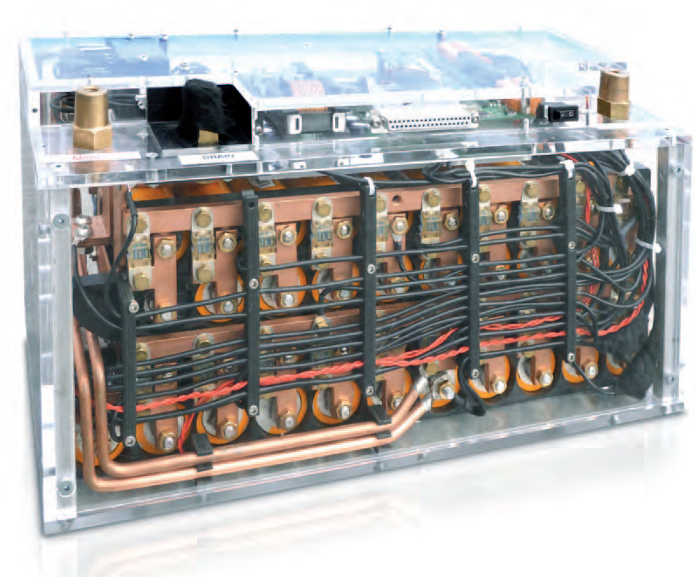
A battery model was developed for simulation-supported studies on how the Li-ion starter battery and the BMS algorithms behave. The model is used for preparatory investigations to obtain important information on the battery's electrical and thermal properties. To represent the battery's characteristic features in real time, it was necessary to combine a terminal voltage model with an electrothermal finite element method (FEM) model. Parameterizing all the models was a special challenge. To obtain a comprehensive characterization of the battery, the step responses of the battery cells were evaluated, and an electrochemical impedance spectroscopy was performed. The results were merged in a hybrid model to produce an overall model with high quality and dynamics. When completely parameterized, the model represents aspects such as the battery's state of health, including calendar aging and charge-cycle-related aging.

Developing the BMS Software

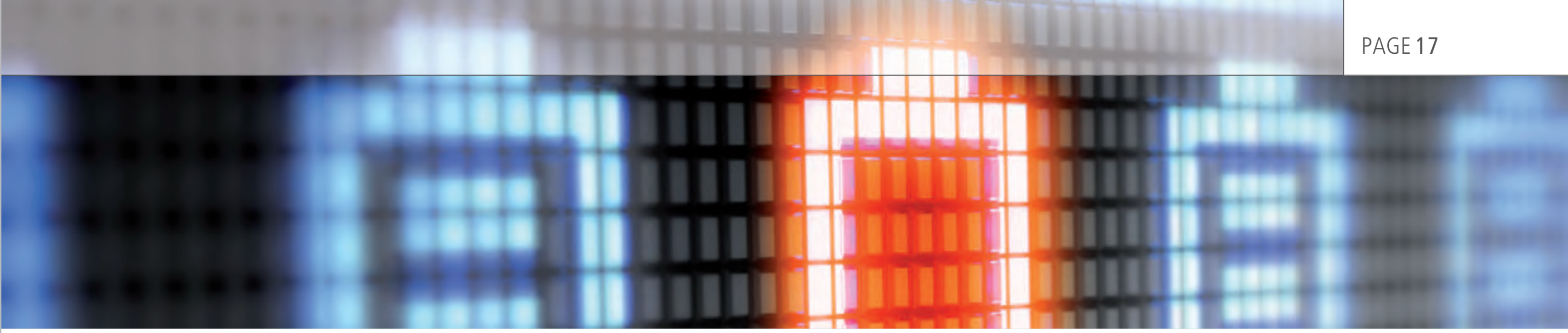
The elementary components in the BMS software are algorithms that control the charge current, initiate cell balancing, and measure the battery's state of charge (SOC) and state of health (SOH). They also redundantly monitor the battery for overvoltage, overtemperature and overcurrent. For the experimental system, the SOC algorithm was designed with a Kalman filter to eliminate measurement errors and malfunctions. In addition to the SOC, the software also analyzes the battery's SOH. The self-diagnostics implemented in the system explicitly address individual cells to provide data on the available capacity and state of health.
To equalize the cell charges, passive cell balancing was chosen. With this method, individual cell groups are discharged selectively down to the level of the weakest group, until all the cells have an identical charge level. The initial predevelopments and subsequent cost effectiveness analysis of active cell balancing, in which the charge is transferred from cell to cell, revealed that investments in active balancing would not have a positive economic impact until after the end of the assumed vehicle life cycle. It was therefore decided not to use it in a starter battery.

Prototype Construction of a BMS

During development, the BMS had to be tested in test drives at an early stage in order to examine and adjust the operating strategy in interaction with the vehicle's energy management (EM) system and to run climate tests. The rapid control prototyping system dSPACE MicroAutoBox was used as the BMS ECU. The control algorithm



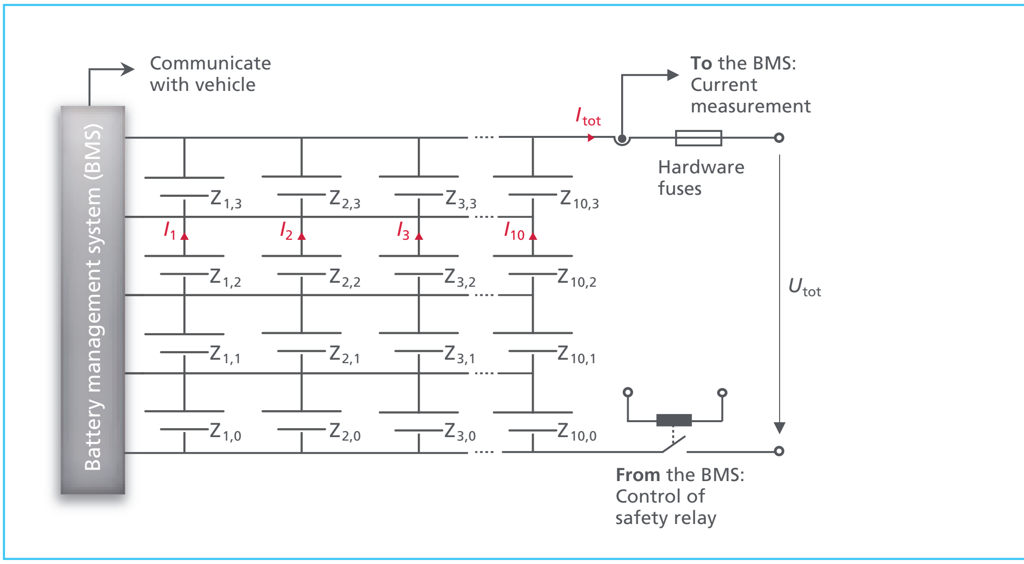
The Li-ion battery demonstrator with transparent plexiglass enclosure. The cells, current rails, contacts and electronics can all be seen. To reduce weight, later production-ready systems will conceivably have aluminum connectors instead of copper current rails.



> "The MicroAutoBox does exactly what is expected of a prototyping system. You just load new controller software and immediately try it out in the vehicle."
>
> *Dipl.-Ing. (TU) David Vergossen, Audi Electronics Venture GmbH*

is created in model-based development and can be loaded straight from the development PC to the MicroAutoBox, where it is executed. The MicroAutoBox is connected to the EM system. The battery's integrated electronics perform the evaluation at cell level. They also include an actuator system for cell balancing, plus output semiconductors for charge current limitation and DC-DC converters for determining the SOH. Communication runs via a serial peripheral interface (SPI)/inter-integrated circuit (I^2C). The MicroAutoBox is connected via a dSPACE Programmable Generic Interface (PGI1). With this setup, the Li-ion starter battery can be operated in a vehicle and also in the laboratory. It is installed in the vehicle simply by replacing the production starter battery with the Li-ion battery demonstrator and connecting the MicroAutoBox to the vehicle's LIN bus and the battery. Laboratory operation is also possible without connection to the vehicle bus.

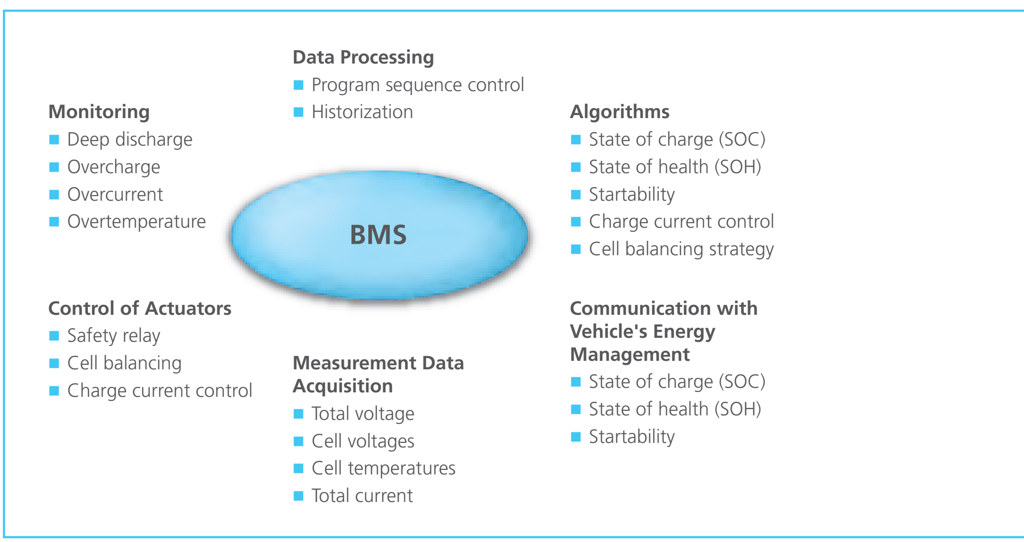
The basic structure of a 12-volt Li-ion multicell battery system.

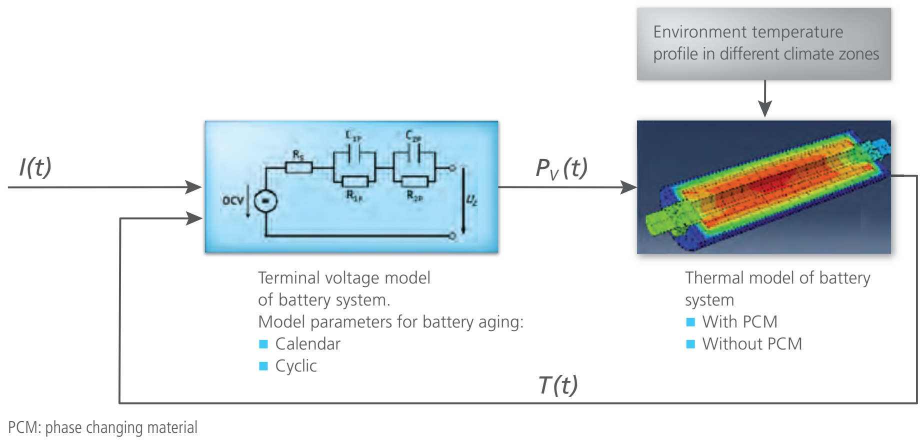


Special BMS and Battery Functions

For optimum operation of the Li-ion starter battery, and to avoid premature aging, the charge current is limited by power transistors that perform linear current control. In the experiment setup, the parasitic heat of the power semiconductors is used to heat the battery so that it can absorb the charge better at low

The BMS for the 12-volt Li-ion starter battery performs a great variety of tasks.





A terminal voltage model coupled to an electrothermal FEM model to predict the life expectancy of the battery system.

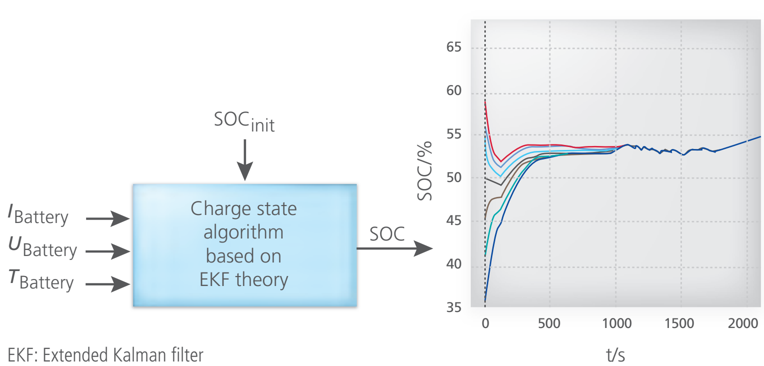
> "The expert field of batteries has been transformed by the Li-ion starter battery, which can already be driven on the road thanks to dSPACE MicroAutoBox."
>
> *Dipl.-Ing. (TU) David Vergossen, Audi Electronics Venture GmbH*

temperatures. The transistors are therefore installed in the battery at various locations with favorable heat properties. The battery's temperature is measured continuously at four measurement points via the integrated electronics. These high technical costs are justified only when they are part of predevelopment.

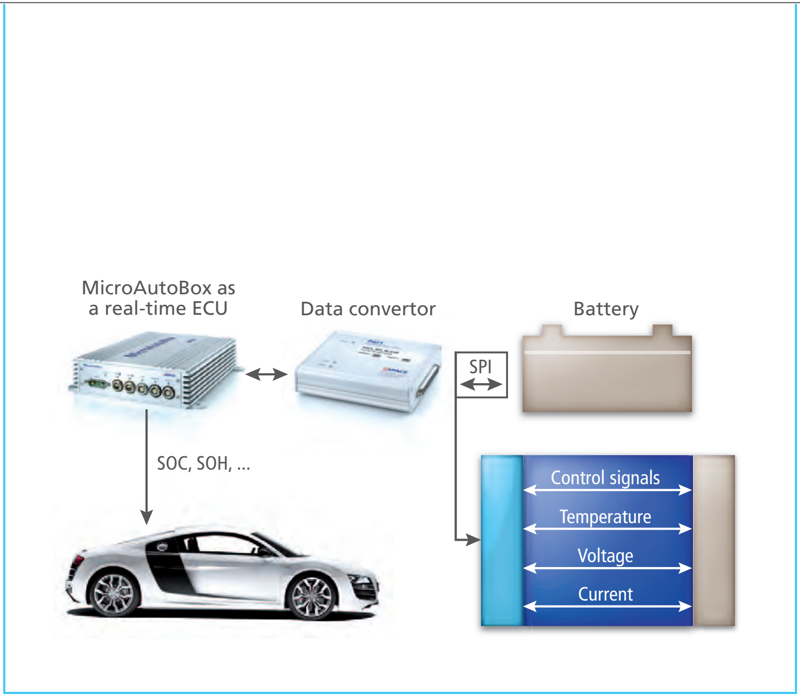
The BMS in Practical Trials

The battery demonstrator with the MicroAutoBox is currently in the test phase, undergoing test drives and also tests on a climate-controlled chassis dynamometer. The battery can be operated with a controller, i.e., with heating, as well as without a controller. The results of these tests are used to optimize the control algorithms even further.

The results show that a Li-ion starter battery with a BMS can be a suitable substitute for a lead-acid battery. Its considerably greater cycle stability meets the requirements of start/stop operation at a low weight, but currently still at a much higher cost.



Developing a charge state algorithm. The signal behaviors show the SOC adaptation with false initializations of different sizes.



Simulation results tried out in practice by test drives with MicroAutoBox. Immediate real-time vehicle tests mean short software development cycles.

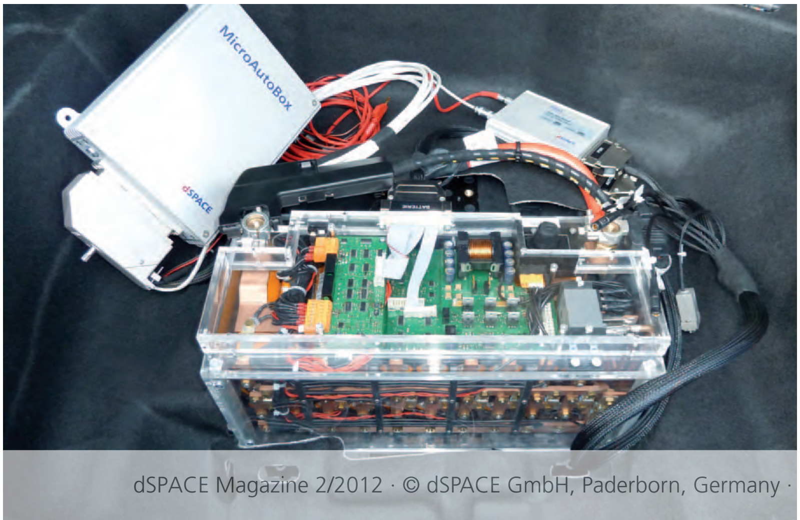
The experience gained with the RCP system can be used if and when production development begins. ■

David Vergossen Dipl.-Ing. (TU)
Audi Electronics Venture GmbH, AEV

Expression of Thanks

This article is based on the E³Car project (Nanoelectronics for an Energy Efficient Electrical Car – AEV Subproject: Research into an Innovative Algorithm for State Detection in Lithium-ion Batteries), which is funded by the Federal Ministry of Education and Research (BMBF) and the EU (ENIAC JU Project) under the reference numbers 13N10395 (BMBF) and 120001 (ENIAC). The authors bear sole responsibility for the contents of this publication.

In the vehicle, the Li-ion battery replaces the conventional starter battery – here it is in the vehicle's spare wheel recess.



In Brief

The use of a lithium-ion starter battery was investigated as part of the BMBF/ENIAC research project at AEV. The project goal was to research a cycle-stable, less heavy replacement for the lead-acid battery. A battery demonstrator and BMS algorithms were created during the development. Fundamental studies were performed to ensure reliable functioning:

- Modeling the utilized cells
- Modeling the entire battery
- Developing the battery electronics
- Battery operating strategy
- Designing the capacity with regard to SOH, startability, quiescent current, cyclization
- SOC measurement with SOH adaptation
- Thermal simulation
- Designing current rails and contactor technology

The prototype was implemented with dSPACE MicroAutoBox. It is used as the ECU in laboratory tests and in test drives, and supports fast function development. Initial testing of the new battery and the BMS software produced convincing results.

David Vergossen
Dipl.-Ing. (TU) David Vergossen is Project Leader for the Li-ion starter battery at Audi Electronics Venture GmbH in Ingolstadt, Germany.

After being lifted to an altitude of 25 km by a balloon, the unmanned space vehicle (USV) glides for close to two and a half minutes, executing a series of flight maneuvers and collecting a wealth of measurement data.

Testing the onboard computer of an unmanned space vehicle

Diving Back to Earth

The Centro Italiano Ricerche Aerospaziali (the Italian Aerospace Research Center, or CIRA) is using an unmanned space vehicle (USV) to research technologies that are vital to the development of future space transporters. The onboard computer used in the test flights previously underwent comprehensive testing with the aid of dSPACE tools.

The Alternative to an Expendable Vehicle

Even before the age of the Space Shuttles came to an end with their very last flight in mid-2011, various research facilities across the world had initiated development programs for alternatives. After all, the idea of a reusable space transporter is an extremely attractive one, as it has enormous potential for saving costs and avoiding space debris as compared with expendable vehicles. For example, it does not result in burnt-out rocket stages orbiting the Earth as hazardous junk. CIRA is using a USV as a "flying laboratory" for research into all the important aspects of developing the reusable space transporters of the future, such as thermodynamics, elasticity, heat shield technologies, navigation techniques, flight mechanics, etc. The USV already performed two test flights and provided valuable data on factors such as the pressure, force and temperature conditions on the outer shell.

Figure 1: The approx. 9 m long USV glides powerlessly back to Earth, guided only by an onboard computer.

Nosedive, Size XXL

The second test flight took place on April 11, 2010, when the USV was first lifted to an altitude of 25 km with the aid of a stratospheric balloon. After undocking from the balloon, it executed a two-minute-long glide during which it executed a measurement program, and finally parachuted into the sea off the coast of Sardinia (figure 3). Its speed was mostly around Mach 1, but for a while it was also approx. Mach 1.2. During the flight, the USV constantly collected all the data (flight altitude, speed, acceleration, etc.) that was necessary for the onboard computer to guide it safely. The onboard computer itself had previously undergone an intensive test program using a dSPACE system.

Flight Guidance System for Autonomous Gliding

To control the gliding flight right up to splashdown, the USV uses various sensors to collect data on its position, attitude, speed, acceleration, etc.:

- Magnetometer (to determine the USV's attitude relative to the Earth's magnetic field)
- Acceleration sensors (MEMS acceleration meters, i.e., micro-electric mechanical systems)
- Optic fiber gyroscope (to determine the USV's attitude relative to its trajectory)
- GPS sensors (Global Positioning System to measure position and speed)
- Air data system (for example, to determine the Mach number via back pressure sensors)

The onboard computer processes the measurement data from all these systems in real time and uses it to compute the commands needed to adjust the control surfaces and ensure that the USV's autonomous gliding flight goes according to plan. "We simulate the flight including all the sensor values with the dSPACE system," explains Giovanni Cuciniello, responsible for the Guidance, Navigation and Control (GNC) Laboratory at CIRA. "This means we can test the onboard computer before the USV even leaves the ground." The USV is studded with all sorts of sensors, such as the more than 300 piezo sensors that measure the pressure distribution on the outer shell during flight. Engineers can use this data to optimize aspects such as the shape of the USV.

Testing the Flight Control System

The dSPACE system (figure 4) for testing the flight control system consists of a DS1005 Processor Board (which computes the flight sequence including the associated sensor values) and various I/O boards for connection to the onboard computer. The experiment software dSPACE ControlDesk is used to monitor and control all the experiments. Typical tasks performed by ControlDesk are monitoring and recording the simulated environment, and possibly changing it, for example, increasing the balloon ascent velocity or varying gust strength during free flight. ControlDesk also allows failures to be injected in the simu-

> "We were able to test the onboard computer's functions comprehensively before the flight with the aid of the dSPACE system."
>
> *Giovanni Cuciniello, CIRA*

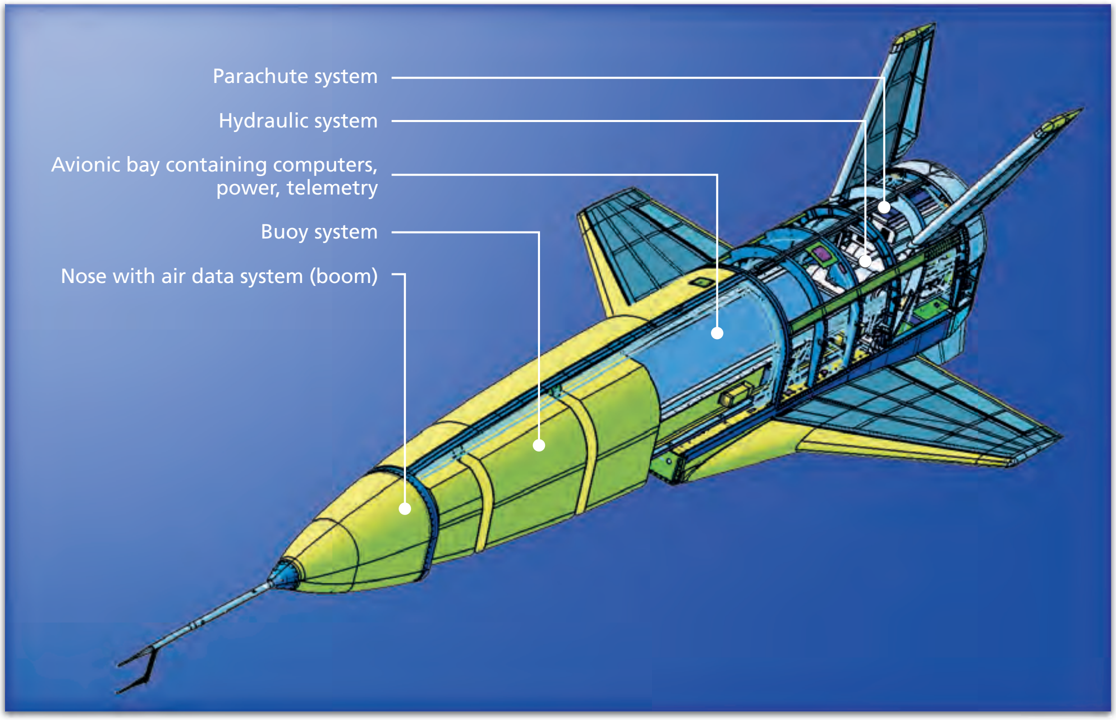
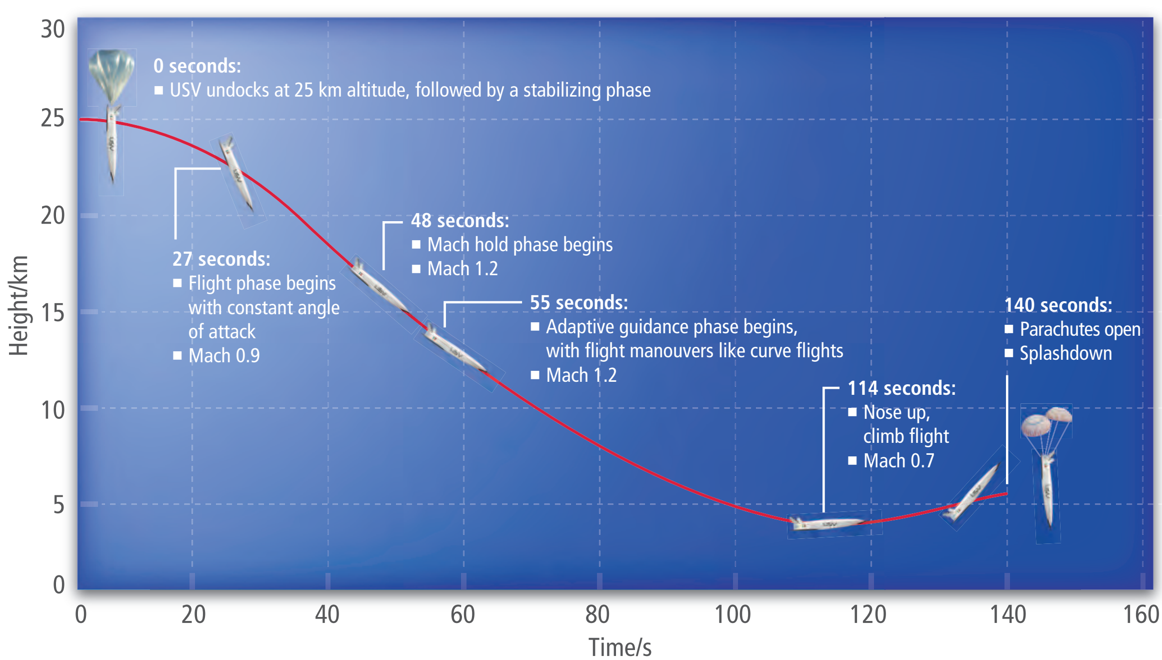


Figure 2: Structure of the USV. Its outer shell is studded with devices such as hundreds of pressure sensors.

lated balloon and vehicle subsystems in order to analyze the system's reactions. Compared with traditional research and development methods, using the dSPACE real-time control platform enabled faster and more complete development of the flight control system; the advantages are both the reduction in time and costs for the system development cycle and also improvements in system reliability.

The tests are performed in 3 stages: (1) software-in-the-loop, (2) mobile

Figure 3: During the two-minute gliding flight, the sensors on the outer shell collect a mass of measurement data during all sorts of flight maneuvers.



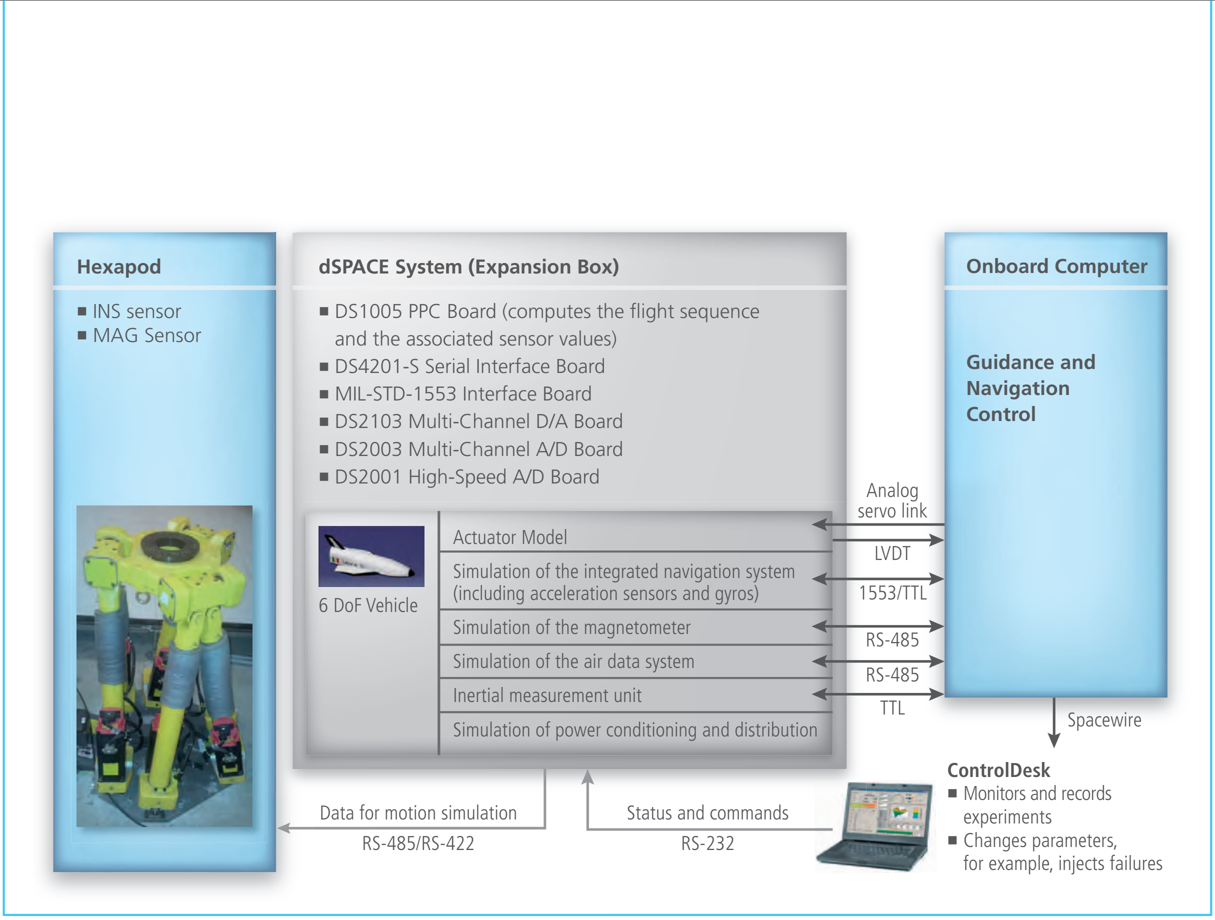


Figure 4: The dSPACE system computes the flight mechanics and sensor/actuator models in real time. This data is used to test the onboard computer. In parallel to this, the current flight movements are performed by a hexapod on which real sensors are mounted.

tests on a ground vehicle, (3) hardware-in-the-loop.

1. Software-in-the-loop:
This is a pretest to check the basic functions of the flight control software. The dSPACE system simulates the USV's flight mechanics properties and all its sensors. All the models were previously developed in MATLAB®/Simulink®. Real sensors are not yet integrated at this stage.

2. Mobile tests:
The real sensors were installed in a vehicle to test whether they work properly during drives (both alone and in interaction), for example, whether they process the constantly changing GPS data and acceleration values correctly.

3. Hardware-in-the-loop:
This step (figure 4) finally tests the exact onboard computer that will be used later in the mission. As in the software-in-the-loop test in step (1), the dSPACE system again simulates the flight mechanics and all the sensor values. This data is then passed to the onboard computer. Its reactions control a hexapod on which real sensors are mounted.

In the Future: Heat Shield Tests
Following the two flights already performed by the USV1, the aim of

> "The dSPACE real-time system speeds up development times, reduces costs, and increases the overall system reliability."
>
> *Giovanni Cuciniello, CIRA*

Figure 5: The new European VEGA rocket lifts off for its maiden flight on February 13, 2012. One of its future flight missions will be to carry CIRA's USV into orbit.

the future unmanned system USV3 is to perform a reentry mission from orbit to ground landing. In order to do this, the European VEGA rocket will lift the USV3 from the European spaceport in Kourou into a low-earth orbit (200-300 km altitude).

After completing a few orbits, the USV3 will execute a de-orbit to start its reentry at hypersonic speed and fly through the atmosphere autonomously from hypersonic down to supersonic, transonic and subsonic regimes to landing on a conventional runway. "It will be exciting to see whether all the systems on board the USV will still function as planned with outer shell temperatures of about 2000 °C," says Giovanni Cuciniello from CIRA. The long-term objective of CIRA's USV program is to develop a space transporter that takes off from the ground like an airplane, reaches its orbital altitude, and can then land on any airfield in the world. ■

Watch the full drop-flight test of the USV1 from preparations to lift-off to parachute landing.
www.youtube.com/watch?v=BhoXgWKjVL0

Giovanni Cuciniello
Giovanni Cuciniello is head of the Guidance, Navigation and Control (GNC) Laboratory at CIRA in Capua, Italy.

Developing an integrated safety system for the Indian automotive industry

Systematic Vehicle Safety

The growing number of powerful vehicles on Indian roads is imposing increasingly tough demands on the vehicles' safety. On behalf of the Indian automotive industry and the Ministry of Commerce and Industry, the Automotive Research Association of India (ARAI) is producing a concept for high-performance safety systems, together with a sample process for the model-based development of such systems.

Safety Systems for the Indian Car Market

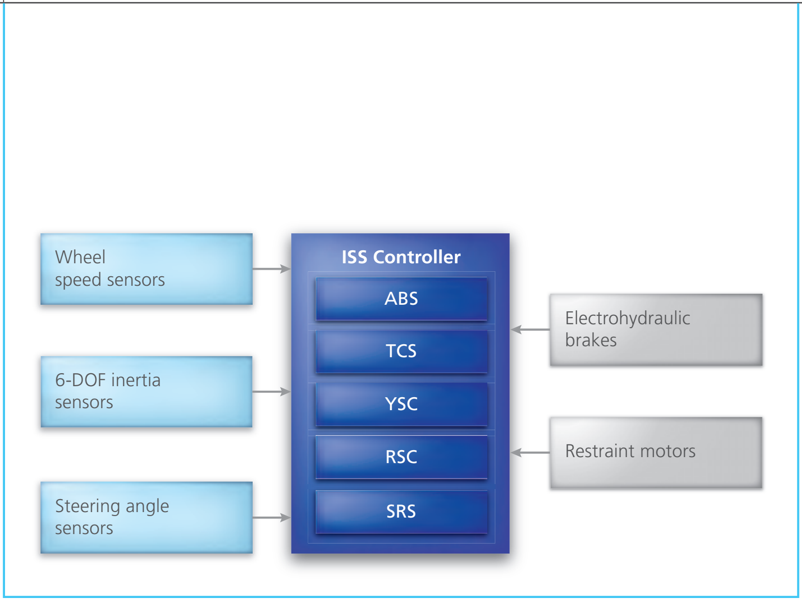
India has one of the largest populations in the world – over 1.2 billion people – and is experiencing a rapid expansion in mobility. The ideal means of transport for many local conditions are pick-ups and sport-utility vehicles (SUVs), large off-road vehicles with powerful engines. ARAI undertook to produce the technical concept and perform proof of concept for developing optimal safety systems for this class of vehicle. The objective of the project was to develop an integrated safety system (ISS) that uses the existing infrastructure of the brake modulator and the integrated sensor cluster in an SUV. The proof of concept involved designing and developing the following functions:

- Electronic stability control (ESC) including an antilock braking system (ABS), traction control system (TCS) and yaw stability control (YSC)
- Roll stability control (RSC)
- Active seat belt restraint system (ASBRS)

Far-Reaching Project Goals

The automotive electronics department (AED) at ARAI performed the kick-off project for an integrated safety system and is making the results available to the Indian automotive industry. Development of the active safety systems was completely model-based and focused on the following project goals:

- Design an integrated, self-developed safety system to be further developed for the Indian market



The integrated safety system (ISS) comprises several safety functions. It evaluates signals from various vehicle sensors and controls the brakes and the belt restraint motors.

- Build expertise in the model-based design of embedded automotive control systems
- Help the auto industry to develop its own solutions for future requirements

New Methods and Tools

Prior to this project, ARAI was using traditional handcoding for controller software. Because the new safety system was of importance to multiple companies, the decision was taken to systematically apply model-based development. This made it necessary to introduce a new, integrated tool chain for model-based development with MATLAB®/Simulink®.

Before starting the project, ARAI thoroughly evaluated various commercially available products for rapid control prototyping (RCP), hardware-in-the-loop (HIL), etc. The developers examined whether each system was suitable for its specific tasks in the new development project and evaluated how well it integrated into the process.

For the rapid control prototyping (RCP) system, ARAI decided to use a combination of MicroAutoBox and RapidPro from dSPACE. The hardware-in-the-loop test station uses a dSPACE Simulator. Together with dSPACE's software tools AutomationDesk® and ControlDesk® Next Generation, these systems form a tool chain that seamlessly supports controller development and electronic control unit (ECU) testing.

Controller Prototyping

After being modeled, the control algorithms have to be tested and optimized on the actual controlled system. This classic RCP task is carried out first in the laboratory and then on a MicroAutoBox in a vehicle. The MicroAutoBox acts as a prototyping ECU which runs the controller models. The RapidPro system adjusts (conditions) the signals to the needs of the controlled system.

Because most parts of the controller model had already been tested by model-in-the-loop (MIL) simulation, it was easy to transfer them to the MicroAutoBox and run them immediately. ControlDesk Next Generation was the central user interface for loading and running models and monitoring signals.

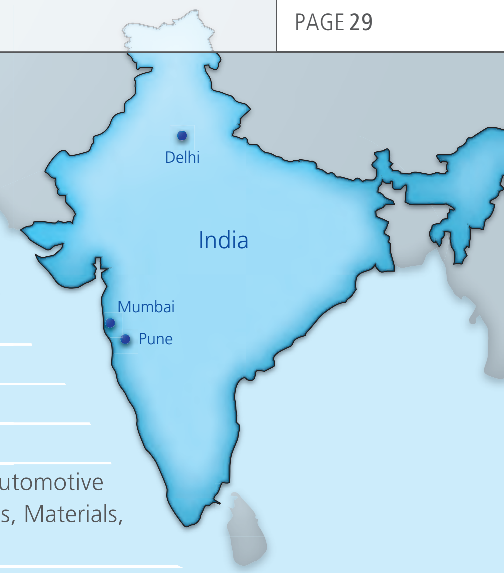
Further Development and Optimization on the HIL Test Rig

This was the first project in the field of chassis control, so a part of the development was performed in an experiment environment in the laboratory. A test rig consisting of real brake hardware and a simulator was set up for this. The ISS model ran on the MicroAutoBox, where it could easily be modified and optimized.

This procedure offers possibilities that MIL simulation does not readily provide. For example, it ensures the precise time behavior of critical components.

The test system was also used to test communications with elementary vehicle components and with actuators and sensors, to detect

The vehicle used to carry out the ISS project and test the developed controllers.



Profile: The Automotive Research Association of India (ARAI)

Established:	1966
Location:	Pune, INDIA (150 km south-east of Mumbai)
Manpower:	More than 530
Facilities:	11 laboratories with a focus on: Emissions, Safety & Homologation, Automotive Electronics, Passive Safety, Vehicle Evaluation, NVH, Structural Dynamics, Materials, Calibration, Post Graduate Academy
Accreditations:	ISO 9001, 14001, OHSAS 18001 & NABL

The Automotive Research Association of India (ARAI) is an industrial research association of the automotive industry in collaboration with the Indian Ministry of Commerce and Industry. The objectives of the association are research and development in the field of automobile construction for industry, product design and development, the evaluation of automotive accessories, standardization, technical information services, courses on using modern technology, and performing special tests. ARAI has been playing a crucial role in ensuring safe, less polluting and more efficient vehicles. The association provides technical expertise in R&D testing, certification, homologation and the framing of vehicular regulations.

> "Because the dSPACE systems were easy to use and very convenient, we were able to concentrate completely on developing the control algorithms."

Arun B. K-omawar, ARAI

errors, and to tackle fundamental calibration tasks. The test sequences can be automated and are completely reproducible, so the controller and the bus communication can be examined and evaluated efficiently and systematically.

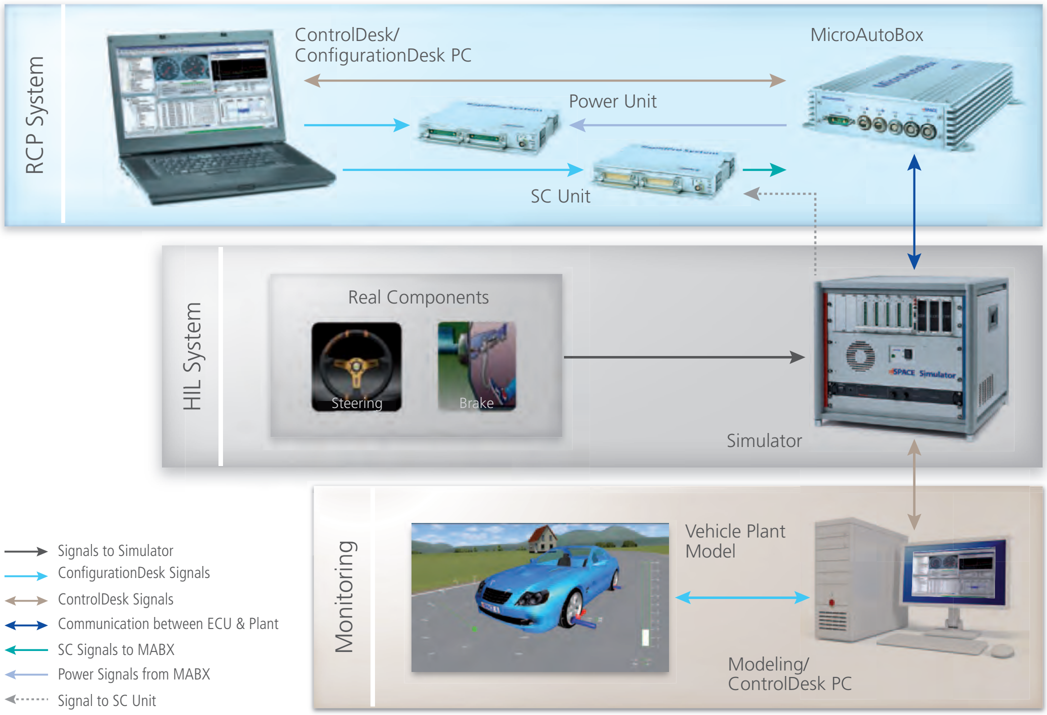
Structure of the Test Rig

The test rig is made up of a simulator and real components. The simulator, consisting of a dSPACE Simulator Mid-Size configuration with a quad-core DS1006 Processor Board combined with DS2202 and DS2211 HIL I/O Boards, runs a vehicle model to test its vehicle dynamics behavior. The real components are the vehicle's actual brake assembly including the tandem master cylinder (TMC), brake booster, hydraulic modulator, vacuum pump, control pedals, steering wheel and gear selector. The rig also houses power drivers to drive the pump motor and the modulator. The overall rig replicates the braking system of the vehicle and provides a human-machine interface (HMI) for realistic chassis control development. The HMI essentially comprises the real pedals, the ControlDesk experiment software, and a real-time visualization of the simulated vehicle. The target vehicle has a manual transmission, so the selected gears are simulated by a position switch. The steering is implemented as a dummy steering wheel and provides the steering angle via a potentiometer. The accelerator pedal is also captured electronically.

Signal Capture with ControlDesk Next Generation

ControlDesk Next Generation is the central software for signal capture, display and test activation. The UI displays parameters such as the brake pressure (of the model and the test rig), individual wheel speeds, vehicle speed, accelerator

The RCP system consisting of MicroAutoBox and RapidPro is installed in the car. It can also be used in the laboratory.



The test rig consists of a simulator, various real components, and the RCP system. It is first being used to develop and optimize the ISS algorithms.

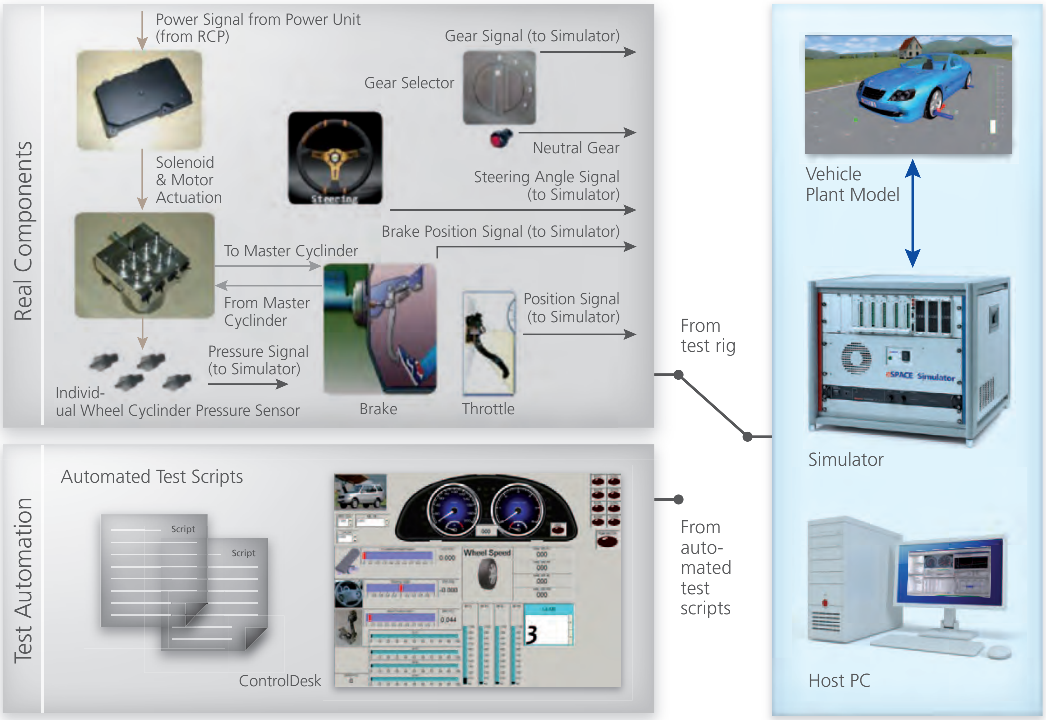
pedal position, brake position, steering angle, etc. The tests can be executed via manual commands on the test rig and also by automated test scripts. It is also possible to quickly switch between automated and manual testing to simulate specific maneuvers. ControlDesk was used from the beginning to the end of the project. Thanks to the basic calibration functions in ControlDesk Next Generation, the developers were able to perform extensive calibration tasks in various project phases.

> "We were able to perform extensive calibration tasks even in early development phases by using dSPACE ControlDesk Next Generation."
>
> *Ujjwala Karle, ARAI*

Safety Objective Achieved

Tata Consultancy Services, Pune, and Tata Motors European Technical Centre, UK, were the development and consulting partners during execution of the program.
The project was completed on schedule with the development of control algorithms for various ISS functions: anti-brake locking system (ABS), traction control system (TCS), yaw stability control (YSC), roll stability control (RSC) and active seat belt restraint system (ASBRS).

The algorithms were implemented on the target hardware and were calibrated and validated by both MIL and HIL simulation. The ABS algorithms were deployed on the MicroAutoBox-RapidPro combination in the vehicle. The project enabled ARAI to build up expertise and experience in using simulation techniques for embedded control system design and functional verification/validation of ECUs. Because proof of concept was provided for the stability control in SUV applications, and because it can be adapted to small passenger vehicles and commercial vehicles alike, the project results are also being used in production projects. The reliability of the dSPACE products proved to be extremely high. They were also easy to handle, which was decisive for the fast development of the controller software.



The test rig is designed for manual and automated test tasks. The pedals, steering wheel and gear selector are the real hardware components of the HMI.

ARAI Keeps up the Good Work

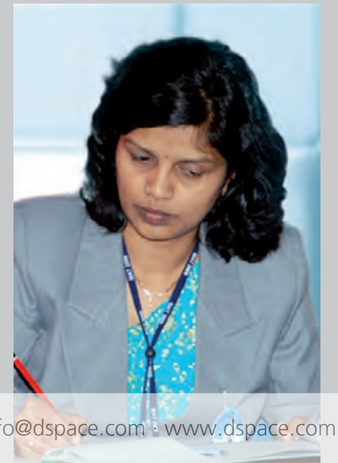
ARAI is actively involved in promoting the model-based development method and anticipates migrating to it completely in years to come. ARAI will now be offering its customers in the automotive industry the possibilities provided by HIL validation of ECUs.

ARAI is seriously considering further work in the areas of powertrain controls, such as strategies for gasoline direct injection, diesel common rail, etc., and is thinking of applying chassis control algorithms to hybrid-electric vehicles. The association will continue to use the methods that were developed and to actively promote their introduction into manufacturing companies. ■

Arun B. Komawar,
Ujjwala Karle
ARAI

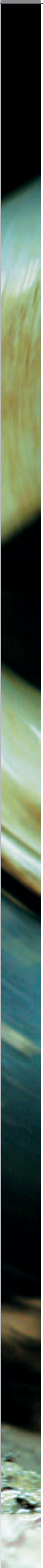
Arun B. Komawar
Arun B. Komawar is Program Head and Senior Deputy Director at ARAI in Pune, India.

Ujjwala Karle
Ujjwala Karle is Program Coordinator and Assistant Director at ARAI in Pune, India.



Surviving Tough Terrain

Active suspension control design for off-road applications



In commercial and military vehicles, the improved mobility provided by advanced active suspensions – especially in rugged terrains – becomes a matter of survivability, effective crew performance, safety and reliability. Active suspensions can boost the speed and comfort of off-road vehicles. Prototypes can be used to demonstrate the efficiency of active systems on wheeled and tracked vehicles.

Development Processes for Active Suspensions

The University of Texas Center for Electromechanics (CEM) has been conducting research and development on active suspension technology for over 20 years, and has established a model-based design and validation approach to develop hardware prototypes quickly and economically. The researchers use the proven approach of modeling and simulation with low-level laboratory testing (figure 1) and high-level hardware verification in the field. A model-based design approach requires the use of multiple domain-specific expert tools that can be integrated and used for overall development. Mechanical component model design and controller design are two different paradigms that are closely interconnected. The vehicle platforms, actuators and mechanical components are developed with the 3-D Multibody Simulation with LMS virtual.lab, formerly known as the Dynamic Analysis and Design System (DADS) package from LMS International. The controller models are developed in MATLAB®/Simulink® from Mathworks. The controller simulation is computed concurrently with the DADS Kinematic simulation for offline development and verification of the controller algorithms (figure 2).

Real-Time Simulation, In-Vehicle Testing and Development

After satisfactory performance of the offline, PC-based simulation in research programs that progress to vehicle demonstrations, the EMS controller (EMS = electromechanical suspension system) with its actuator and sensor interface is directly transferred to a dSPACE real-time system. The code generated with the MathWorks Real-Time Workshop in combination with dSPACE Real-time Interface (RTI) is directly targeted to a modular dSPACE system consisting of a processor board and I/O boards. This process facilitates a straightforward transition from simulation, to prototype demonstration, to production hardware.

Role of dSPACE Platform in the Development Process

The development of controller models for real-time application evolves, along with I/O models, to include sensor and actuator interfaces, interrupts from external signals, as well as communication buses such as CAN. An easy, one-button code generation and deployment process makes the iterative development task much easier and faster. It is further aided by a strong user interface and data capturing with dSPACE's ControlDesk tool. ControlDesk is also utilized for code and parameter downloading, terrain stimulus function generator control, and both manual and automated suspension controller parameter tuning tasks. The use of multiple UI layouts allows the operator to quickly get to graphical parameter controls specific to

> "Without a doubt, much of the success of these programs may be attributed to the seamless interaction of the various dSPACE software and hardware components."
>
> *Damon Weeks, Center for Electromechanics, University of Texas at Austin*

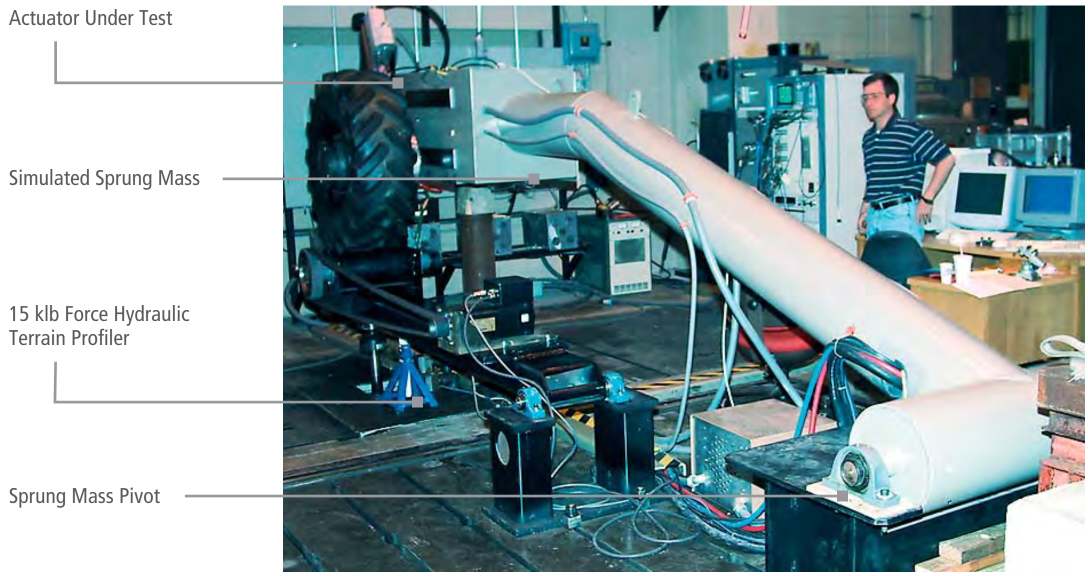


Figure 1: CEM laboratory dynamic test rig used to validate dynamic actuator performance for both mobile (vehicular) and stationary applications. The test rig is suitable for testing at full scale and allows dynamic and static testing. The vertical degree of freedom for sprung mass is approximated by a long pivot arm rotating about the pivot point. The hydraulic ram provides up to 20 inches of simulated vertical motion.

each of the previously mentioned task areas (figure 3).

Measurements with the Flight Recorder

ControlDesk's flight recorder capabilities were used in the development of an adaptive EMS controller. CEM incorporated neural network system identification to update its model parameters. dSPACE engineers worked together with CEM on the nonvolatile storage of the learned model parameters so that they could be written to the flight recorder at shutdown and then read at startup.

Vehicle Demonstrations

CEM has successfully demonstrated EMS technology in multiple vehicle platforms that include manned military wheeled and tracked vehicles (HMMWV High Mobility Multipurpose Wheeled Vehicles, LMTV Light Medium Tactical Vehicles und FCS-Tracked Manned Ground Vehicles). In addition, EMS technology has been deployed on an advanced technology transit bus and an off-road emergency vehicle (figure 4). Off-road performance was measured by a metric called average absorbed power, the mechanical power per kilogram that the vehicle occupants and equipment are subjected to.

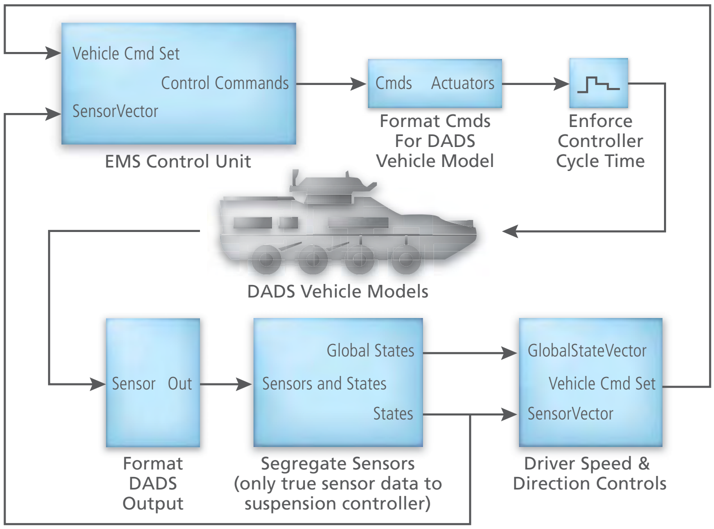


Figure 2: CEM's simulation environment links the Simulink control system and the multibody DADS vehicle model in a co-simulation. Shown here is the top level of the resulting Simulink model.

Figure 3: A typical ControlDesk layout used to develop the active suspension.

> "A common remark from the test team during EMS evaluations was how amazing it was that we could incorporate their suggestions into software changes in just a few minutes."

Damon Weeks, Center for Electromechanics, University of Texas at Austin

Greater Speed and Comfort, Lower Costs

The generally recognized ride limiting absorbed power for a vehicle while negotiating off-road terrain is 6 watt on average. For the military and off-road civilian vehicle demonstrations tested to date, the EMS suspension roughly doubles the 6-watt ride limiting speeds on all but the most severe terrains (with amplitudes so severe that they impinged with vehicle bumpers, skid plates, and/or drive sprockets at higher speeds).
In HMMWV human factors testing performed by the National Automotive Test Center (NATC), US Marine soldiers performed a variety of tasks while negotiating off-road trails. EMS demonstrably improved the ability to complete common tasks such as map orientation, radioing in coordinates, and targeting.
Although initially conceived to improve vehicle ride quality, EMS has demonstrated a 30 % improved off-road fuel economy in coast-down tests, enhanced safety and handling performance through improved understeer characteristics and active vehicle height control, and 50% lower vehicle lifetime operational costs. ■

Damon Weeks,
University of Texas at Austin

Conclusion

Over the past two decades, the Center for Electromechanics (CEM) at the University of Texas has completed more than a dozen EMS demonstrations, of which more than half were prototype demonstrations on military vehicles. CEM used a model-based design approach that coupled expert tools LMS DADS, MATLAB/Simulink and dSPACE Real-Time Interface with dSPACE rapid prototyping systems to develop EMS control systems, design EMS actuator and power system hardware, and predict system performance. Testing performed at various independent test facilities indicates that EMS may double cross-country ride limiting speeds, provide a 30 % improvement in off-road fuel economy, and improve crew function and vehicle handling.

Figure 4: Areas where the EMS suspension demonstration is used.

Damon Weeks
Damon Weeks is a research engineer responsible for electromechanical design at the Center of Electromechanics at the University of Texas in Austin, USA.

Optimizing diesel engine controls for extremely low emissions

Less Is More

ISUZU is developing an electro-hydraulically actuated variable valve system as an engine device to simultaneously reduce exhaust gases and fuel consumption. One development goal is to undercut the limits of the Japanese exhaust emission standard. The prototype controller has to cope with numerous valves and actuators and deliver high computing performance.

Stricter than the Emission Regulations

Together with the National Institute of Advanced Industrial Science and Technology (AIST), Japan, ISUZU participated in the project 'Comprehensive Technological Development of Innovative, Next-Generation, Low-Pollution Vehicles' promoted by Japan's New Energy and Industrial Technology Development Organization (NEDO) from 2004 to 2009. The development target values for this project were NO_x (nitrogen oxides) 0.2 g/kWh and PM (particulate matter) 0.01 g/kWh, even stricter than Japan's domestic Post New Long-Term Emission Regulations. The fuel consumption target was set at the extremely rigorous level of a 10 % improvement over the current standard (figure 1).

The Engine Concept: Camless Valve System with Hydraulic Actuation

To meet these tough project targets, ISUZU developed a concept for a future engine that simultaneously reduces emissions and fuel consumption. The concept includes a hydraulic variable valve actuation (camless) system that improves the trade-off between exhaust gas, especially NO_x, and fuel – the most crucial issue in achieving reductions.

System-Specific Requirements

In the camless system, supplying high-pressure actuation fluid opens the valves, and draining the fluid closes them. By controlling the timing of fluid supply and discharge, and the volume of fluid supplied, this system allows the intake/exhaust valve to be set to any opening-closing timing and any amount of lift (figure 2).

However, the system requires actuators for supplying and discharging the fluid, and each valve needs two actuators.

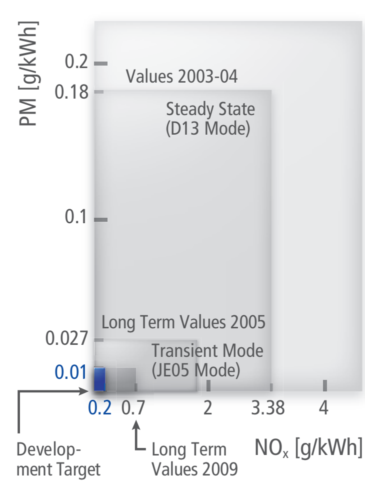
The development system will be applied to a large inline six-cylinder diesel engine. A total of 24 intake/exhaust valves and 48 actuators are needed. In addition, if control of the fuel injection and air systems is included, the system needs sufficient driver capacity to operate a total of 56 actuators, and the controllers and drivers require the following capabilities:

- Ability to support high-speed, precise pulse output synchronized with the crank angle
- Ability to control the current peak/hold time and current values

System Design Outline

To reliably control all 56 actuators and allow flexible system changes, a rapid control prototyping (RCP) system based on modular dSPACE hardware and RapidPro was chosen. This control system uses one proces-

Figure 1: Emission Regulations in Japan.



> "In the future, creating control logic systems that are highly precise and diverse will increase loads on systems. However, the high level of expansibility and flexibility of dSPACE products should avoid any problems."
>
> *Kikutaro Udagawa, ISUZU Advanced Engineering Center*

Figure 2: Schematic diagram of the intake/exhaust valve opening-closing method in conventional cam actuation (left) and in the hydraulic camless actuation system (right).

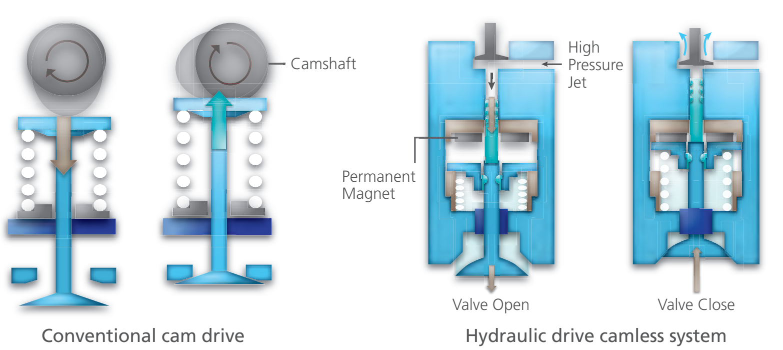
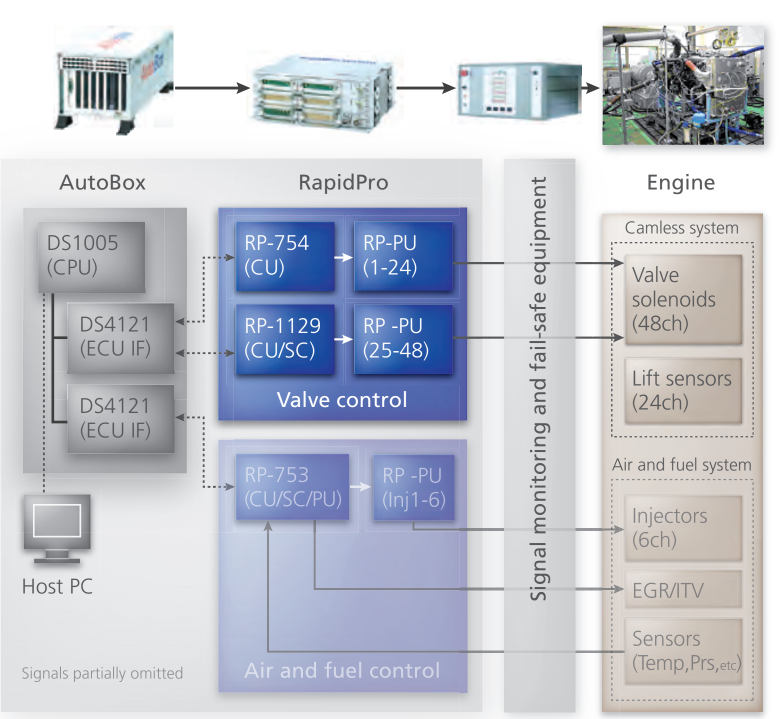


Figure 3: Schematics of the control system.



sor board as a controller and, because of constraints on the number of control unit TPU channels, uses three RapidPro units as drivers for intake/exhaust valve control and for control of the air and fuel injection systems (figure 3).

Fail-safe Requirements and Solutions

While the camless system intake/exhaust valves can operate without any constraints on the positions of the pistons, a control abnormality or inappropriate target instruction can cause valves and pistons to collide, resulting in serious damage to the engine. Therefore, from a fail-safe perspective, it is essential that the quality of the control software be improved to protect the engine, and that protection measures be devised for the case of control abnormalities. This leads to the following basic requirements for the development tools:

- *High-precision signal processing*
  Use a RCP system supporting high sampling rates and high I/O performance.
- *Measures to protect the engine during control abnormalities*
  Adopt a software-based abnormality monitoring function plus a hardware-based protection system. Accordingly, insert a fail-safe device between the control unit and the power unit to protect the engine by forcibly closing the intake/exhaust valves.
- *Securing control software reliability*
  Use hardware-in-the-loop (HIL) simulation to simulate a camless engine and run software evaluation tests before running the actual engine. To further verify operation in the actual engine, use the control system and actual camless system installed in the engine to actuate the valves, and also perform rig evaluation tests.

Role of Development Tools in Resolving the Issues and Expectations

As explained above, the controllers for the camless system require high performance and high reliability. And because this is a system under development, the controller and driver hardware configuration must also be modified by additional actuators and sensors in response to frequent model changes, or to specification modifications to the engine itself and any auxiliary components. Responding flexibly to these kinds of structural changes in the model and the controller hardware demanded flexible dSPACE products rather than in-house controllers and drivers.

Evaluating dSPACE Products after Development

The hardware (DS1005, RapidPro) is highly reliable and has the flexibility to fit new I/O specifications and upgrades in computing performance. Also, ControlDesk and other development tools operate visually and intuitively, allowing parameters to be visualized. First-time users can use the tools with ease. The reliability, operability and flexibility of the development tools are balanced to a high level. dSPACE products were successful in controlling the camless system – that is, in dealing with the difficult issue of accurately controlling an extraordinary number of actuators at high speed.

Results and Outlook

Multi-cylinder engine tests confirmed a fuel consumption improvement effect under the same NO_x emission conditions in steady-state operation. Furthermore, partially transient operation resulted in a proposal for a next-generation control system for stable valve control. These ideas are being implemented with the next generation of engine management. This consists of a multiprocessor configuration, and contains a DS1005 and the DS1006 Processor Board for model-based control. The two processors are interconnected via Gigalink to provide even more processing power for the extended controller software. ■

> "Using dSPACE RapidPro allows I/O of almost any signal, and cuts the time and effort needed to design and build external interface circuits."
>
> *Ryo Kitabatake, ISUZU Advanced Engineering Center*

Figure 4: dSPACE hardware in the test rig. Parts of the wiring harness were removed for this photo.

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Building large-scale test systems

SCALEX

SCALEXIO, dSPACE's new hardware-in-the-loop (HIL) system, has been expanding since its launch in 2011. The latest version helps users build especially large-scale test systems, including failure simulation, and makes it possible to use complex environment models.

Multicore for Large Systems

As the amount of electronics in vehicles increases, so does the functional scope of the ECUs. The resulting, more complex ECUs have large amounts of I/O and numerous software components, and require powerful test systems. At the same time, the environment model is also usually extremely extensive: for example, if it has to represent the entire vehicle. The ECUs are tested together with the environment models in large-scale hardware-in-the-loop (HIL) simulations.
To guarantee that complex models can always be simulated in real time, the SCALEXIO® Processing Unit contains an Intel® Core™ i7 with four cores. One of the cores computes the system processes, and the other three are completely available for model and I/O calculation. The result is that SCALEXIO can perform the real-time simulation of very extensive, very complex models that a single core cannot cope with.

Two Ways of Distributing Models

The environment model has to be distributed flexibly for computation on several cores in parallel. Just as important are a streamlined workflow, clearly defined tasks for model developers, and short compile times. Optimal model management is needed to ensure well-designed communication between model parts and

IO Is Evolving

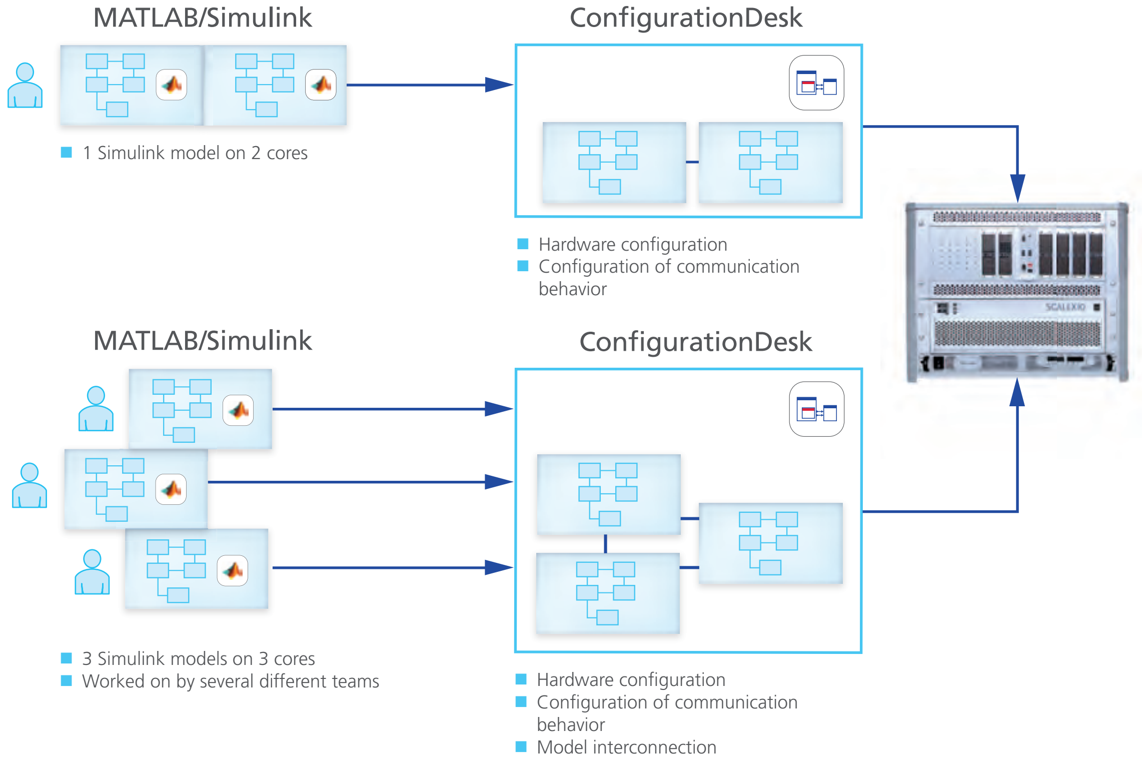


Figure 1: Two different workflows for model distribution.

well-organized connections between the model interfaces and the I/O boards.

There are two methods for creating models and distributing them on different processor cores (figure 1):

1. The model is developed as one overall system and then divided up for distribution to the cores. For this to be possible, the overall system must contain several "cuttable" model parts. Any arbitrary number of subsystems can be implemented in each of these model parts, and the subsystems can contain referenced models. dSPACE has developed a special MATLAB®/Simulink® block for assigning model parts directly to a processor core so that interprocessor communication (IPC) blocks are not needed. This makes the model easier to handle, and when changes are made to the assignment, only the model parts concerned need to be recompiled. Changes are made in the overall model itself, so offline simulation in Simulink is possible. Depending on the size of the model, long load and compile times might be necessary.
2. The Simulink model is developed as individual model parts instead of as one large overall system. Each model part holds processes that are coupled closely to one another and that must be computed in sequence, so they have to be placed on one and the same processor core. Each model is then assigned to exactly one core. Changes are made only in the individual submodels, so load and compile times are short. The advantage of model parts is that several development teams can work in parallel.

Graphical Configuration with ConfigurationDesk

If the model is created as an overall system, model communication and I/O board communication are configured with dSPACE ConfigurationDesk®. The same applies when model parts are created, except that model connections also have to be created. The model components and the corresponding communication files are imported from Simulink and displayed graphically in ConfigurationDesk. This procedure is identical for both model distribution methods. The communication files make it easy to transfer information and implement subsequent modifications.
ConfigurationDesk also lets users create configuration sets and use them to generate different, compiler-specific build versions for each model part. This maximizes the efficiency

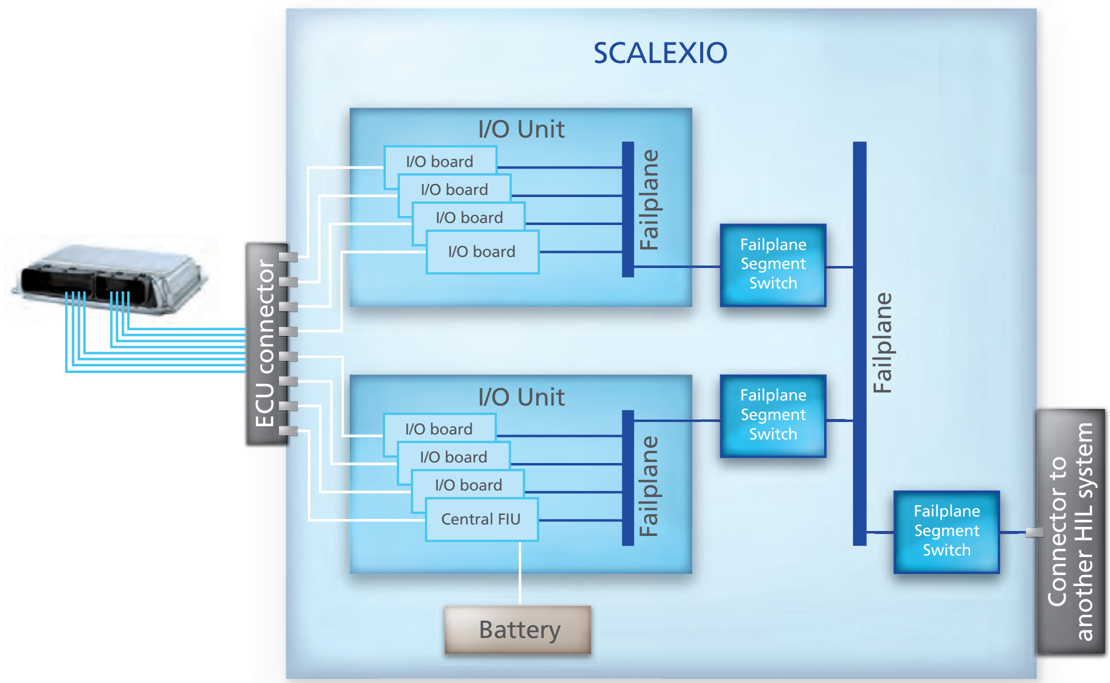


Figure 2: Infrastructure of the FIU in large systems.

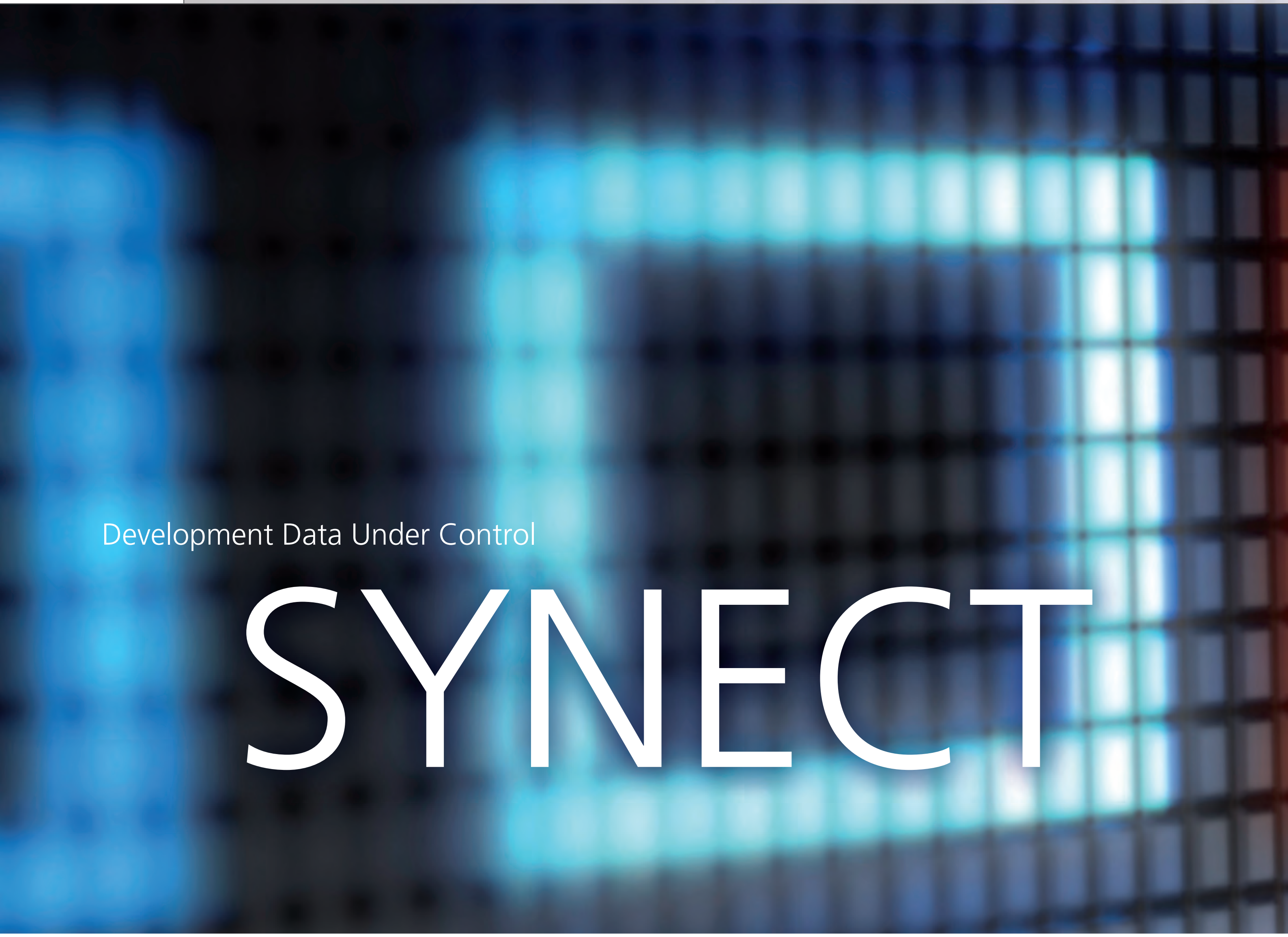
of the generated code for varying conditions such as different memory sizes.

Better Signal Quality During Failure Simulation

Large SCALEXIO systems with a high number of I/O channels also need optimized solutions for failure simulation (figure 2). A Failure Insertion Unit (FIU) is used to insert electrical failures on the I/O pins of an ECU. To use the FIU for failures on all ECU signals, all the signals can be routed to the central FIU components via so-called failplanes. It does not matter if the routing runs through several cabinets in a large simulator, because the failplanes in the individual cabinets can be connected to one another and extended whenever more I/O channels are added. The failplanes are subdivided into segments that can be switched in separately. This minimizes cabling – long cables can cause signal corruption – and guarantees high signal quality. When a failure has to be inserted, the failplane segment switches activate only the segments that are actually needed for signal routing. Segmentation is performed after each I/O unit and for each cabinet individually. Extending the system is therefore not a problem, and extensions never impair its quality. The failplane segment switch is addressed directly via SCALEXIO without the user having to interact.

Free Choice of Power Supply

With a SCALEXIO system, the battery simulation can be addressed straight from the simulation model. The power supply unit is controlled by the DS2907 Battery Simulation Controller, which provides the current and voltage values. Up to two different power supply units can be used for each DS2907 in a SCALEXIO system.
This provides a way to implement electrical systems with different voltages to test whether the ECU behaves correctly. ■



Development Data Under Control

SYNECT

Now available: First modules of a brand-new dSPACE product called SYNECT, the software environment for managing data in model-based development from the requirements phase to ECU testing. This new approach will support engineers throughout the entire development process, even when global teams are involved. Michael Beine, Product Manager at dSPACE, explains the product strategy.

Why did dSPACE decide to provide a data management solution?

Our customers' development departments produce enormous quantities of data, models, tests and test results. These include numerous variants and versions, plus a huge number of interdependencies. Managing this data is a growing challenge. This is where dSPACE comes in with our solution for centrally managing and interlinking the accumulated data. For our customers, this means consistent data versions, complete traceability, and reliable and efficient reuse of data in other projects, by other users, or for new vehicle and ECU variants.

What will SYNECT do, and what will be its strengths?

Our special focus is on supporting the model-based development process and ECU testing. These have become firmly established methods over the last few years. Yet at the moment, our customers do not have a dedicated solution for managing all the resulting models and data. Two of SYNECT'S great strengths will be its close integration with engineering tools and its support of the relevant standards. Engineering tools such as MATLAB®/Simulink®, dSPACE tools like ControlDesk, AutomationDesk and TargetLink, as well as tools from other vendors, are mostly the producers and consumers of the data that has to be managed. For our customers, having direct connections to these tools and being able to import and export data in standardized file formats will mean simple, efficient hand-offs and data reuse in the different development phases.

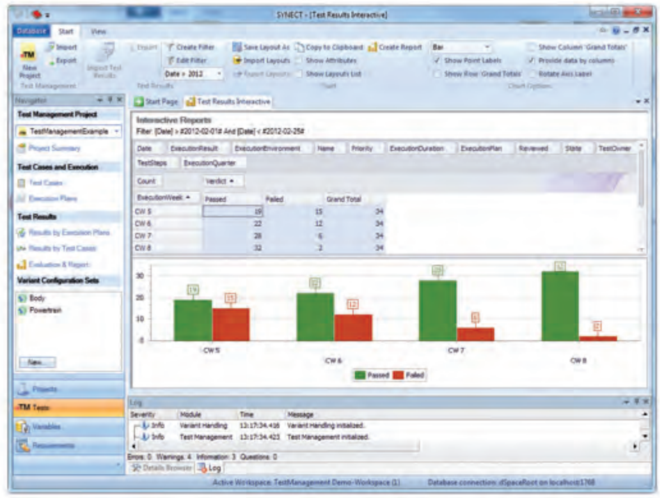
The increasing number of variants is a particular challenge. How will SYNECT handle this?

Integrated variant management will be a major feature. SYNECT will enable users to explicitly define and manage all the variants and variant configurations that they need to

SYNECT

Data Management and Collaboration Software

- Data management for model-based development and ECU testing
- Integrated variant management
- Direct connection to engineering tools
- Scalable for use in small, local teams up to globally distributed teams

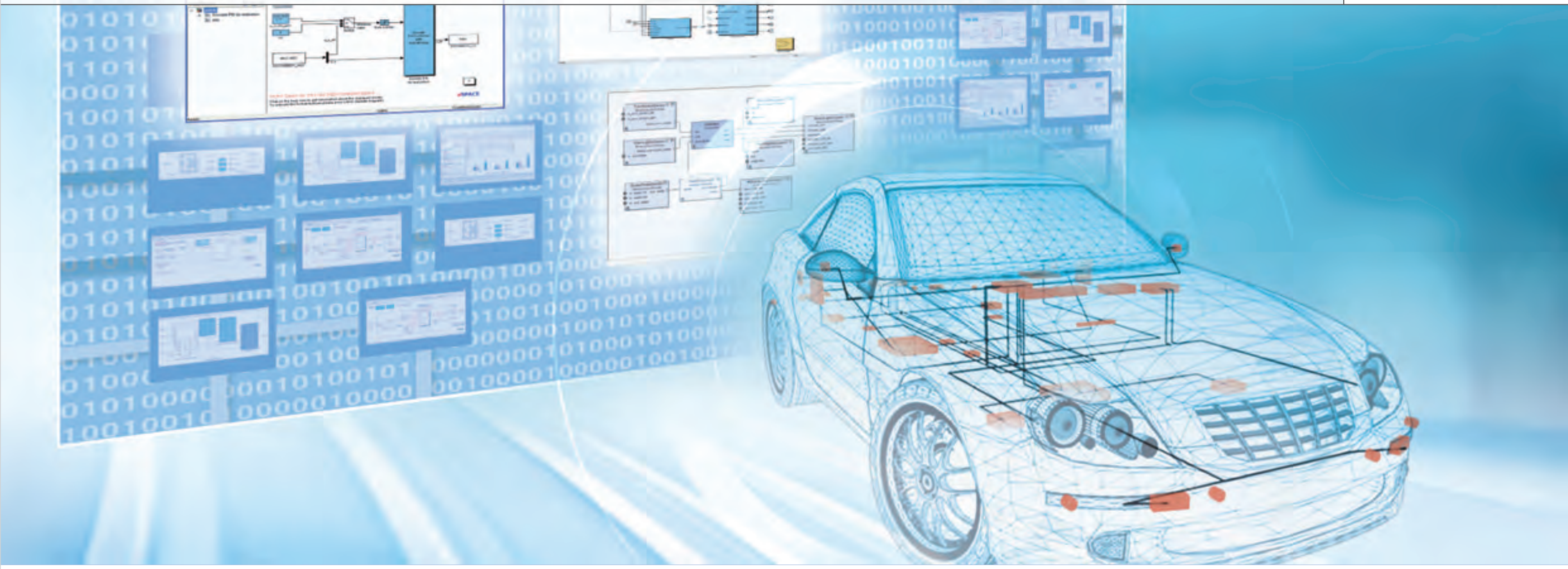


> Two of SYNECT'S great strengths will be its close integration with engineering tools and its support of the relevant standards.

handle. Thus, they can manage all the data not only in different versions, but also in relation to different variants – from beginning to end of the development process.

What role will requirements management play in SYNECT?
Requirements are essential elements of the model-based development process, so to integrate them, we offer connections to existing requirements management tools that have been in widespread use for some years now. For example, data can be exchanged via ReqIF, a requirements exchange format standardized by the Object Management Group (OMG). With this format, our data management system can mirror requirements without data loss, so they can be linked to any arbitrary objects – to models, tests, parameters, etc. In the medium term, I can also envision that SYNECT itself will be able to manage requirements. The technical abilities for this exist.

How do customers manage their data today? And how does the dSPACE solution differ from conventional solutions?
Configuration management today is



> Users can manage all the data not only in different versions, but also in relation to different variants.

usually performed by versioning entire files and checking them in and out. But simply using files to handle all the data from the model-based development process is not enough. Our customers expect "intelligent" management of single data objects, often with semantics, so that they can represent and track relationships and dependencies on object level. For example, they describe function or model interfaces by means of signal objects. We will contribute our years of experience with countless ECU projects to the new solution, and also our knowledge of the established file formats and relevant standards such as ASAM, AUTOSAR and FIBEX.

Will SYNECT be adaptable to different needs?

What often happens is that to begin with, development teams need a solution for individual tasks like test management and model management, or a central signal and parameter management system. We have therefore designed modular software that grows with our customers' needs and can expand step by step to become a comprehensive central data management system. Our solution will address small teams just as much as large organizational units with international workflows.

When will the first product version of SYNECT be available?

The first SYNECT version, a test management module, was already released in October. Pilot projects with OEMs and suppliers have been running since spring 2012. In addition to managing test cases, creating test suites, linking requirements and analyzing test results, we are focusing on connecting to test automation tools. A connection to AutomationDesk is already available, allowing test suites to be executed directly on HIL systems. A connection to BTC Embedded-Tester, the tool for MIL, SIL and PIL tests in the TargetLink context, is under development and will be released at the beginning of 2013. There is also an initial version of our variant management software, which enables variant dependencies to be handled as part of test case and test suite management.

What other modules will become available in the next months?

A central signal and parameter management module with connections to TargetLink is planned for the beginning of 2013. And we already successfully completed our first project for variant-based parameter management. We are also working on a solution for model management, with release of the first version planned for mid-2013.

Thank you for talking to us, Mr. Beine.

Michael Beine is Lead Product Manager for the SYNECT and TargetLink products at dSPACE GmbH.

Seeing is Knowing

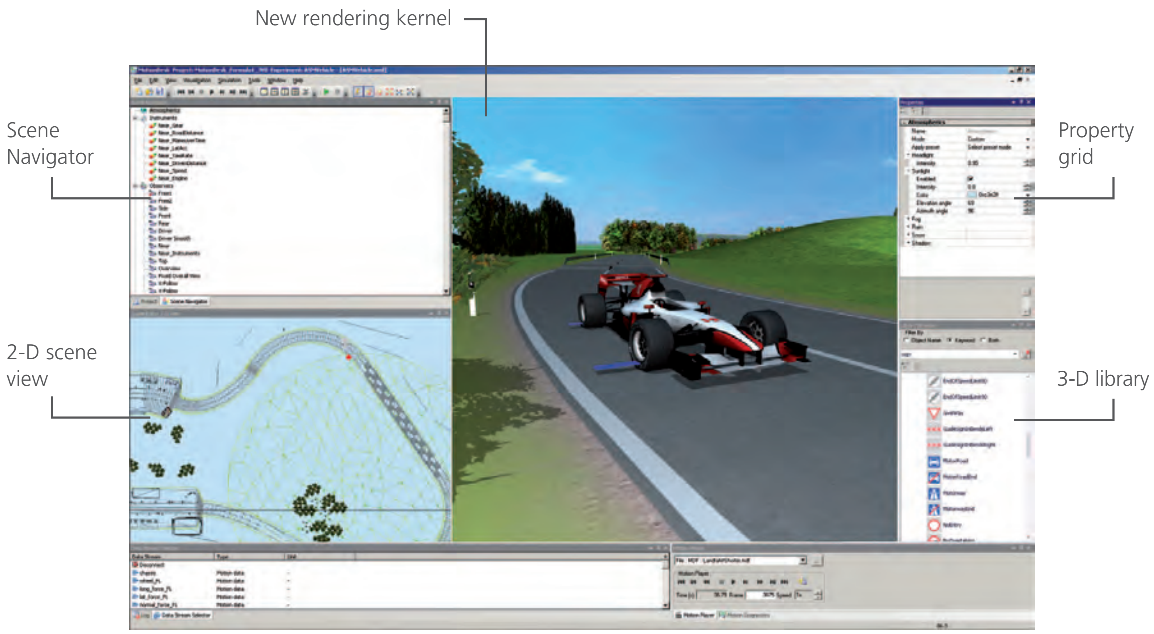
In developing controllers for applications like vehicle dynamics or driver assistance systems, simulations are crucial. The best way to understand the behavior of a simulated system is animated visualization in realistic 3-D scenes. dSPACE MotionDesk has successfully visualized the kinematic movement of simulated objects in the 3-D world for more than 10 years. Now a brand new version has arrived, redesigned to face the challenges of the future.

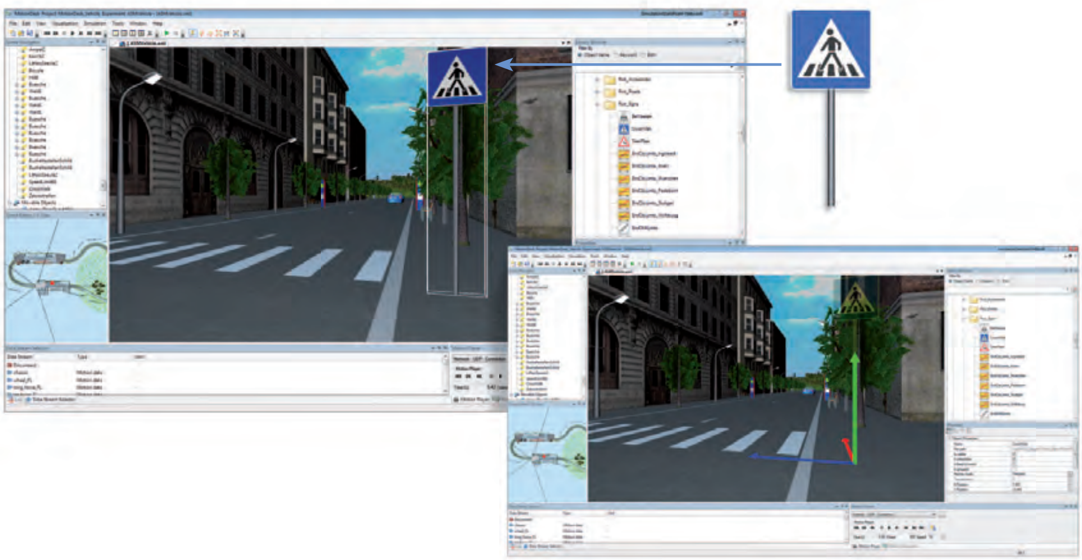
MotionDesk: 3-D visualization software optimized for driver assistance systems

High complexity and a reliably high frame rate result in a stunning, realistic simulation.

With MotionDesk, simulations are vivid and easy to understand through visualization of the simulated system and its surroundings. MotionDesk reads the data from a dSPACE Simulator, dSPACE VEOS® or MATLAB®/Simulink® and displays the animation of the moving objects (vehicle, wheels, steering wheel, etc.) in real time. The graphical visualization gives users a clear understanding of how the simulated objects actually behave. For example, several simulations can be integrated in one single animation. This method is ideal for reference comparisons, where different vehicle dynamics strategies can be compared with one another.

Everything you need in one tool – for example, the 3-D library with completely new objects.





3-D objects – like the traffic sign shown here – are simply added to the scene by drag & drop. Their size, position, rotation and other attributes can then all be modified.

Make It Real

MotionDesk is the perfect tool to visualize any kind of vehicle dynamics development and driving maneuvers, such as lane change, µ split, cornering, etc. From Version 3.0, MotionDesk gives enhanced support to all aspects of advanced driver assistance systems (ADAS), where the complexity of an action has to be seen to be understood. When camera-based ADAS are tested, the simulation must be realistic enough for object recognition, and a high frame rate is crucial. MotionDesk's completely new rendering engine guarantees much more detailed and realistic visualization, and even complex scenes are rendered at a steady 60 frames per second.

Very Convenient, Very Quick, Very Useful

The new version is also easier to handle. All important operations such as 3-D scene creation can now be done in one tool, mainly by drag & drop. With MotionDesk's new 3-D Scene Editor, 3-D scenes can be developed much more quickly and efficiently than with an external scene editor. The new, comprehensive library of 3-D objects lets developers set up scenes very quickly by simply selecting and positioning the objects. A 3-D Library Browser helps them find the objects they need: for example, by keyword search.

Seamless Change from Older Versions

Migrating projects from an older MotionDesk version is easy. All existing projects run immediately, and users can choose the old 3-D look or the new look. Users can also integrate custom objects that comply with the COLLADA or VRML2 standard, and group objects to structure and handle scenes more conveniently.

MotionDesk can also display changing weather conditions like rainfall and snow. Coming dSPACE Releases will bring further functionalities, such as highly realistic shadow visualization.

With its technological redesign and extensions, MotionDesk is ready for developing and testing the intelligent mechatronic systems for the mobility of the future – especially advanced driver assistance. ■

The same scene in different weather conditions – sunshine, rain, fog.

Optimized tools for simulating vehicle dynamics and driver assistance scenarios

Virtual Road Construction

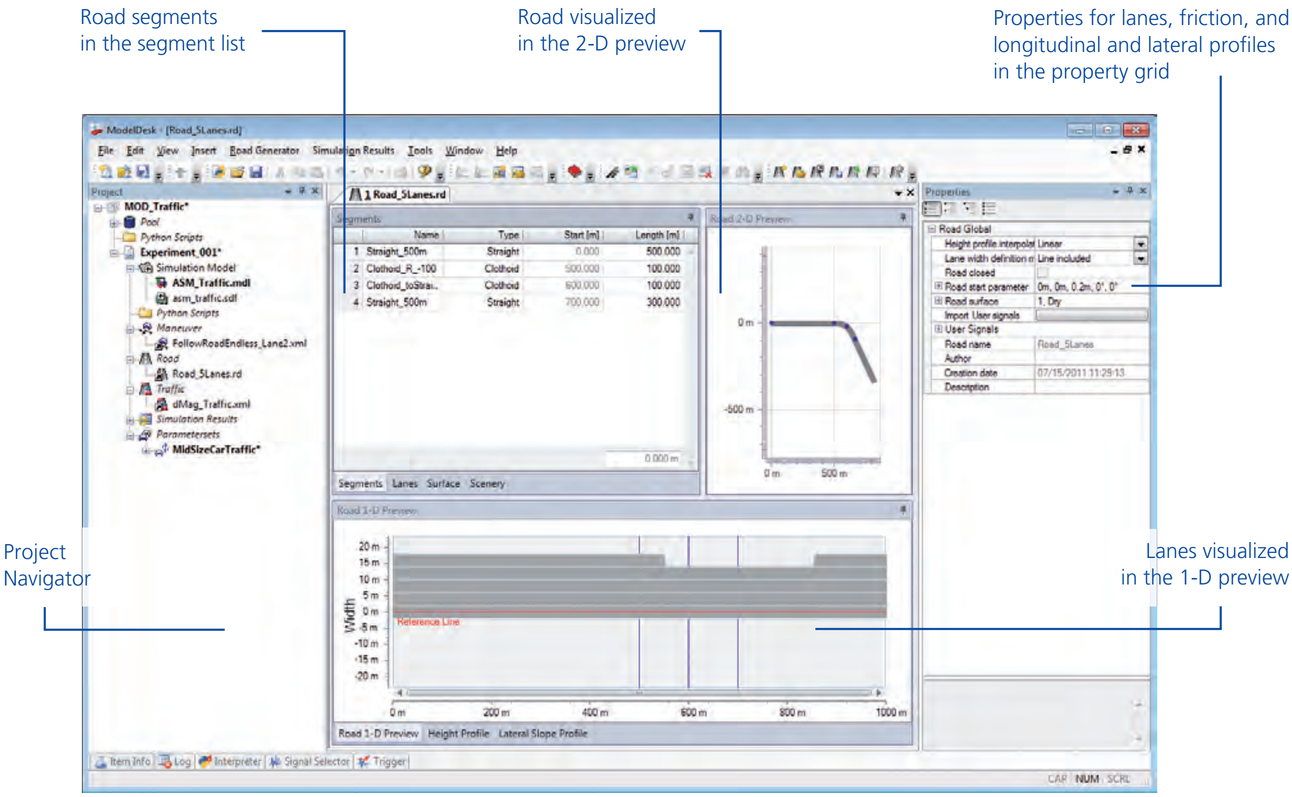
A car is traveling along a multilane road, surrounded by numerous other vehicles. To ensure the driver can relax and cope safely with any situation that arises, driver assistance systems evaluate the surroundings and intervene if necessary. To develop and test these systems efficiently, realistic simulations of all kinds of situations are needed. dSPACE has further optimized its Automotive Simulation Models for such applications.

Simulating Multilane Traffic Scenarios

Advanced driver assistance systems (ADAS) evaluate data on the road and surrounding traffic obtained from devices such as radar and video sensors. These supply the data needed for adaptive cruise control (ACC), the parking assistant or the lane departure warning system. The Automotive Simulation Models (ASM) provide extensive simulation options for developing and testing these systems. In a virtual environment, a test vehicle drives along a multilane road with other vehicles in the same way as in a real scenario. Virtual sensors detect the scene and provide data to the algorithms in the driver assistance systems. The simulation runs in real-time and can be visualized by 3-D animation. The animation can be integrated into the control loop by using real cameras that recognize virtual objects in the animation, such as traffic signs.

Construction Tool for Roads and Lanes

The functionality and handling of the simulation environment have been extended and optimized in dSPACE Release 7.3. Most of the new features are in ModelDesk, the graphical ASM control center for simulation, parameterization and parameter set management. The integrated Road Generator now lets users define multilane roads in addition to all its previous road-building



The new Road Generator in ModelDesk is the construction tool for the virtual road.

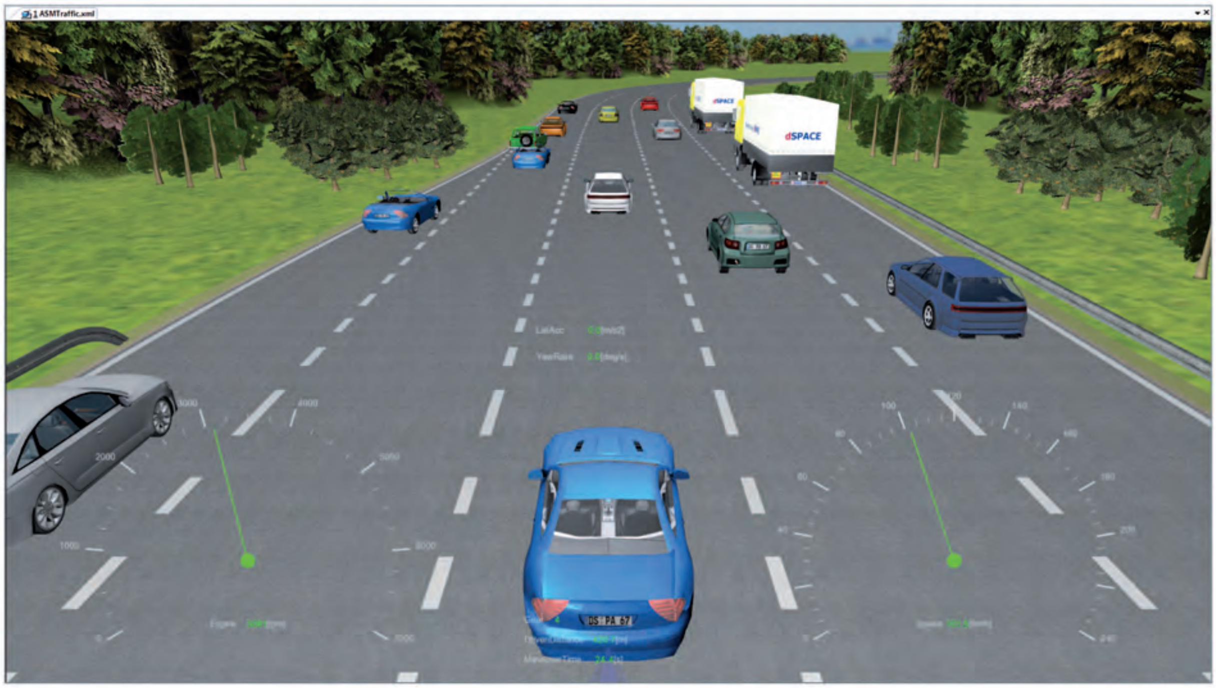
Easy definition and vivid visualization of roads and surface properties.

options. The new functions were designed for easy handling of complex definitions and greater flexibility in creating roads with and without lanes, for vehicle dynamics and driver assistance applications alike.

- *Basic Road*
  The basic road is the foundation for a virtual simulation road. In the Road Generator, it is created by assembling segments such as straight sections, curves and splines, or alternatively, it can be imported as GPS coordinates. The basic road provides the reference line for defining other road features.
- *Road Profile*
  The height and lateral incline of the road can be specified flexibly. A new option is to apply special height profiles (for curbstones, potholes, etc.) to selected areas of the road. The road's lateral profile can also be finely defined to create sections such as concave steep curves.
- *Surface Friction*
  The road surface friction can be specified for any selected areas. These are placed on the road with freely definable lengths and widths.
- *Lanes*
  The Road Generator provides detailed settings for up to 5 lanes per road. Lanes can be added and removed at any point along the length of the road. Transition zones can also be defined for widening or narrowing the road.
- *Road Markings*
  Each lane is marked, and the type of line (solid, dashed, etc.) can be set for each marking. The lines are then displayed in the 1-D preview and during animation.

Preview, Simulation and Animation

Dedicated views show users all their parameter properties at a glance: individual lanes, markings, surfaces and profiles, and also the entire road.



The Road Generator interacts with MotionDesk, the 3-D animation software, to produce realistic visualizations of simulated driving scenarios.

The overall view provides a complete picture of the road and surface features. There are synchronous zoom and scroll functions for easy handling. The next step is to simulate the road with the vehicles and a maneuver – such as "Follow the road" – in real-time. Complex driving maneuvers and complete traffic scenarios with up to 15 fellow vehicles can be simulated. During simulation, the scenario is visualized realistically by the MotionDesk 3-D animation software.

In Brief

Constructing virtual roads is now even more convenient and flexible with the new version of ASM/ModelDesk. With its integrated Maneuver Editor and Traffic Editor, it simulates complex traffic scenarios for fast, precise testing of test driver assistance systems. Vehicle dynamics studies such as investigating brake maneuvers on a split-μ surface also profit from the new expanded functionality and handling. With all these features, the ASM/ModelDesk simulation environment is ideal for developing and testing modern driver assistance and safety systems from an early phase to the end of the development process. ■

Product Profile ASM/ModelDesk

Simulation environment for vehicle dynamics and traffic (dSPACE Release 7.3)

- New Road Generator supports multilane roads
- Flexible definition of road features
- Intuitive definition of traffic scenarios
- Simulation of environment sensors

Self-sufficient with the wind and the sun

Smart Home

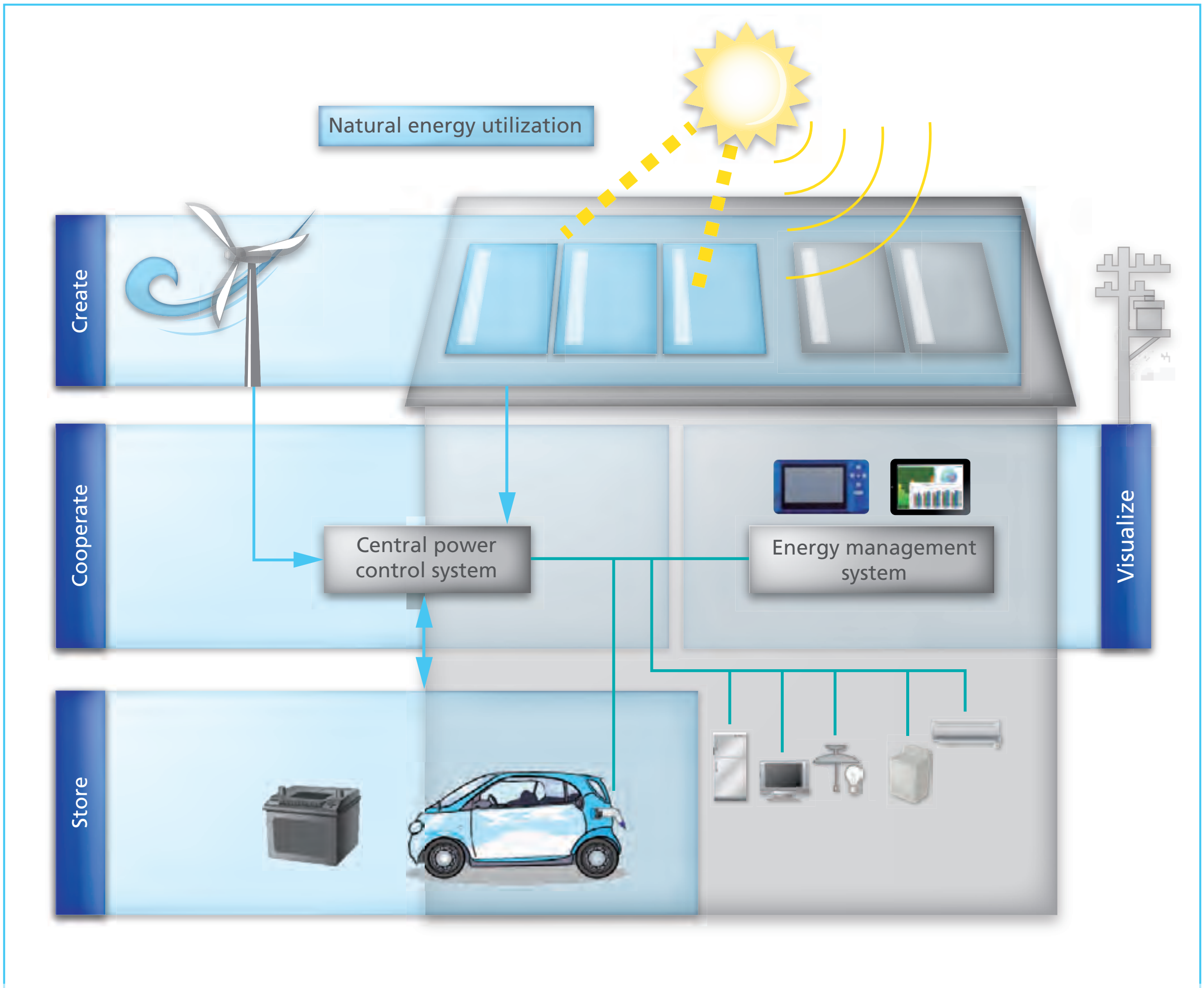
In the face of prospective fossil fuel shortages and environmental concerns, energy generated by wind power or solar power is a strong alternative. Numerous pilot projects are being conducted worldwide to efficiently research, develop and generate renewable energy sources. In Japan, in the wake of the nuclear power plant accident accompanying the Tohoku earthquake on March 11, 2011, people’s expectations of renewable energy sources have soared. dSPACE Japan K.K is actively participating in 3 consortia that are carrying out pilot projects on energy control.

All over the world, energy consumption is constantly increasing. There are several reasons for this – such as global economic growth, advancing electrification, and a growing world population. It has long been clear that to guarantee a stable power supply, we need a fundamental revolution in the overall energy control cycle for energy generation, storage and distribution. One approach is to use self-contained solutions in which electricity and heat are produced and consumed locally, where the consumer is. This solution is intended to ensure stable electric power distribution generated from renewable energy sources in the case where the system power is disabled due to a blackout or other reasons, and also to reduce CO_2 emissions which are unavoidable in conventional power generation such as coal power plants.

What's Smart?

Electricity and heat generation in the consumer's own home is part of the local energy supply, because it takes place where the energy is required, instead of in a large central power plant which distributes it via power cables. The word "smart" is frequently used to describe local energy concepts – "smart house" and "smart grid" are two examples. What these mean is that energy generation, energy consumption control and energy storage are all integrated, with individual components connected to a central control unit via a communication network (figure 1). This monitors every change in the overall energy system and reacts by adjusting the energy supply and consumption. The goal is to ensure an adequate energy supply at all times and also minimize the number of storage units needed, because rechargeable batteries are still a high cost factor. A typical smart house has regenerative energy installations such as photovoltaics, solar thermal devices and wind power. For energy storage, classic components such as stationary rechargeable batteries and hot water boilers are used. Electric vehicles are connected to the system

Figure 1: Schematic of an idealized smart house.



Projects Supported by dSPACE

Fukuoka Smart House Consortium
The Fukuoka Smart House Consortium is a joint project by various companies and research institutions. Since June 2010, they have been researching possibilities for a sustainable power structure that will meet the interests of public authorities and power companies alike. The Chairman is Yoshimichi Nakamura from the Smart Energy Laboratory, and the Vice-Chairman is Hitoshi Arima, President of dSPACE Japan K.K. dSPACE supports project implementation with know-how and with dSPACE hardware and software. The smart-house concept was designed jointly with a technical partner, the Smart Energy Laboratory founded by Yoshimichi Nakamura.

Yokohama Smart Community
The Yokohama Smart Community is another project where dSPACE Japan K.K. is actively involved. Hitoshi Arima is its Chairman. Following project launch in 2011, the design of the smart house began in early 2012. Here too, the goal is to research ways to generate energy while avoiding CO_2 and saving resources. As with the Fukuoka Smart House Consortium, dSPACE supports the project with technical know-how, software and hardware. dSPACE also offers the participating groups a presentation platform, such as the dSPACE User Conference in Tokyo, where the mini smart house and other results were presented.

Long-Term Goals of the Experiments
- Promote a renewable energy society
- Consortium (activity forum) and platform (development environments)
- Compact Smart Community that harnesses the power of community
- Create total visions for food, energy and care
- Develop ways for individuals and companies to prosper in each region.
- Disseminate futuristic new concepts of the electric system
- Provide a social infrastructure for a decentralized energy system

Many participating members in pilot projects are proactively involved in the development of energy-related technologies and independent research. In July 2012, the Nagasaki Smart Society was established to provide more opportunities for community-based demonstration experiments. We will dedicate ourselves to building a sustainable social system through cutting-edge science technologies.

Figure 2: Brick house in Island City in Fukuoka where demonstration experiments are carried out.

primarily for recharging, but can also be used as temporary additional energy sources if required. This is a way to even out fluctuations in supply and demand (figure 2).
Despite its independence, a smart house is not cut off from the public power grid. It can draw power from the grid when it experiences an acute energy bottleneck, and supply power to the grid during massive overproduction. Developing control algorithms for the central control unit is a challenge because optimum energy management has to detect numerous factors and mutual effects and handle them all.

Current Technical Situation

The technical developments that have taken place over the last few years are what make smart houses and smart cities possible. Batteries now have a much greater capacity and better charging properties than they used to, and at an affordable price. The number of electric vehicles is also increasing. They need a practical and feasible charging facility – which a smart house provides – and can also themselves be used as storage. Networked communication between different household appliances has also advanced, allowing them all to be controlled by one central unit. When all these innovations are brought together, building a smart house is both possible and economically viable.

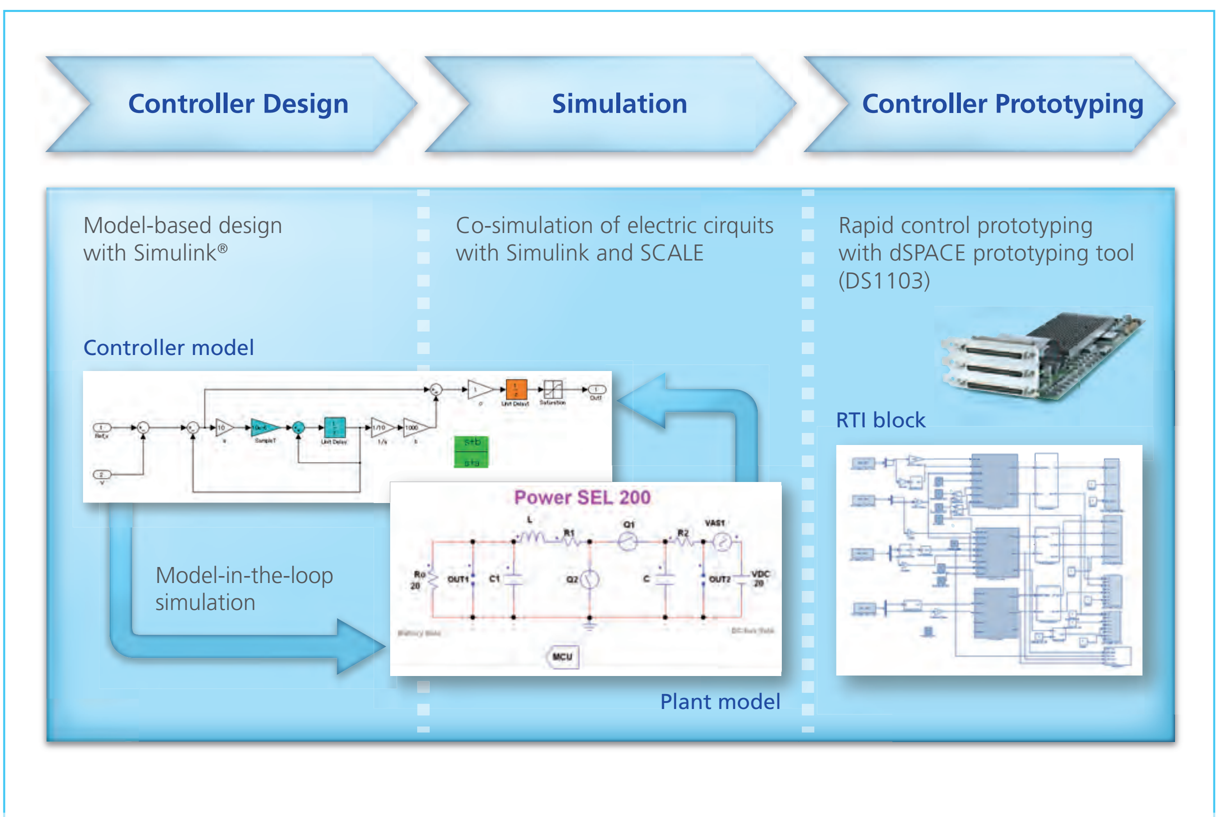
Control Algorithm Evolution

Efficient energy management in a smart house comprises a number of tasks:

- Monitoring electricity generation
- Managing electricity storage
- Reconciling consumption with supply
- Controlling energy consumption according to availability

The pilot project at the Fukuoka Smart House Consortium started with the development of the energy management control algorithms in Simulink. The model-based approach dramatically reduced development times in comparison to conventional approaches. Realistic testing requires not only the actual control algorithms, but also an environment model that represents outside effects. The environment model that was used for testing together with the control algorithms has been developed by Professor Nakahara of the Electronics Research Lab at Sojo University using SCALE. The controller model was optimized iteratively by model-in-

Figure 3: The model-based development process for the Fukuoka Smart House pilot project.



> The objective of energy management experiments is to use the generated energy on-site as much as possible.

the-loop simulation (figure 3). After optimization, the finished control algorithms were downloaded to the dSPACE rapid control prototyping hardware DS1103. This serves as the central control unit for a mini smart house.

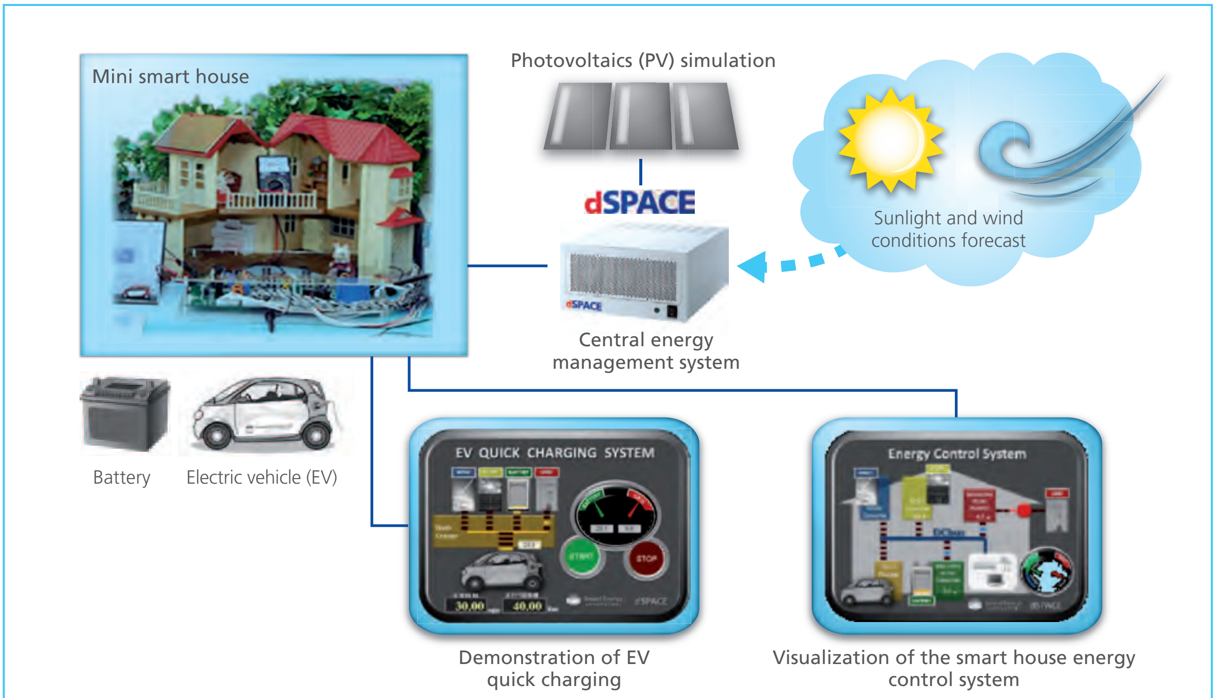
Mini Smart House

The mini smart house is a downsized physical model (figure 4) of a real smart house and is used as a test object to further test the control algorithms. To develop intelligent energy management, it was first necessary to obtain data on the behavior of energy cycles in order to understand the effects of different control strategies on energy efficiency. Despite having only a fifth of the energy requirement of a real house, the model house has a complete central control unit. Weather forecasts are used to calculate and simulate electricity generation by photovoltaic and wind power installations. A real battery and a simulated electric vehicle are used as storage units. The assumed energy consumption is based on the standard consumption curves of an average family. The objective of energy management experiments is to use the generated energy on-site as much as possible to avoid pressure on the public power grid caused by feeding electricity into it. Self-consumption and storage prevent the extreme fluctuations that would occur if numerous households supplied power simultaneously during high winds. Nevertheless, it still has to be possible to supply power to the grid to balance energy shortages at other locations. The energy flows and control options are visualized with dSPACE ControlDesk. This made it possible to thoroughly test the effects of different behaviors and their impact on energy efficiency, and to simulate their effects on the overall mini smart house system. Whenever necessary, the control algorithms were adapted quickly and easily to incorporate new research findings.

Life-Size Smart House

The research results gathered from controlling the mini smart house were then transferred to a real house. This smart house was built in Fukuoka (figure 2), and a permanent exhibition of the latest smart house and energy control technologies opened there in April 2012. At the Fukuoka Brick House exhibition, you can view

Figure 4: Schematic of the mini smart house.



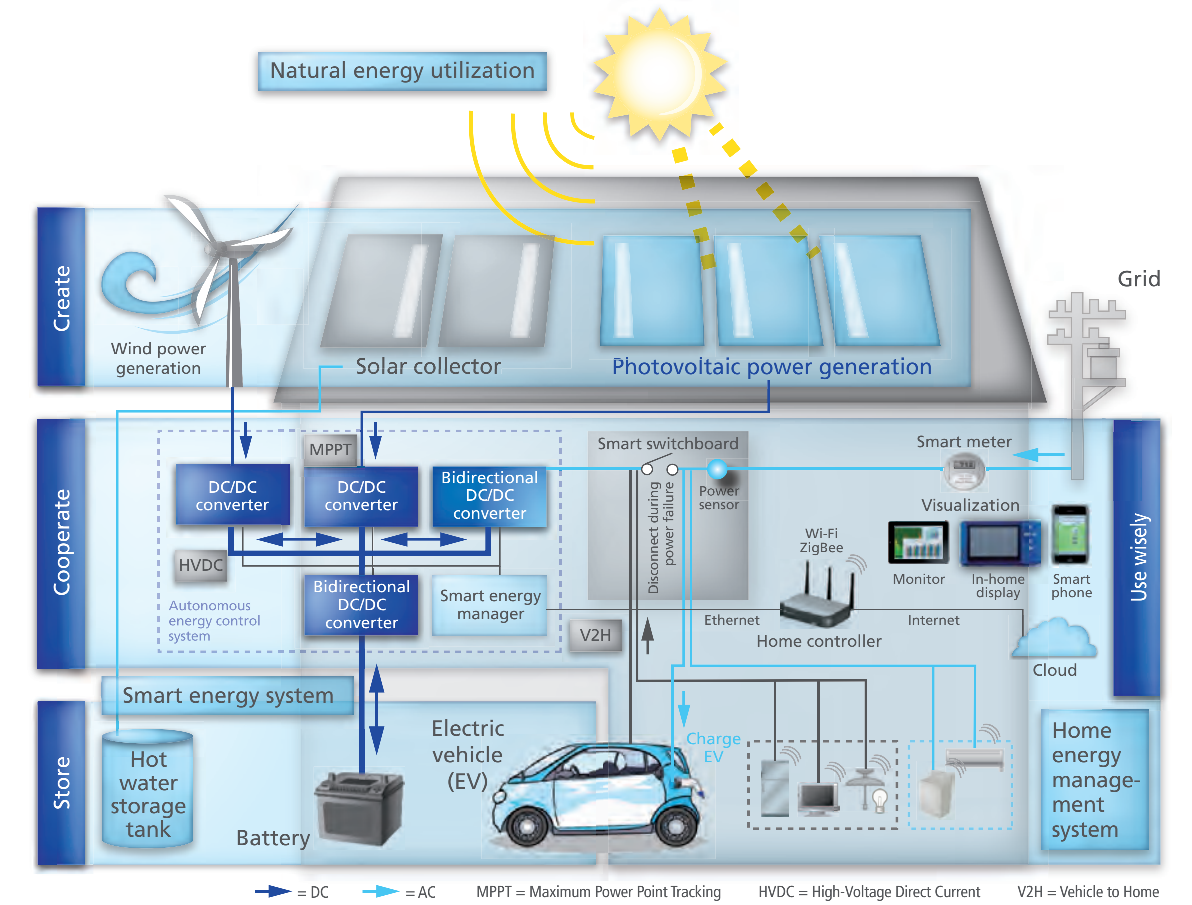


Figure 5: Transferring the mini smart house concept to a real building.

experimental products and element technologies which are either the result of individual research or were codeveloped by participating companies, educational institutions and other organizations.

Concept of Smart House Technologies

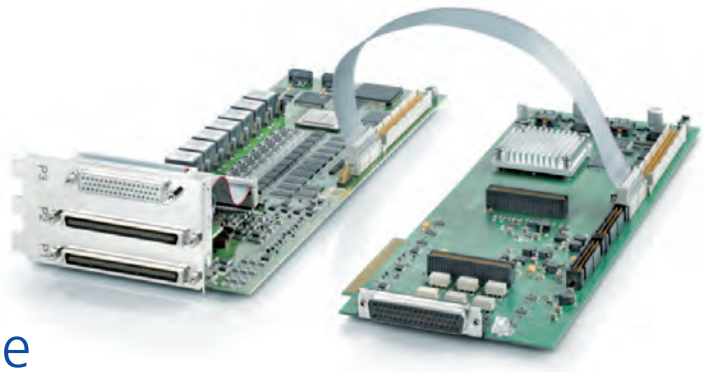
The energy is generated by photovoltaic and wind power installations, and stored in a stationary lithium-ion battery that is charged during energy-rich phases. The same applies to the hot water boiler and the electric vehicle's battery. There is also a connection to the power grid (figure 5). Here too, the central control unit is the heart of the system where all the data comes together for evaluation. Large batteries are very expensive, so efficient energy management and consumption control are essential. Weather forecasts provide only a rough estimate of the energy yield expected from regenerative energy generation, so the system has to be highly flexible. Restricted availability must also be taken into account, because solar energy is present only during the day, while wind energy is plentiful during the fall and winter months. Sensible energy management shifts actions that are not time-critical, such as charging the electric vehicle or running the washing machine, are restricted to high-yield times.

Access via WLAN

The smart house's central control unit can be accessed by smart phone or tablet via WLAN, so that the house's occupants can view the current status and consumption values, make changes, or obtain information on a power cut.

Conclusion

So far, the experiments and experience with smart house energy management have been very promising. Model-based development has proven very useful for the development of efficient smart energy concepts.
dSPACE will continue to proactively research energy control technologies through various pilot projects. ■

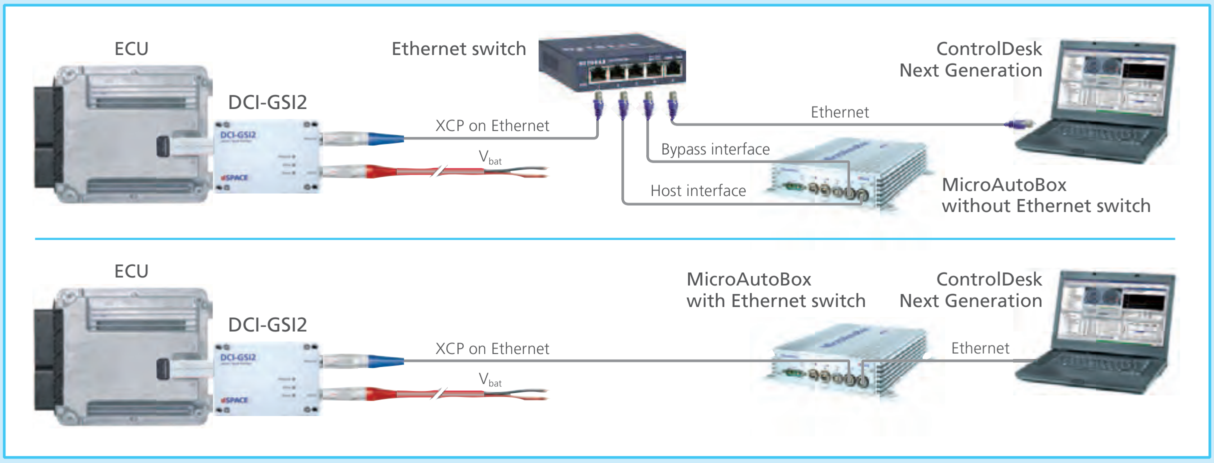


High-Precision Engine Angle Computation for HIL Simulation

During hardware-in-the-loop simulation, the dSPACE DS5203 FPGA Board performs signal preprocessing to reduce the computational load of the processor board.
As of dSPACE Release 7.3, the DS5203 provides a connection for an APU bus in addition to the user-programmable FPGA. The angular processing unit (APU) calculates the engine angle with high precision as a basis for providing I/O values to the HIL simulation.
The DS5203 can be used as a master or a slave. When it is the APU master, the angle values for the simulation model are computed and used on the FPGA itself, and if necessary transmitted to other I/O boards via the APU bus. As the APU slave, it receives the engine angle values from another dSPACE I/O board such as the DS2211 HIL I/O Board. The angle data can then also be used in the simulation models running on the DS5203. ■

MicroAutoBox Now Has an Ethernet Switch

The dSPACE MicroAutoBox now has an integrated GBit Ethernet switch that makes setting up prototyping applications much simpler.
The example scenario in the illustration shows the difference when parallel communication is needed, on the one hand for measurement and calibration tasks between ControlDesk® Next Generation and the generic interface DCI-GSI2, and on the other for bypass communication between the MicroAutoBox and the DCI-GSI2. With the predecessor version of MicroAutoBox, this setup would have required a separate Ethernet switch and several additional cables. ■



Top: Typical setup with the earlier MicroAutoBox II when ControlDesk Next Generation is used for ECU measurement data capture or parameter adjustment in parallel to bypass communication.
Bottom: The same scenario using the new MicroAutoBox II with integrated Ethernet switch.

Updated EMH Solution: Greater Safety, Higher Resolution, Better Handling

The dSPACE's EMH (Electric Motor HIL) Solution provides all the I/O channels needed for the HIL simulation of electric motors. The upcoming new version brings a range of attractive innovations: increased electrical safety, extended channel functions, and an enhanced user interface. The EMH Solution comprises a DS5202 FPGA Base Board with a dedicated electric motor I/O module and the associated Real-Time Interface (RTI) blockset for model configuration under MATLAB®/Simulink®.

The electrical protection in the new version is ±50 V for all channels to avoid voltage damage during electrical failure simulation. The resolution of the digital I/O channels for PWM measurement has been raised to 12.5 ns (80 MHz), with a measurement range of 0 V to 20 V.
In addition, the switching threshold can be set steplessly between 1 V and 8.5 V. Configuration and resource management are performed with the RTI blockset, which has also been reworked. It can be used to check the entire simulation model on a PC following partial updates and discover how often each simulation block is used, whether it was configured correctly, and so on. This saves users the work of downloading the model to the hardware and performing a build process for test purposes.
The new version of the EMH Solution is pin-compatible with its predecessor. The new RTI blockset is downward compatible, so that existing as well as new EMH solutions can be configured with it. ■

More Voltage Guaranteed: Electronic Load Module up to 60 V

Another electric load module has been added to dSPACE's range for the hardware-in-the-loop (HIL) simulation of electric motors. The new module emulates motor and generator currents so that mechanical test benches are no longer needed to test the ECUs that use these currents. With a voltage range up to 60 V, the module is also ideal for use with higher in-vehicle voltages of 42 and 48 volts or where there is a high level of electrical equipment. Three-phase real currents are emulated and energy recuperation is also included to boost the energy efficiency of the overall system. Typical test application areas are electrically supported steering, starter and generator systems, and mild hybrid drives. ■

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