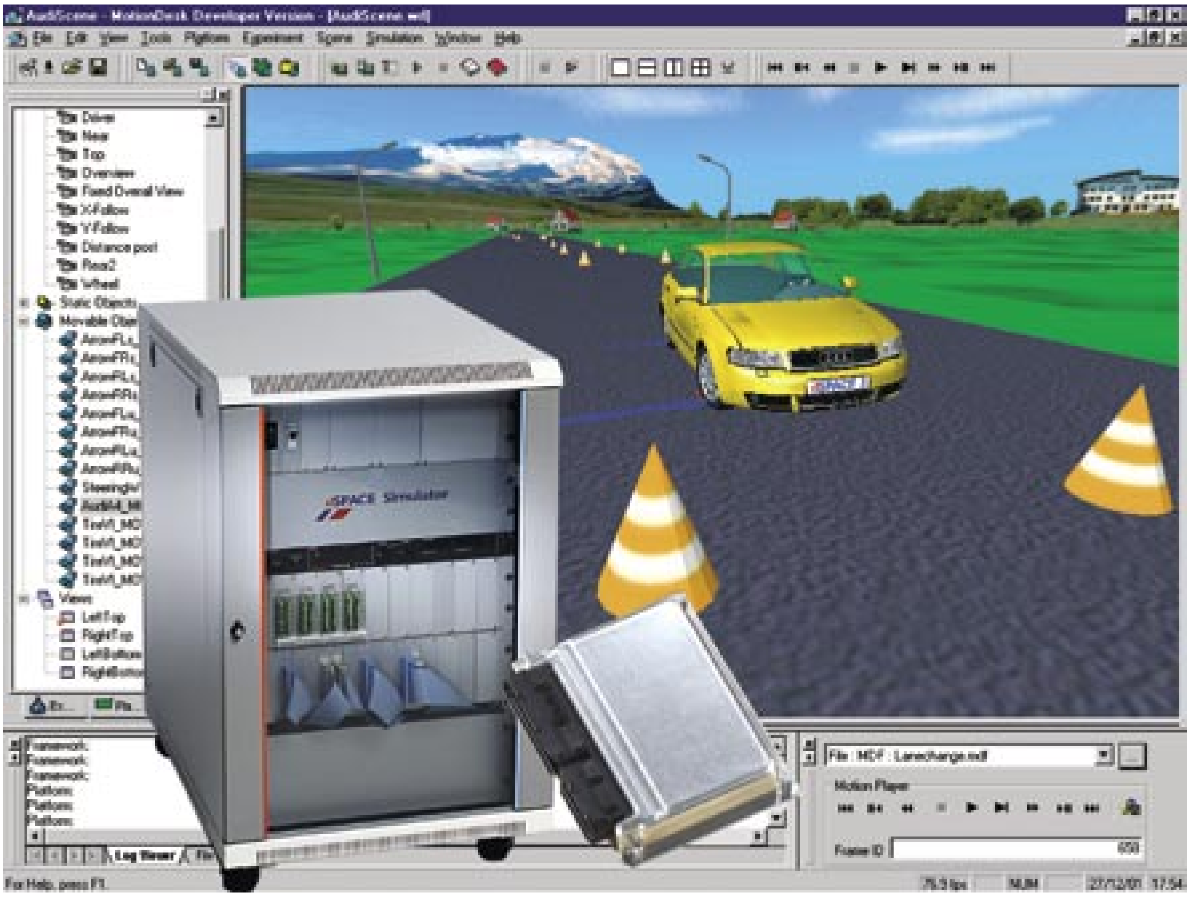
Systematic Testing –
Modern Solutions for Hardware-in-the-Loop-Simulation



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Hardware-in-the-loop (HIL) simulation is establishing itself as a milestone within automotive electronics development processes. HIL systems and the products used for them must be more rigorously tailored to concrete applications and to solving automotive problems. The main focus is on fast and simple configuration of complex I/O functions, efficient use of functions and interfaces for automation, and the flexibility and scalability of both individual simulators and simulator networks. This paper describes how dSPACE is meeting this challenge with modern HIL concepts such as dSPACE Simulator.

Fig. 1: dSPACE Simulator: Proven solutions for hardware-in-the-loop simulation

1 Introduction

In the development of modern automotive electronics, hardware-in-the-loop simulation (HIL simulation) has established a firm place for itself as an integral component of the development chain [1]. The electronic control units (ECUs) being developed and tested are not installed in an actual vehicle, but connected to a simulation system that simulates the ECU's mechanical, electrical, hydraulic and electronic environment in real time. Some examples of earlier applications for HIL simulation are controls for the engine, vehicle dynamics and air conditioning. Nowadays, however, all the electronic control units (ECUs) in a vehicle series are tested by means of HIL simulation, as the overall network of electronics systems in any vehicle has reached an almost unmanageable level of complexity [2].

Up to 90% of all faults occurring in test drives can be reconstructed by means of HIL simulation. Thus, the cost-benefit ratio of HIL simulation is extremely positive despite what at first sight seems to be an enormous investment, and experience shows that this investment pays off within three to six months.

2 Changes in HIL Technology

HIL technology is currently undergoing changes. It is no longer possible to measure the performance of HIL simulators on individual applications only. What is needed more than ever are HIL concepts that can be mapped to a large number of applications. The current challenges, described below, go far beyond the "classic" issues of real-time simulation with signal conditioning and load simulation:

- Products oriented to applications and solutions
- Orientation to solving automotive problems
- Modular, flexible and scalable hardware
- Availability of ready-to-go turn-key systems
- Comprehensive automation options
- Support of automotive standards and standard tools such as ASAM-MCD, MATLAB®/Simulink®, etc.

For users of HIL systems, the main thing is not simply being able to test their ECUs, but rather how they can test them. Application-oriented products and solution-oriented operation must be combined with technical concepts that are flexible and scalable with reference to the application. This will protect the often considerable investments involved. The market leader in HIL systems for testing automotive electronics is dSPACE. dSPACE Simulator [3] provides modern HIL systems in a variety of technical constellations (see Fig. 1).

3 No Need for Coding, Just Configure

One typical example of an HIL simulation application is the testing of ECUs for ESP [4]. The ECU can detect a short-circuit to the supply voltage only during a control action, because valve control is via a low-side switch. Thus, to test the detection function, a driving maneuver involving full braking has to be simulated. The entire vehicle model must run through a number of different transient, but plausible states. Such scenarios make enormous demands on the simulation of vehicle dynamics. Vehicle dynamics models such as ve-DYNA [5] from TESIS therefore provide more than 50 degrees of freedom computed in real time.

A further example is the testing of engine management systems [6]. The powerful control algorithms require very fast closed-loop reactions with regard to throttle valve control, injection and ignition angle. This can be achieved only by using a suitably precise real-time simulation model. Typical model sampling rates are 1 ms and less, and the torque behaviors in the individual cylinders have to be represented selectively for each cylinder. This means that it is possible to test functions such as misfire detection as part of onboard diagnostics (OBD).

However, HIL simulation of engines, and the running and testing of real engine ECUs, both make enormous demands on simulator I/O. Nowadays, special I/O boards such as the DS2210 HIL I/O Board from dSPACE are used for this. This board is tailor-made for engine and vehicle dynamics applications. It has a special computing section, called the angular processing unit (APU), for fast injection and ignition signals relating to the crankshaft angle, which generates the appropriate crankshaft and camshaft sensor signals at a resolution of less than 0.1 degrees. For users, the important thing is that the APU and the entire I/O can be configured graphically in Simulink®. This is extremely practical, since the engine model itself is usually available in Simulink®. The MATLAB®/Simulink® development environment is a quasi-standard in this respect, not only in the automotive industry.

4 Signal Conditioning – More than Level Conversion

The DS2210 HIL I/O Board is an "automotive I/O board" equipped with the necessary signal conditioning. Thus, the I/O channels of the DS2210 are adapted to the voltage ranges typically found in a vehicle. This means that no further action on signal adaptation and level conversion is necessary.

However, signal conditioning often goes beyond the necessary measures for level conversion between standard I/O levels (typically 0 to 10 volt or –10 to +10 volt) and the voltage levels common in vehicles (0 to 18 volts for passenger vehicles). For example, signal conditioning is used for preparing relatively complex valve flows in the HIL simulation of gasoline and diesel direct injection engines.

dSPACE has developed a suitable signal conditioning model for precisely this application. Depending on the gradient of the current flow, the module is able to detect a variety of threshold values, which can be set by software. This means that it can distinguish between the boost and the hold phases of the valve control. At the output, the module generates a binary signal correlated to the fuel flow. This can easily be captured and evaluated using

Fig. 2: ECU tests with integrated diagnostics interface

conventional standard I/O. With the help of the module, it is possible to fulfill the high speed and precision required by the simulation of direct injection engines. Like all other signal conditioning modules from dSPACE, the module can be used in different simulator types.

5 The Full Benefit with Test Automation

HIL simulation is not an end in itself. The full benefit is reaped only when automation is performed. A typical example of tests that can be automated is the testing of diagnostics functions [7]. The same sequence is performed for every pin on the ECU and for every possible electrical fault:

- Desired operating point is reached
- Electrical fault is applied
- Fault is removed
- ECU fault memory is read out
- Diagnostic trouble code is compared with the reference entry
- Fault memory is cleared
- Automatic documentation of results

This process does not always have to run in this precise sequence. For example, it depends on the specific application whether a different operating point has to be reached before a new fault is applied, or whether the ignition has to be switched off for the fault memory to be cleared.

What is important for efficient operation of the test system is that the definition of operating points, the control of the electrical fault simulation, frequently performed by means of relays, and access to the diagnostics memory are all integrated seamlessly into the HIL simulator. For example, access to the diagnostics memory of the ECU can be implemented by integrating a standard diagnostic tool such as the Diagnostic Tool Set (DTS, [9]) from Softing. Control and automation continue to be performed from the operating software of the HIL simulator, in this case ControlDesk from dSPACE (see Fig. 2).

Testing times can be reduced to a tenth by automating test sequences of this kind [8]. Obviously, automation is not restricted to the testing of diagnostic functions. On the contrary, the degree of automation is constantly growing. Automated operation – also overnight and on weekends – is now quite common. And the testing of complex Formula 1 ECUs would scarcely be possible without HIL simulation, because of the short iteration cycles between races and because it is vital to completely exclude the possibility of new software strategies having any side-effects [10].

6 Networked Simulation – the "Virtual Vehicle"

Frequently, several simulators are installed, for various applications such as engine, transmission and vehicle dynamics control. The ECUs are tested individually on these systems; ECUs that are not physically present are simulated (restbus simulation). Here again, the ECUs are networked. Moreover, in the vehicle they affect the same plant: the vehicle itself. Thus, they are linked to one another at various levels, and have to be tested as a unit.

The optimum solution is to reuse the existing simulators to test the overall networked system. This is possible when they are interconnected by Gigalinks. Gigalinks are used to link fast dSPACE real-time systems. At more than 1 GBit/s, the data rate is higher than with USB 2.0 or Firewire (IEEE1394). The highly dynamic simulation models exchange their state variables such as engine torque and engine speed via Gigalinks.

An important aspect of linking simulators is that project engineers can specify the overall networked system very simply within Simulink®. They do this by means of special blocks from the Real-Time Interface for Multiprocessor Systems from dSPACE, which represent the Gigalinks graphically within Simulink®. The real-time application, including real-time synchronization and data exchange between the simulators, is generated automatically at the press of a button.

Fig. 3 shows a HIL simulator consisting of individual systems that have been networked [11]. Operation can be performed via ControlDesk or by means of a physical vehicle cockpit. A 3-D animation program such as MotionDesk [12] from dSPACE completes the virtual ECU environment. Multiple use of HIL simulators thus contributes considerably to investment protection.

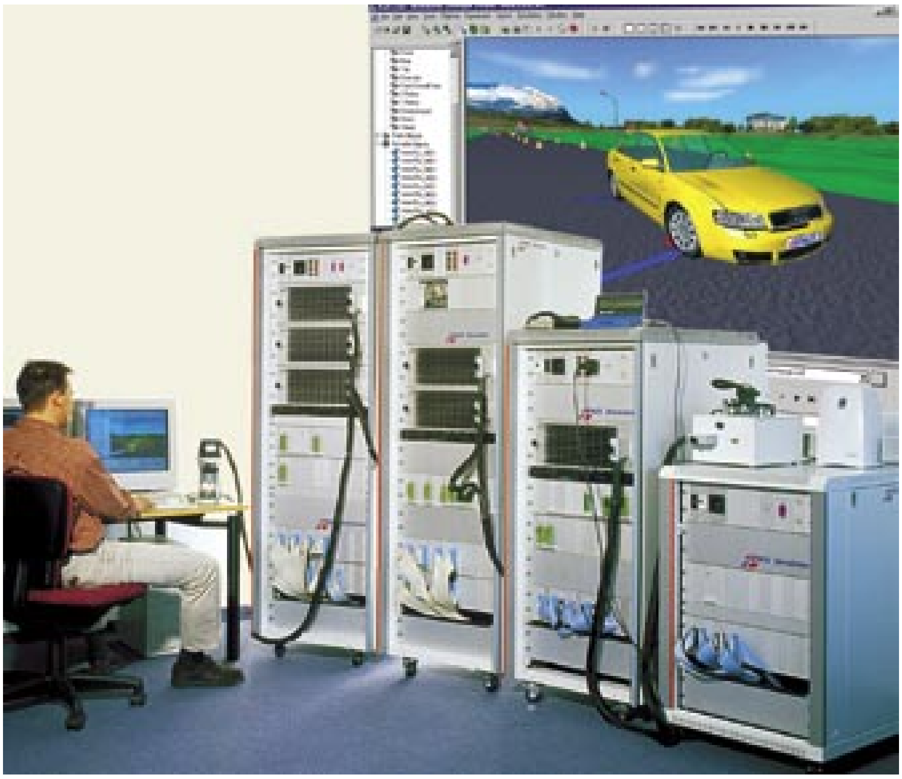

Fig. 3: The "virtual vehicle" in use

7 Future Challenges

The requirements of automotive electronics testing now and in the future demand flexible solutions that are geared to specific applications. dSPACE Simulator offers not only technical advantages in this respect. Its major strengths are as follows:

- HIL systems as part of a modern tool chain based on MATLAB®/Simulink®
- HIL technology dedicated to the testing of ECUs and ECU networks
- Extensive experience in testing automotive electronics

The importance of automated testing is constantly growing. Test automation is increasingly being used in early phases, for example, during function development and trials, and is no longer restricted to HIL simulation. This approach will be specifically supported in the future by means of AutomationDesk, dSPACE's test automation tool. AutomationDesk will provide seamless development and performance of tests in all development phases, from model-in-the-loop to software-in-the-loop and right through to hardware-in-the-loop simulation. A major focus of AutomationDesk will be the structuring and managing of test projects, test data and test results. In addition, efficient, graphical test development and automatic test performance will be at the core of work with AutomationDesk. This will further consolidate the leading market position of dSPACE Simulator in the testing of ECUs.

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