

Full Vehicle HILS for Enhancing Development Efficiency of Electronic Control Systems

Toshiaki KAWAMORI*

Yoshiharu SUDANI*

Satoshi SHIMADA*

ABSTRACT

Electronic control systems mounted in vehicles are increasingly functioning cooperatively by means of multiple communication that uses multiple ECUs (electric control systems), and verification of actual ECUs as a full vehicle integrated electric control system that links these ECUs is more efficient in securing quality. To increase the verification efficiency, Honda has developed the Honda Electrical Revolution for Control Unit by using the Large Examination System (HERCULES) as an environment that can perform integrated verification of all ECUs that comprise the on-board network, in advance of tests using actual vehicles. This enables verification of ECUs approximately three months earlier than with the conventional method, and automated test operation functions constructed at the same time also reduced the testing period by one-half.

1. Introduction

Recently, large numbers of electronic control units (ECU) are mounted in automobiles to satisfy high-level demands in diverse fields such as safety, environment, and comfort. These ECUs boost their cooperative functions by sharing sensor signals and influencing individual actuator control via multiplex communication using multiple on-board networks such as the controller area networks (CAN) shown in Fig. 1. This realizes advanced functions and high performance throughout the vehicle⁽¹⁾.

As a result, the incorporation of ECU verification (hereafter, “ECU integrated verification”) is increasing as a key to securing quality as a full vehicle integrated electronic control system that links the entire on-board network. However, verification centering on prototype vehicles had the following efficiency issues.

(1) Delay in the testing

It is a challenge to secure prototype vehicles that correspond to all vehicle-type variations (model, destination, grade, options) in the initial development stages. This delayed the timing at which ECU integrated verification was performed, with the result that testing processes were concentrated in the later development stages.

(2) Prolonged testing time

It is a challenge to accurately simulate actual conditions such as running, operations, degradation elements, and other factors under special environments, to measure the electrical characteristics of ECUs in the condition assembled in the vehicle, and to reproduce identical conditions for analysis.

The testing procedure including preparation and analysis therefore takes a long time.

In response to these issues, European and American automobile manufacturers are leading the introduction of verification environments for actual ECUs without using actual vehicles. These include the creation of static verification environments that connect multiple ECUs and their control subjects on a bench, and dynamic verification environments that replace multiple control subjects with Hardware In the Loop Simulation (HILS)^{(2), (3)}.

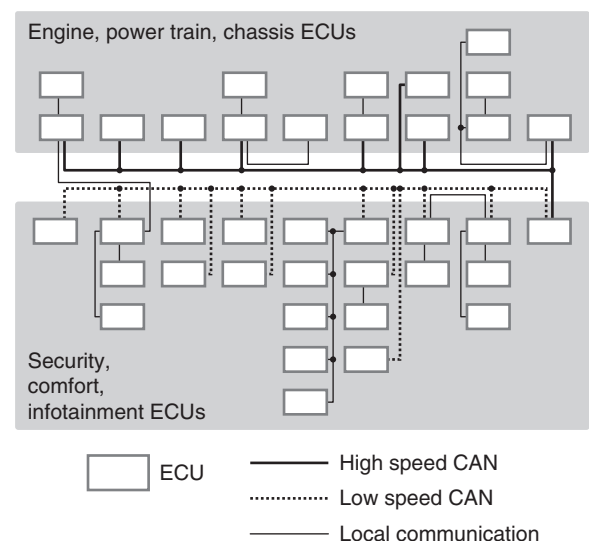


Fig. 1 Example of ECU network

* Automobile R&D Center

To address the issues noted above, Honda has developed HERCULES, which replaces the control subjects of all the ECUs that comprise the on-board network with HILS, and applied it to the mass production vehicle development process on a trial basis. This paper describes the system composition and reports the effects obtained by trial application.

2. Development Goals

The HERCULES development goals were set as follows.

- (1) Construction of an environment that enables dynamic ECU integrated verification at a whole vehicle level, in advance of tests using actual vehicles. This is achieved by modeling all control subjects of all the ECUs that comprise the on-board network.
- (2) Working to shorten the period required for testing and analysis, by creating data of standard manned test conditions to secure reproducibility of identical conditions and employing a structure that enables automatic test operation.

3. System Composition

As shown in Fig. 2, HERCULES consists of a vehicle model that includes all ECU control subjects comprising the onboard network, environment and driver models that simulate running tests, processor boards that perform the calculations for these models in real time and feed the results back to the ECUs as electrical signals, Input/Output (I/O), and a host PC that manages automatic operation of the system.

3.1. Hardware

3.1.1. I/O, processor boards, racks

The following I/O were incorporated to support

approximately 40 ECUs.

- Digital I/O = 828 ch
- Analog I/O = 454 ch
- Other I/O = 484 ch

Relay circuits were integrated in the wiring between these I/O and the ECUs to generate intentional connection breakdowns (broken wires, short circuits). In addition, a total of seven full-size racks were used as frames to house all of the processor boards, power supplies and other hardware.

3.1.2. ECU power supply

Batteries mounted in vehicles produce voltage fluctuations as a result of current loads due to factors such as degradation and the state of charge. Therefore, as shown in Fig. 3, a programmable power supply was mounted that generates voltage fluctuations equivalent to those of an actual battery. In addition, separate relay circuits were mounted for each ECU to vary the ECU power supply connection structure that differs for each model, and reproduce various blown-fuse conditions. This enabled simulation of various power supply states equal to those of actual vehicles. Furthermore, separate ammeters were mounted in the wiring upstream from the ECU power supplies, enabling measurement of the current consumption of each ECU.

3.1.3. Other characteristic functions

Additional I/O functions were developed exclusively for ECUs that have I/O channels other than those described as standard in Sub-section 3.1.1.

(1) Power level simulator

The electric power steering (EPS) ECU incorporates a power circuit to drive the motors, so the actual motor current that corresponds to the load of the steering system that is the control subject must be fed back to the ECU.

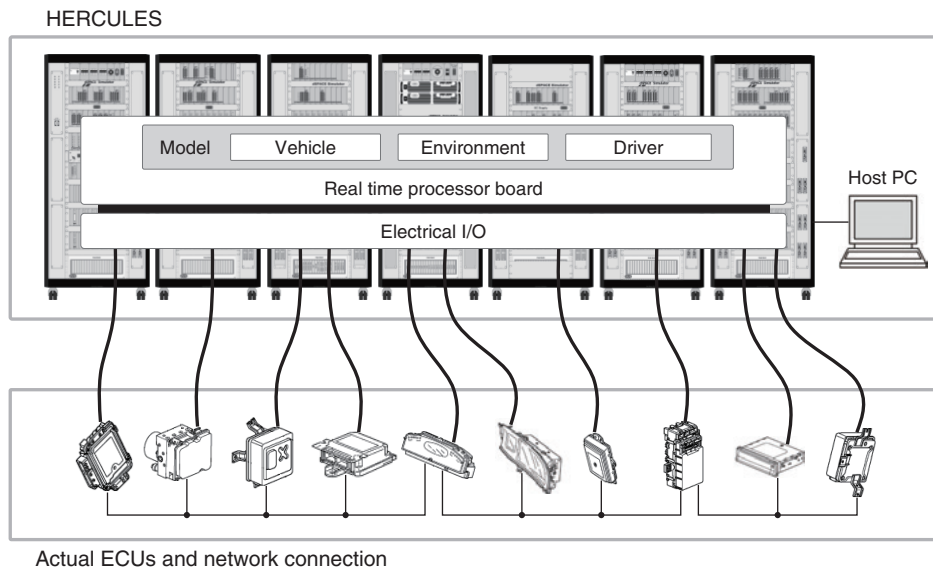


Fig. 2 HERCULES structure

Therefore, a power level simulator was constructed as shown in Fig. 4, using a field-programmable gate array (FPGA) board that calculates the electrical state of the brushless motor in real time, and an electronic load unit that generates the calculated motor current in real time.

(2) Wireless simulator

The tire pressure monitoring system (TPMS) ECU receives the pressure values detected by sensors built into each wheel as radio frequency (RF) band wireless signals. Therefore, a wireless simulator was constructed that can generate simulations of these signals in accordance with the conditions of each vehicle model.

3.2. Models

Figure 5 shows the overall model structure. The overall

model is divided into vehicle, environment and driver models, and these are linked in a loop.

A model package made by dSPACE GmbH was used as the base, and functions related to original mechanisms, locations in the base model lacking body electronics and electrical components, and I/O control were added.

3.2.1. Vehicle model

The vehicle model includes all the ECU control subjects connected to the network. The accuracy requirement for model creation was that all control subjects satisfy the behavior within the normal range specified by the ECUs. The features of this model are described below.

(1) Engine auxiliary units

Models that simulate exhaust gas recirculation (EGR)

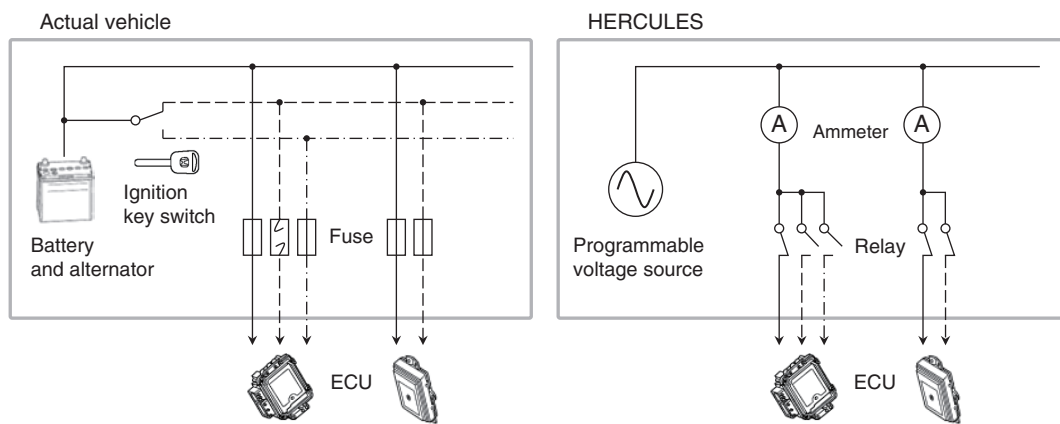


Fig. 3 ECU power supply structure

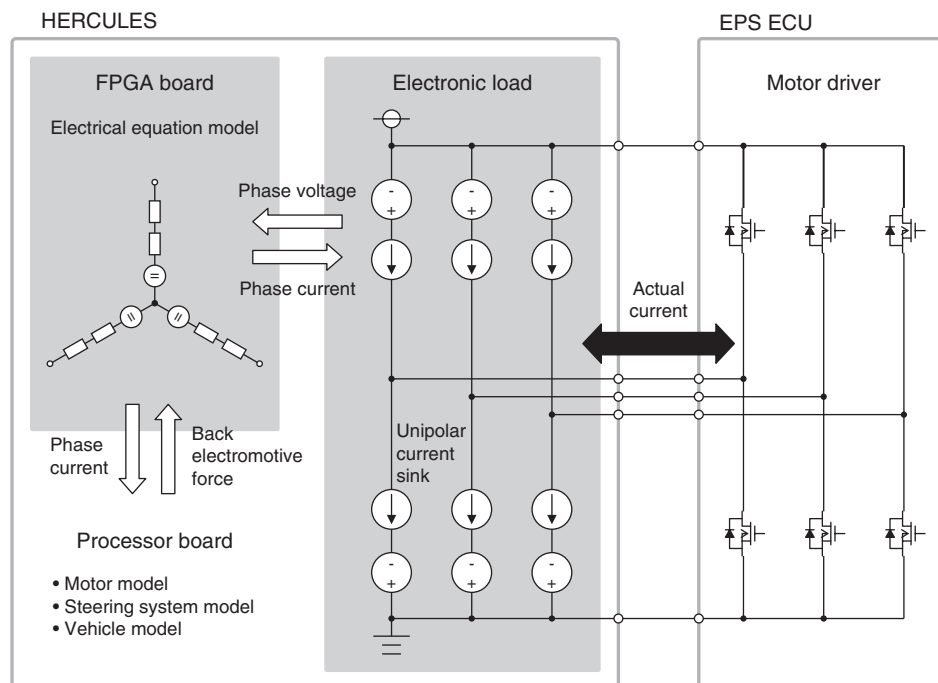


Fig. 4 Power level simulator for EPS ECU

and the evaporative emission control system (EVAP), and models of the alternator and starter motor, which influence the battery state, were added.

(2) Power steering

A brushless motor model and a steering gear box model were added for the EPS power level simulator.

(3) Battery

A model was added to simulate voltage fluctuations corresponding to electrical loads due to degradation and the state of charge.

(4) Body electronics and electrical components

Models were added to simulate the motorized actuators used for power windows and various comfort equipment.

3.2.2. Environment model

The model structure enables arbitrary definition of road conditions such as course layout and road surface friction to simulate various running conditions.

3.2.3. Driver model

This model enabled autonomous lane-following running (autonomous accelerator pedal, brake, and steering operations), and vehicle equipment operations (ignition key, various switch operations) at arbitrary timings synchronized with the running conditions, to simulate manned test conditions. In addition, the structure also enabled the use of external diagnosis tools that presume vehicle inspection processes.

3.2.4. Model calculations

The basic model calculation cycle was set at 1 ms, and partial iterative operations are used in locations that require high speed. Calculations are performed in real-time by parallel processing using seven processor boards.

3.3. Automated Tests

A function that continuously and automatically performs multiple test items was constructed to reduce the process time for periodically repeated tests and the operation time for manipulations and measurements. Users define arbitrary test conditions (test patterns) and designate the execution sequence and judgment conditions, and the series of tasks through generation of the results report are performed automatically.

3.3.1. Test patterns

Figure 6 shows an example of a basic test pattern definition. Here, vehicle speed and equipment operations at different running positions or over time are converted to data according to the manned vehicle running and operation test mode definitions.

3.3.2. Judgment conditions

The vehicle status (model variables) and the status output values of each ECU can be judged according to arbitrarily defined threshold values and logical equations.

3.3.3. Results report

Figure 7 shows an example of a results report generated by an automated test. In this example, the judgment conditions define the failure warning lamp indication, standby current after shutdown, and diagnostic trouble code (DTC) storage for each ECU, and the results for each item are displayed in ECU units.

3.4. System Overview

Figure 8 shows the general appearance of the completed system. The ECUs subject to verification and their network connections are arranged in the two ECU racks in the center

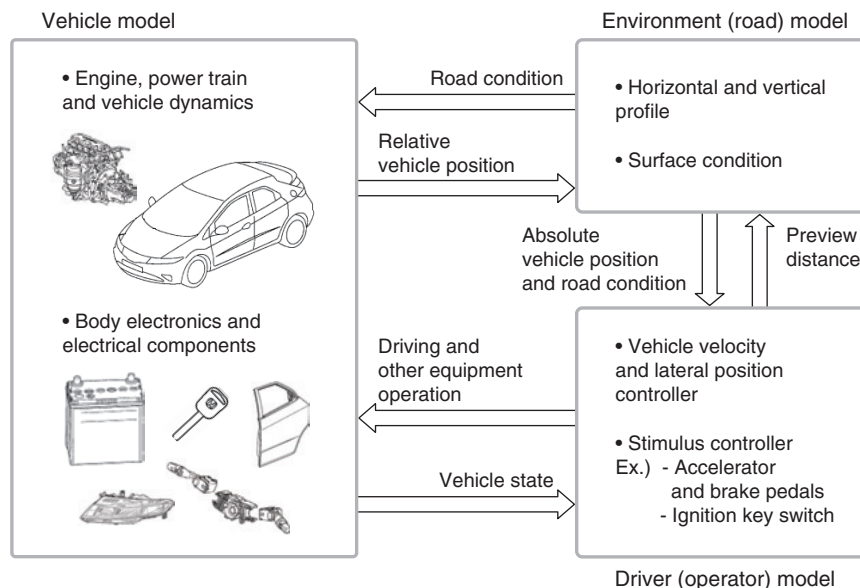


Fig. 5 Model structure

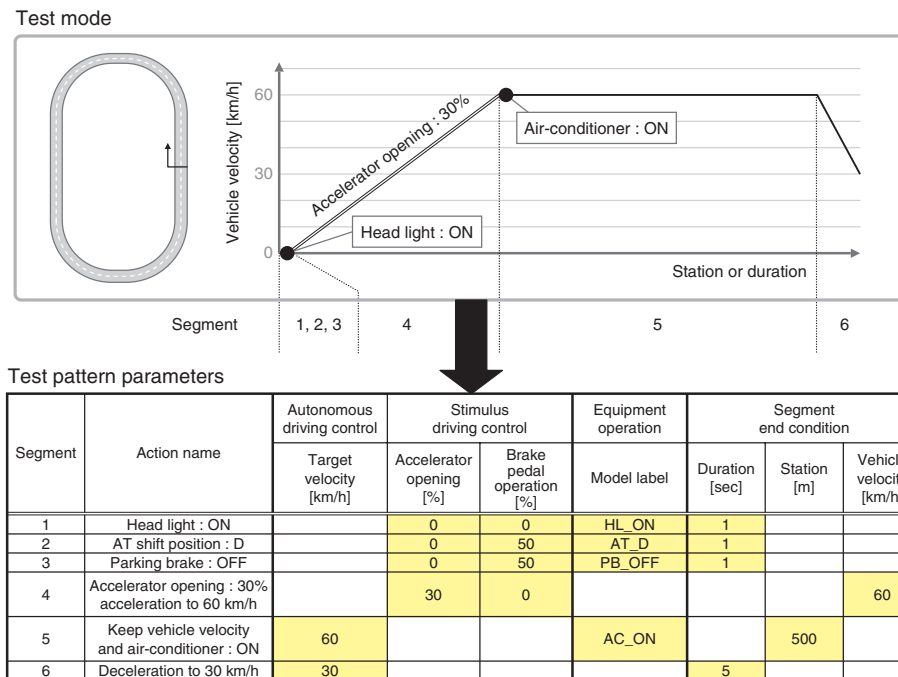


Fig. 6 Example of test pattern parameters

Test pattern No.1

ECU name	Warning lamp	Standby current	DTC
ECU_A	Failed	Passed	Failed
ECU_B	Passed	Passed	Passed
ECU_C	Passed	Passed	Passed
ECU_V	Passed	Passed	Passed
ECU_W	Passed	Failed	Passed
ECU_X	Passed	Passed	Passed
ECU_Y	Passed	Failed	Passed
ECU_Z	Passed	Passed	Passed

Fig. 7 Example of report file

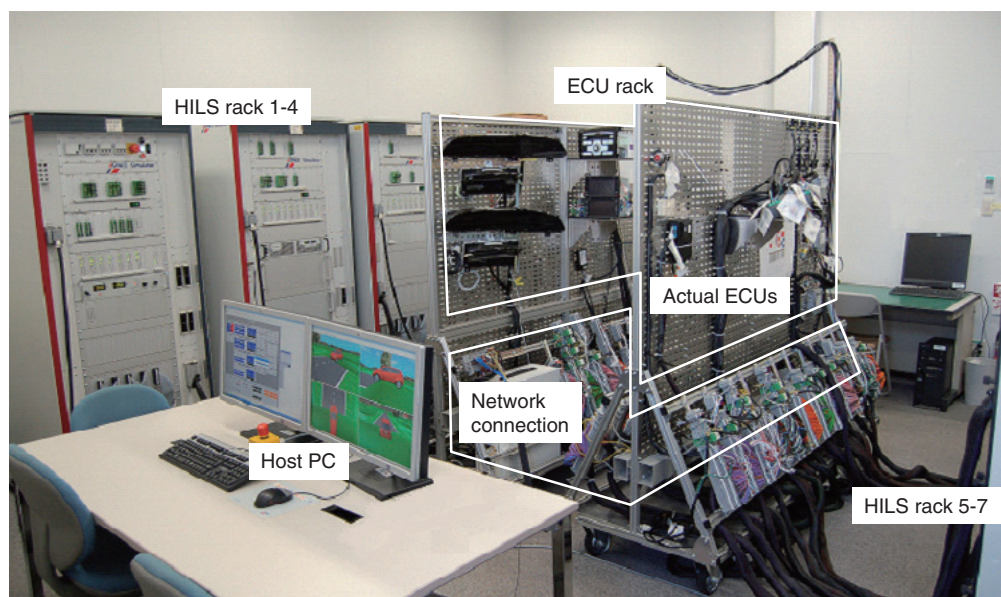


Fig. 8 HERCULES overview

of the photograph. The vehicle model for verification is switched by replacing these ECU racks.

4. Verification of System Accuracy

All control subjects replaced with HILS were verified to satisfy the behavior within the normal range specified by the ECUs.

The verification example for the vehicle model, in which all the ECUs that comprise the on-board network were connected to each other and activated, is presented below. Figure 9 shows the model calculation results and actual vehicle measurement results for the vehicle trajectory, lateral acceleration, and yaw rate while turning.

In this example, the correlation of the model calculation results for lateral acceleration and yaw rate was confirmed to be within the normal ranges specified by the ECU.

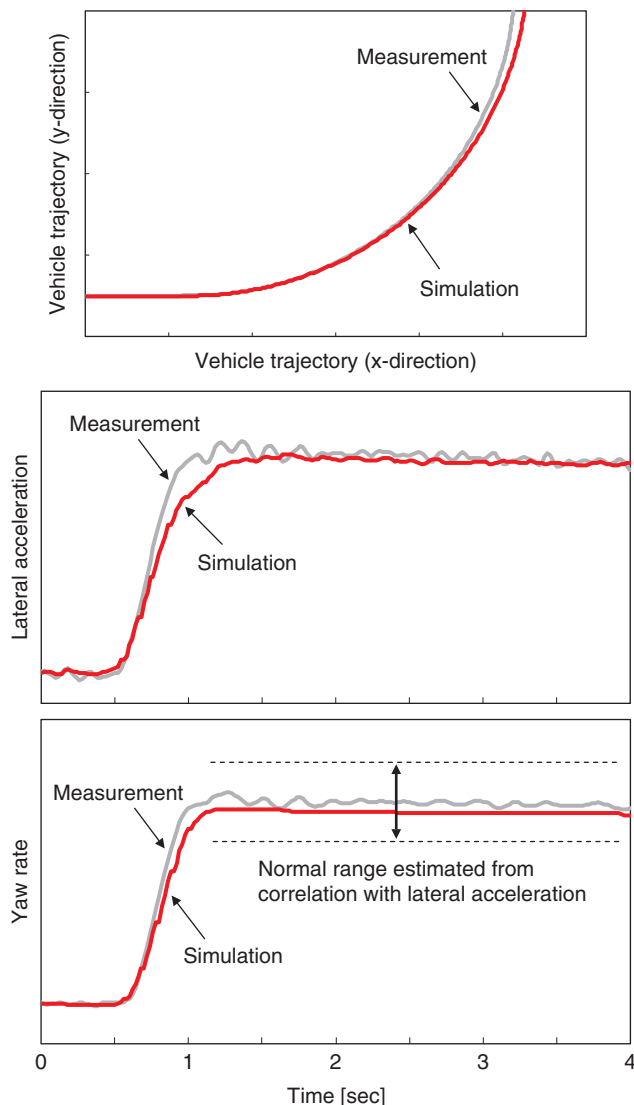


Fig. 9 Example of HILS verification

5. Effects of Trial Application

Trial application was made of HERCULES to the 2011 model year mass-production vehicle development process, and the following effects were confirmed.

- (1) Approximately 1200 patterns of test items could be performed approximately three months earlier than with conventional tests using actual vehicles. It was confirmed that HERCULES was able to reproduce and extract trouble phenomena in the same manner as those extracted by tests using actual vehicles.
- (2) Day-and-night continuous operation using the automated test operation functions, and the high reproducibility of various conditions and ease of analysis provided by HILS enabled reduction of the time needed for testing and analysis to half or less of the previous period.

6. Conclusion

The development of HERCULES enabled ECU integrated verification in advance of tests using actual vehicles, without using actual vehicles, and also enabled reduction of the testing period. The newly constructed system and test patterns have expandability and compatibility, and further effects can be expected by expanding the system to cover more models in the future.

References

- (1) Schaeuffele, J., Zurawka, T.: Automotive Software Engineering, SAE International, 408 p. (2005)
- (2) Plöger, M., Sauer, J., Büdenbender, M., Held, J., Costanzo, F., De Manes, M., Di Mare, G., Ferrara, F., Montieri, A.: Testing Networked ECUs in a Virtual Car Environment, SAE Paper, No. 2004-01-1724 (2004)
- (3) Heimig, B., Haupt, H.: Hardware-in-the-Loop Testing of Networked Electronics at Ford, SAE Paper, No. 2005-01-1658 (2005)

■ Author ■



Toshiaki KAWAMORI



Yoshiharu SUDANI



Satoshi SHIMADA