Platform Technologies that Support High-quality Automotive Products

To satisfy the needs of autonomous driving and environmental protection, Hitachi is developing platform technologies designed to bring high quality to the increasingly advanced and diverse automotive products that it provides. Specifically, the company is developing control system and information system software platform technologies, as well as software design validation technology in the form of high-performance HILS and virtual environment simulation (vHILS) technologies. Hitachi is also working on CAE technology by developing a three-way (structure — magnetic field — fluidity) coupled analysis technology, and technology for sensory evaluation rating and estimation of operating noise. Its work on materials technology covers analysis and design technologies for suspension damper oil seals and oil materials. These platform technologies are being applied to product development to increase the efficiency of design/validation work and help improve quality.

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1. Introduction

The software and mechanisms used to create products that support autonomous driving and the environment are becoming increasingly complex every year, making design efficiency and quality assurance pressing concerns. Moreover, autonomous driving and electrification are freeing vehicle occupants from driving operations and engine noise, making design technologies for conventional chassis components increasingly important. These technologies are used for applications such as increasing suspension performance to improve ride comfort, and reducing noise and vibrations in parts such as brakes.

To overcome these challenges and to provide high-quality products in a timely manner, Hitachi is working on developing platform technologies with the aims of incorporating quality into the upstream design phase and preventing design revisions from originating in downstream processes. These platform technologies cover areas such as analysis-driven design used to boost efficiency when creating software platforms and validating software, and selecting mechanical structures and materials.

This article presents the work Hitachi is doing on platform technologies in the areas of software platforms, software design validation, computer-aided engineering (CAE), and materials.

2. Software Platform Technologies

To improve the maintainability and portability of the increasingly large-scale software used in the electronic control units (ECUs) that control vehicles, the software is usually implemented in layers after being divided into control applications and platform software called the Basic Software (BSW). Standards released by the European Automotive Open System Architecture (AUTOSAR) consortium have become the industry standards for the architecture and application programming interface (API) used by ECUs. Platforms enabling information processing used for driver assistance and autonomous driving applications are also becoming increasingly necessary.

This section presents Hitachi's work on platform technologies for control system platforms and information system platforms.

2. 1
Control System Platforms

Quality (safety, reliability) and real-time performance are very important requirements for the BSW that serves as the control platform in vehicles.

Hitachi is working on ensuring and improving quality by creating software based on a software development process that can satisfy Automotive Safety Integrity Level (ASIL) D, the highest classification of hazard defined in the ISO 26262 functional safety standard for road vehicles.

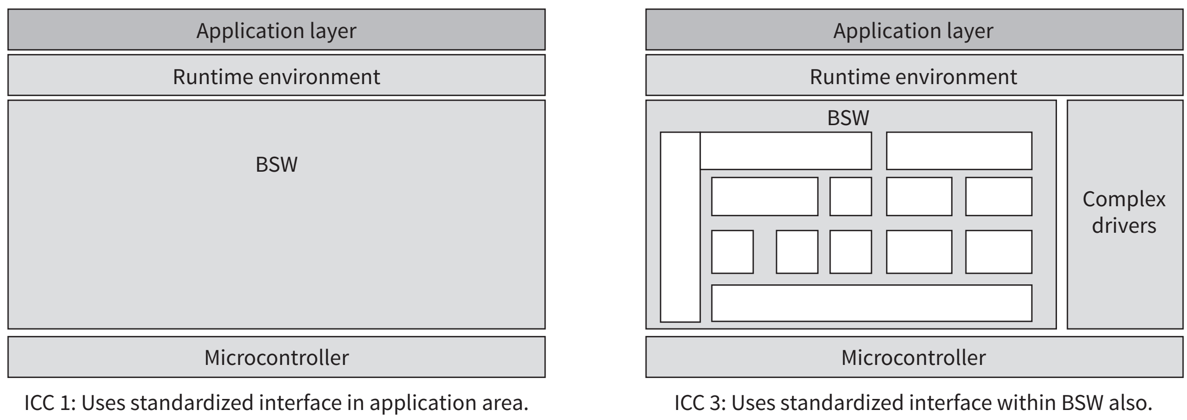
To ensure real-time performance, Hitachi is optimizing the internal structure by prioritizing performance, using Implementation Conformance Class (ICC) 1, which enables the BSW to be implemented as a black box while using the API standardized by AUTOSAR (see **Figure 1**).

On the other hand, car manufacturers are increasingly designating BSW — and the vendors that provide it — based on ICC 3 (which standardizes the BSW down to the internal modules), which means that the quality and performance of the BSW must be ensured when combining BSW purchased from different vendors.

When problems occur in BSW that consists of modules, etc. purchased from different vendors, it is difficult to identify which module is causing the problem. In response, Hitachi has developed a new operating system (OS) trace function that can be implemented in ECUs. The OS trace function uses a special method of recording task operations, interrupt processes, and operation timing to enable identification of the operating states of applications and the BSW even in ECUs that have limited central processing unit (CPU) performance or memory capacity. This ensures quality and performance by enabling technicians to identify the cause of problems, while

Figure 1 — BSW Internal Structure Example

ICC 1 and ICC 3 support the use of common applications, but have different BSW internal structures. ICC 1 enables construction that prioritizes performance. ICC 3 enables modules from different vendors to be combined.



BSW: basic software ICC: Implementation Conformance Class also identifying where bottlenecks are occurring when performance problems arise.

2. 2 Information System Platforms

With autonomous driving expected to make major progress strides in the coming years, information-oriented operating systems such as Linux*1 and the middleware they run are becoming increasingly common formats for implementing the data processing and intelligent processing applications needed for autonomous driving. While the AUTOSAR consortium's application standardization concept was originally created for control system platforms, the consortium is now expanding its use to information system platforms designed for applications such as autonomous driving. This expansion has been made possible by the development of the Adaptive Platform, a set of middleware that runs on Linux and other operating systems conforming to the Portable Operating System Interface (POSIX)*2 standards. A phased-in release of the new middleware began in April 2017.

Based on these circumstances, Hitachi is developing middleware that runs on Linux and the Adaptive Platform, while also working to achieve functional safety, to improve real-time performance, and other technology enhancements designed to ensure information platform quality and performance.

3. Software Design Validation Technologies

Hitachi is working on the development and application of software design validation technologies that enable more rapid development and delivery of software products while dealing with the increasingly advanced functions and larger scale of today's onboard control software, ensuring product viability, and ensuring quality that satisfies functional safety standards. This section presents the high-performance hardware-in-the-loop simulation (HILS) and virtual HILS (vHILS) technologies it is developing aimed at a tenfold increase in control system development efficiency by creating simulation-based development processes.

*1 Linux® is the registered trademark of Linus Torvalds in the U.S. and other countries.
*2 POSIX is a family of standards specified by the IEEE.

3. 1 High-performance HILS

HILS-based validation enables testing to be done by combining the ECU with a 'plant model' without using a test vehicle. It is widely used as an effective way to automate validation test processes and improve their comprehensiveness. But HILS has various problems and restrictions, such as the fact that the actual ECU is required under test and validation of the overall vehicle is difficult. Hitachi is working to overcome these challenges by developing a high-performance version of HILS that uses a CPU board and field-programmable gate array (FPGA).

Hitachi's high-performance HILS combines a general-purpose CPU board and FPGA-packaged input/output circuit that substitute for an actual ECU board. This enables real-time simulation without using an actual ECU (see **Figure 2**). High-performance HILS also enables linked simulation of multiple control targets by connecting and linking multiple high-performance HILS units together. The company is now conducting trials of integrated engine/brake tests using two linked HILS units.

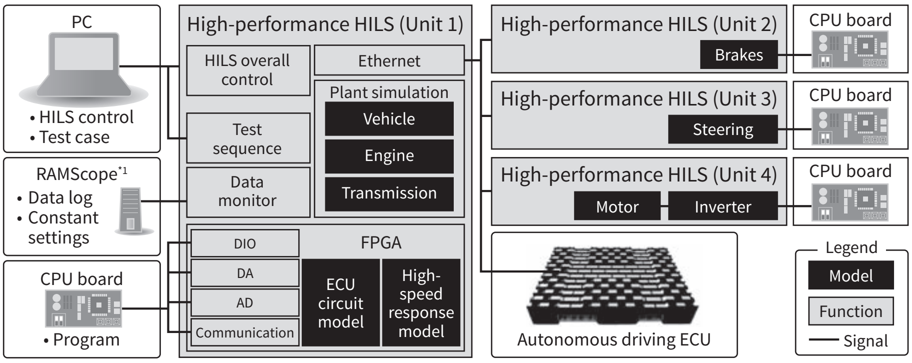
In the future, Hitachi will continue to work on extending it to enable all-in-one vehicle validation, and on linking to external environments for autonomous driving evaluation.

3. 2 vHILS

vHILS is a new validation technology for in-vehicle control software that has attracted interest for its ability to model the ECU under test using a microprocessor simulation that runs the control software in executable form. vHILS does not support the real-time execution that is possible with HILS or the high-performance HILS described above. But Hitachi is continuing to explore its uses since it can perform PC-based control software validation without using a CPU board or an actual ECU board.

To further reduce the time needed for the validation work done with vHILS, Hitachi has developed a tool that automates the series of processes required (registering the test data, running the simulation, then performing a pass/fail evaluation of the simulation results). This tool was used to create an automated

Figure 2 — High-performance HILS Test Environment
Hitachi achieved the linked simulation of vehicle systems by connecting multiple high-performance HILS units with built-in vehicle control models.



HILS: hardware-in-the-loop simulation FPGA: field-programmable gate array ECU: electronic control unit PC: personal computer CPU: central processing unit
DIO: digital input/output DA: digital-analog AD: analog-digital
*1 RAMScope is a registered trademark of DTS INSIGHT.

vHILS test environment(1). After using this test environment for pre-delivery regression testing of control software for engine control systems, it was found to reduce the time needed for validation to about one-thirtieth of the time needed when testing with physical test equipment.

Hitachi is also using this technology to satisfy functional safety standards by extending its use to the area of virtual failure mode and effect analysis (vFMEA, is applied to the fault injection testing for ECU hardware), and has started to use it in mass-production development(2).

4. CAE Technology

While Hitachi has worked on creating more advanced CAE technology for individual physical areas such as structures, heat, fluids, and magnetic fields, many automotive parts and industrial products are exposed to multiple physical fields at once. Since simulations of these composite areas will also be needed to make headway in improving product quality, the company has been working on developing coupled analysis methods that allow for simultaneous interactions among multiple physical quantities.

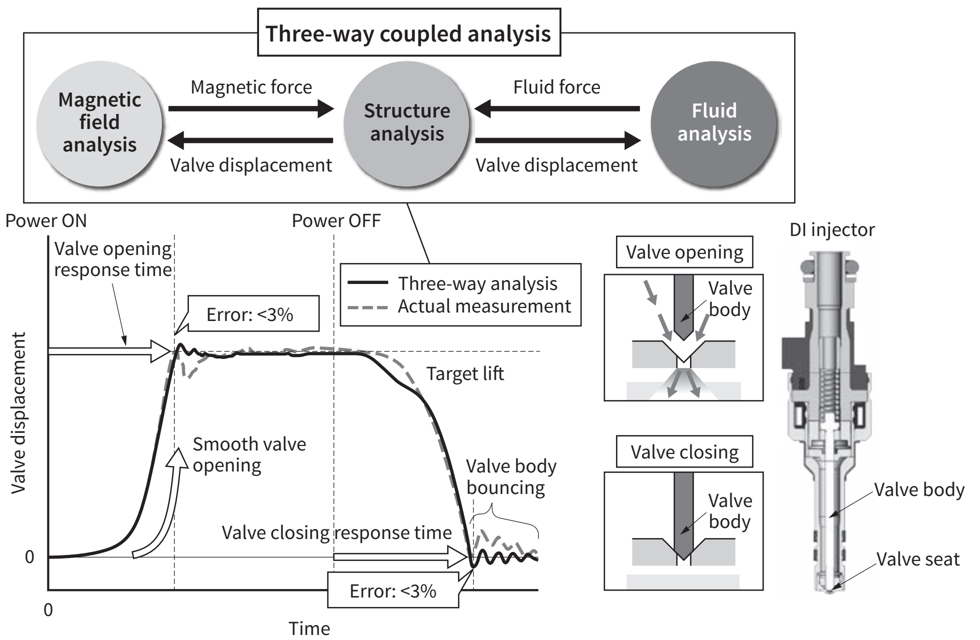
In some cases, product characteristics are highly dependent on human perception, making it impossible to base product quality evaluations solely on physical quantities. The unpleasantness of sounds and ride comfort are typical examples. To handle these types of characteristics, Hitachi has been working on developing technology capable of predicting sensory-based quality evaluations by discovering correlations between physical quantities and sensory evaluation ratings.

4. 1
Three-way (Structure — Magnetic Field — Fluid) Coupled Analysis Technology

Direct injection (DI) injectors and high-pressure fuel pumps are fuel system components that use solenoid valves to control operation. Predicting the behavior of these valves is an important part of product development. Solenoid valves are influenced by the three physical quantities (spring force, magnetic force, and fluid force), and the valve behavior includes component deformation and collisions. Hitachi is developing a valve behavior prediction technology that handles these multiple physical phenomena.

To do so, the company has created a technology that couples three different 3D analysis tools used to analyze structures, magnetic fields, and fluids respectively. Specifically, it has created an interface used for bidirectional transfer of the physical quantities calculated by each analysis tool, along with a control mechanism that calculates multiple physical fields simultaneously, and a mapping mechanism that accurately applies multiple physical quantities to the target regions. It has also created a method of passing calculation results back-and-forth between the structural

Figure 3 — Comparison of Three-way Coupled Analysis and Actual Measurement Results for Valve Behavior
Using three-way coupled analysis, Hitachi was able to reproduce smooth valve body opening behavior and valve body bouncing after closing.



DI: direct injection

analysis at the center, and the magnetic field analysis and fluid analysis. This technology enables three-way (structure — magnetic field — fluid) coupled analysis (see **Figure 3**).

This coupled analysis technology can accurately calculate elastic deformation of parts such as valve bodies, and has accurately reproduced phenomena such as smooth valve opening behavior and bouncing after valve closing.

The technology is being applied to develop new products, and promoting improved calculation accuracy and speed.

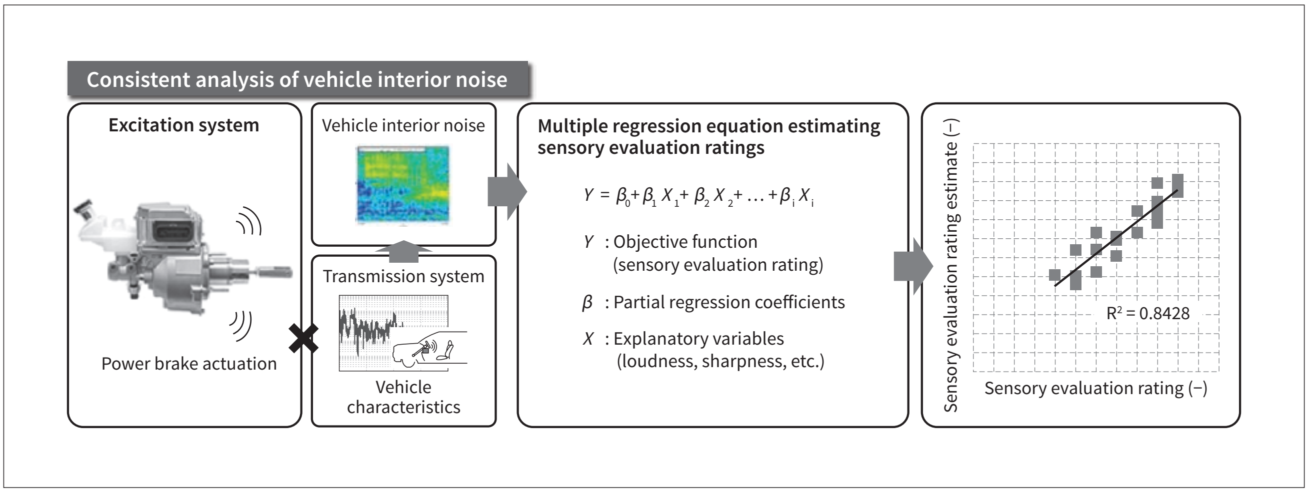
4. 2
Operating Noise Sensory Evaluation Rating and Estimation Technology

The automotive cabin background noise in passenger vehicles has been dramatically reduced since the appearance of hybrids, significantly improving cabin comfort. But, as background noise has diminished, the operating noise of automotive parts has become more noticeable, creating demand for noise volume and noise quality that is unobtrusive to occupants in quiet automotive cabins. Hitachi has responded by developing a technology for consistent analysis for prediction of automotive cabin noise. It allows sensory evaluation ratings given to operating noise by car manufacturer evaluators to be estimated during the design phase.

The operating noise created by power brake actuation has traditionally been evaluated by noise pressure level alone. It is used here as an example to illustrate how the technology quantitatively estimates sensory evaluation ratings from automotive cabin noise. Subjective evaluation tests given to test subjects yielded sensory evaluation ratings demonstrating the effect of not only loudness, but also of factors linked to vehicle added values such as luxury and security. Correlation analysis enabled Hitachi to obtain psychological effect parameters such as loudness and sharpness that are highly correlated to these factors, along with other auditory characteristics. It estimated sensory evaluation ratings by using multiple regression analysis with these parameters as the explanatory variables, obtaining a prediction accuracy of over 84% (R-squared coefficient of determination of over 0.84) from the regression equation. This technology enables quantitative, highly accurate estimates of sensory evaluation ratings for power brake actuation operating noise during the design phase (see **Figure 4**).

Figure 4 — Sensory Evaluation Rating Estimation for Power Brake Actuation Noise

Highly accurate estimates of sensory evaluation ratings for operating noise produced by power brake actuation was achieved by using multiple regression analysis with factors such as psychological effect parameters as the explanatory variables.



The company is now working to improve this estimation technology by expanding its application to other automotive parts with different sound qualities.

5. Materials Technology

Materials technology for automotive parts has always faced demands for quality and reliability improvements in areas such as strength and rigidity. These demands have recently been joined by growing demands for weight reduction to improve fuel economy, and for material design and shape optimization to improve ride comfort and steering stability.

Hitachi has been working to reduce weight by switching materials from steel to nonferrous metals and plastics, and by optimizing shapes using various analytical methods.

The company is also working on material design and shape optimization by developing analysis-lead materials technology to eliminate development delays caused by conventional experiential methods.

The being done work on sliding parts for suspension dampers is described here as an example of these efforts. The key demands for suspension dampers are oil (hydraulic fluid) air-tightness (reliability), and the friction characteristics, which affect product performance (ride comfort, steering stability). Both demands need to be met simultaneously. The sections below describe the design technology for oil seals and oil, key areas for improving air-tightness and friction characteristics.

5. 1
Oil Seal Design Technology

To improve oil seal air-tightness, Hitachi began by changing the oil seal shape and material, but its initial bench test results did not match the practical results it obtained from reliability evaluations of equipment and vehicles, indicating it had not identified all the design factors through its initial evaluation alone.

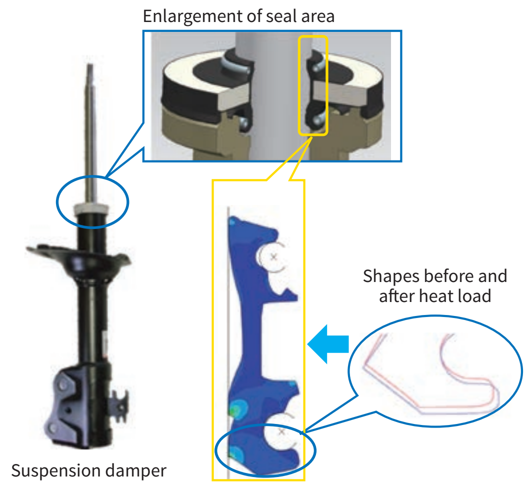
To overcome this challenge, the company used finite element method (FEM) analysis of the physical properties and shapes under heat and load conditions simulating actual usage conditions, and found that operational and environmental degradation significantly affected air-tightness.

By using an evaluation method that simulates actual usage conditions, it aims to improve design accuracy during the prototyping phase. This improvement should help improve quality and performance while helping reduce development time by reducing the number of prototypes needed (see **Figure 5**).

5. 2
Oil (Hydraulic Fluid) Design

Friction can be reduced by formulating extreme pressure agents, friction modifiers, and other additives for hydraulic fluid. The selection of additives is an important factor in determining friction

Figure 5 — Oil Seal Analysis Example
The figure shows an example of FEM analysis for physical properties and shapes under heat and load conditions simulating actual usage conditions.



FEM: finite element method

characteristics. But, the mode of action of additives at the interfaces of sliding parts is complex, making their formulation for hydraulic fluids highly reliant on oil manufacturer experience.

Hitachi addressed this problem by using molecular dynamics (MD) analysis to create a molecular simulation that explicates the mechanisms by which additives produce effects on the rubber-metal interface in oil seals prior to additive selection. It has been used to select additives that can provide stable performance in the temperature environments found during actual use in vehicles, significantly reducing the selection time relative to the time needed to evaluate actual oils.

6. Conclusions

This article has presented some of the platform technologies Hitachi is developing that support high-quality products. It has developed an AUTOSAR-compliant software platform (high-performance HILS) and simulation-based software design validation technology (vHILS). Its three-way (structure — magnetic field — fluid) coupled analysis technology enables highly accurate prediction of solenoid valve behaviors. It has developed technology that can estimate sensory evaluation ratings for operating noise. It has also developed design technology for suspension damper oil seals and oil using FEM analysis and MD analysis.

Using analysis-driven design and simulations, Hitachi will continue to improve validation in upstream processes, provide software platforms, and take similar measures to help improve product quality and design efficiency.

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