Virtual Product Simulator (VPS)

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The manufacturing industry is increasingly requested to improve reliability, shorten development periods, and reduce development costs in all phases from concept to design and manufacturing. To fulfill these requests, there is a pressing need to promote manufacturing efficiency through the extensive use of information technology (IT). The virtual product simulator (VPS) developed by Fujitsu over a 10-year period is demonstrating its advanced capabilities on various manufacturing worksites in combination with the proliferation of 3D-CAD systems. VPS is based on simulation technologies researched for many years by Fujitsu Laboratories. This paper describes VPS in terms of its background to development, the functions supported, typical examples of application, and future possibilities.

1. Introduction

The manufacturing industry has recently been reviewing overall manufacturing activities. There is an urgent need to improve reliability, shorten development periods, and reduce development costs in all phases from concept to design and manufacturing through the extensive use of information technology (IT). While the penetration rate of 3D-CAD systems is 50% or higher in the United States, it is less than 30% in Japan. However, 3D-CAD systems are expected to become increasingly important and spread among Japanese users to match the U.S. level. The 3D product models obtained from existing 3D-CAD systems have ensured the seamless analyses of stress, vibration, and resin flow. Moreover, in line with recent improvements in computer numeric and 3D drawing capabilities, digital mockups are now being used to build realistic virtual products on computers and conduct various verification activities. The virtual product simulator (VPS)[1] described in this paper is one of those digital mockup systems.

VPS has focused on producing a virtual mechanism that reproduces the mechanical operation of products. Its use of the computer virtual mechanism allows engineers to conduct such mechanical verification activities as checking for interference between parts before completing a prototype. Consequently, mechanical design can become more efficient.

It should also be noted that mechatronics has been promoted for recently developed products with advanced requirement specifications, and mechatronics products account for a huge percentage of all newly developed products. Mechatronics products usually have electronic devices. In particular, the development scale of embedded software for products incorporating microcomputers in the electronic circuit board has grown so significantly as to affect product quality. Hence, there is an urgent need to develop embedded software of higher reliability and efficiency. Moreover, mechatronics products mount other important devices such as sensors, motors, and operator panels connected via cables

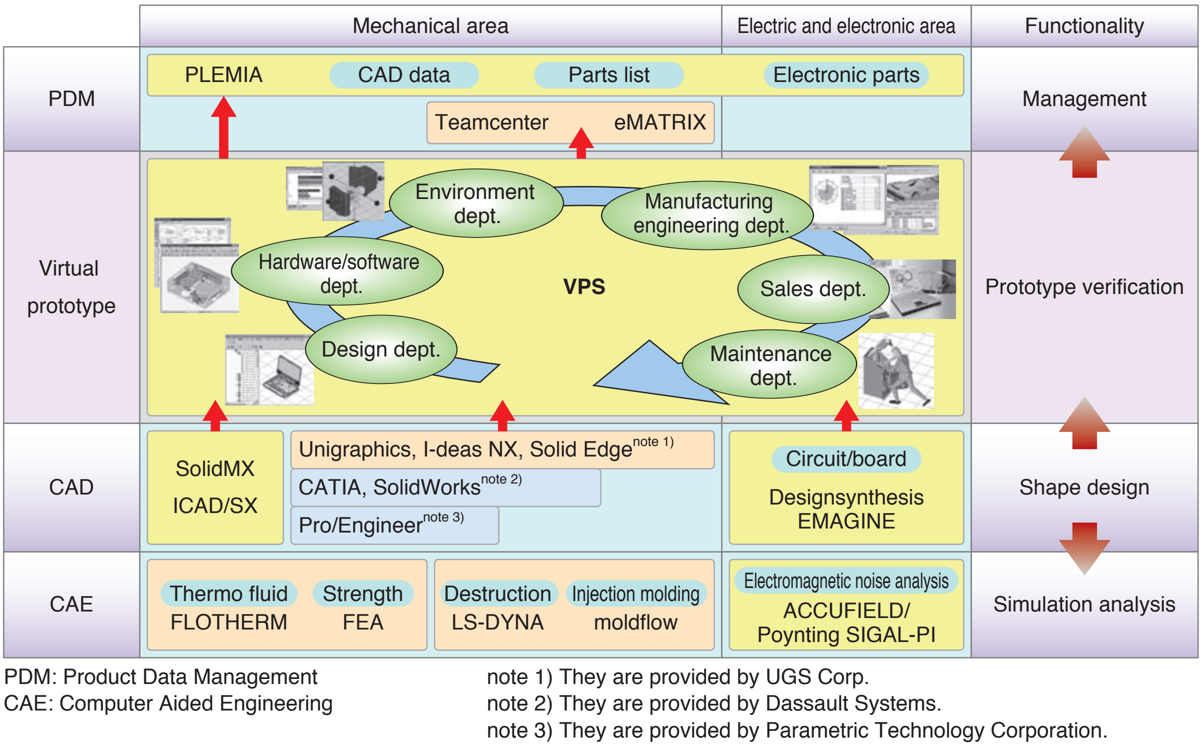

Figure 1
VPS positioning.

and connectors (wire harnesses). More efficient verification of the routes and lengths of cables and connectors are also expected. For example, it is ideal to virtually allocate wire harnesses along the product so that excessive pulling, bending, and torsion can easily be checked during product operation.

As mentioned above, VPS is intended to shift a large portion of existing manufacturing activities for continuously producing actual prototypes to a virtual computer simulation base. VPS links CAD/computer-aided engineering (CAE) used to design the shapes of each part with product data management (PDM) that manages manufacturing data. Thus, VPS can be regarded as a system that accumulates and inherits the manufacturing knowledge acquired through virtual simulation (**Figure 1**).

2. Background to VPS development

Although Fujitsu began developing VPS in 1994, it has accumulated technologies since the 1980s through the development of robot simulators. In the 1980s, it was almost impossible to operate simulation models in real-time because 3D-CAD systems technology had just been introduced and the graphics computing environment was somewhat primitive. In succeeding years, physical laws and geometric calculations were incorporated in the robot simulators as necessary. As a result, a technology to predict the behavior of robot satellites in the space environment using simulations and a technology to rapidly detect the shortest distance or collision between objects were developed.[2] In the mid-1990s, graphics computers were personalized and from there, the robot simulators were converted into systems for designing and developing consumer devices. That is how VPS was

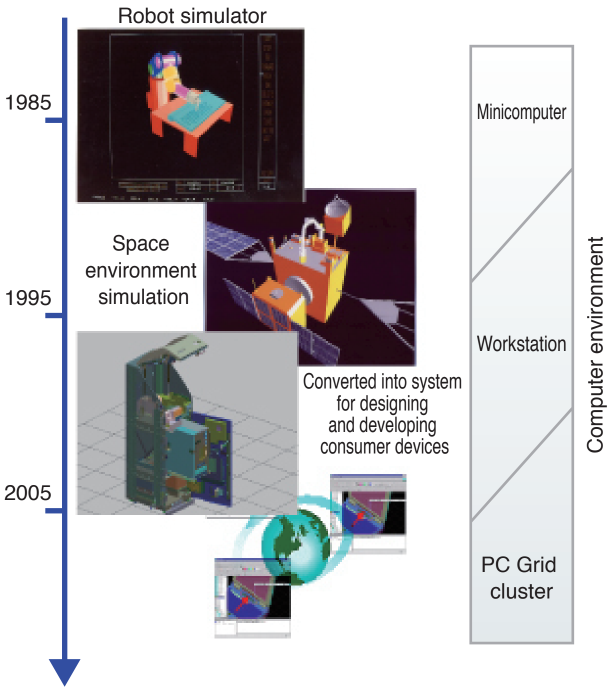

Figure 2
History of VPS development.

born (**Figure 2**).

Since the first version of VPS was shipped in 1999, its sales have grown steadily. More than 3000 VPS units have been shipped inside and outside Fujitsu. In 2001, the Fujitsu VPS received the Software Products of the Year award sponsored by Japan's Information-technology Promotion Agency (IPA).

3. VPS as a digital mockup

Fujitsu started developing VPS as a digital mockup to promote manufacturing using virtual simulation instead of developing actual prototypes. The advantages offered by VPS are described below.

The first advantage is that VPS can be offered at a low cost. Because most components of a prototype are special order parts, it costs anywhere from several million up to a hundred million yen to prototype a single device. A digital mockup is merely data requiring no expenses other than for the software and the personnel needed to enter the data. The purpose of prototyping is to verify a diversified range of such items as the defects, operability, maintenance capability, assembly capability, and design of a given product. The product development process repeats operations from prototyping to reviewing, correcting, and verifying those models. By using digital mockups to substitute for certain verification items, product development activities can be reduced for the number of digital mockups, resulting in reduced development costs.

The second advantage is that VPS enables more rapid manufacturing. Prototype production entails time for procuring and assembling components. Moreover, any failure occurring in the assembled components could disable the prototype. A prototype may also be destroyed during a test and thus would require components to be rearranged or reprocessed. Should such defects occur, verification work must be suspended. In that respect, the computer virtual mechanism allows engineers to simply change the data and continue operation.

The two advantages of low cost and high speed can demonstrate the multiplier effect in generating various benefits. For example, images on how to assemble a product or how the product will work conventionally remained in the designer's mind until a prototype could be produced. In other words, such images could not be shared with other people until an actual prototype was manufactured. Digital mockups allow the persons concerned to share product images at an early stage after completing the design. Because digital mockups can easily be duplicated, mechanism designers, hardware designers, software programmers, factory line employees, sales employees, and others involved in design work can perform verification activities in parallel.

The third advantage is that VPS allows engineers to conduct verification activities under physically impossible conditions. For instance, an assumption of "If this part is fixed here" can

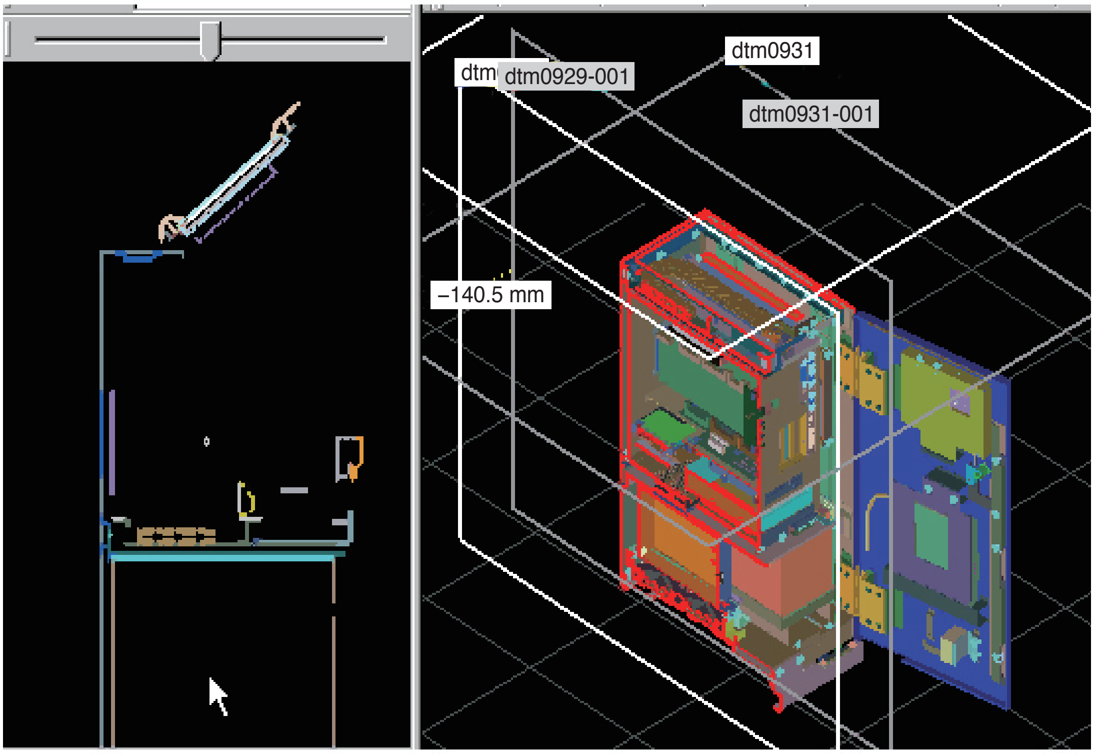

Figure 3
Cross-sectional view.

easily be considered beforehand. Many possibilities regarding part fixation techniques and methods of assembly can thus be quickly considered.

VPS can also artificially produce abnormal states that are difficult to actualize with normal prototypes in conducting various verification activities. Because digital mockups are not destroyed unlike actual prototypes, verification activities for failure states can be carefully repeated, thus helping to build systems with a higher tolerance against failure.

Digital mockups allow engineers to see inside an assembled product model just like when using a CT scan (**Figure 3**). Noteworthy part groups can be clipped from the overall model as required to carefully check whether such groups can be easily assembled or disassembled through operations involving the clipped images (**Figure 4**). This also represents a unique and advantageous aspect of digital mockups that offer excellent operability.

4. Mechanical representation

The greatest characteristic of VPS is its ability to reproduce a virtual mechanical motion that works just like a real product. This technique is used to interactively operate the mechanical parts on a digital mockup using the mouse to conduct various verification activities instead of using an actual prototype. Although this technique requires high-speed mechanical simulations, real-time simulations are difficult because general mechanism analysis software precisely calculates friction and other factors. VPS places emphasis on the reproduction of ideal movement for designers. Complex dynamic calculation is thereby simplified as much as possible

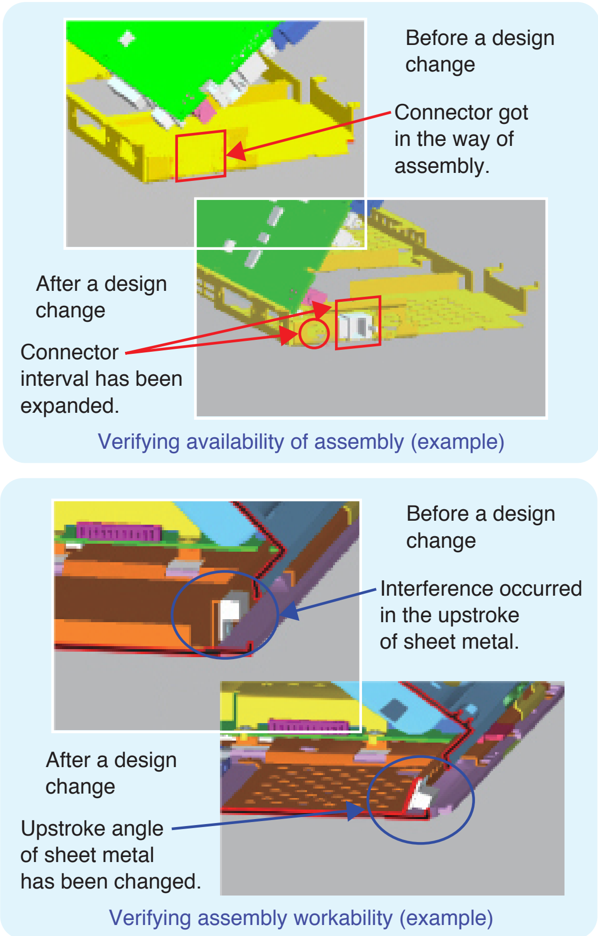

Figure 4
Verification of assembly capability through real-time operation.

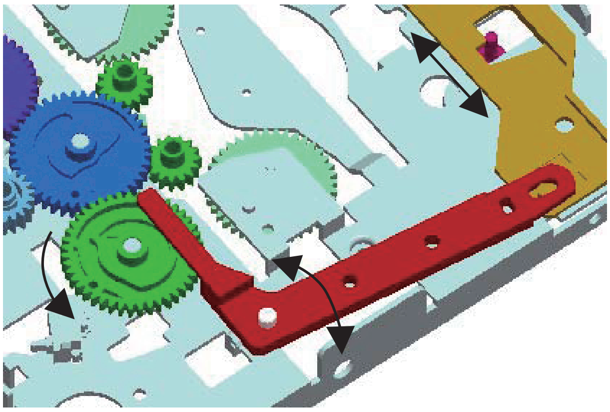

Figure 5
Mechanical representation.

to reproduce the kinematics of the mechanism in real time.

The fundamental elements of mechanical representation are rotational movement around the rotational axis and translational movement in the linear direction. All types of mechanisms can be represented in combination with these factors (**Figure 5**). When the relation of movement between the driven side and the passive side has been preliminarily defined as a linkage relation between the factors, even large-scale mechanisms can be quickly calculated. By controlling the linkage timing, even complex transfer mechanisms such as a clutch and ratchet can be simulated.

These movement representations are ideal. In real products, backlash in a gear or play in a groove mechanism will always occur. A mechanism that can maintain its desired functions for a certain level of variation is a vital point that mechanism designers must always keep in mind. VPS can generate backlash or play to enable an operation check of a mechanism having variation or estimate the variation tolerance.

VPS incorporates techniques that enable high-speed calculation as needed for the dynamics of force as well as kinematics. For example, the transfer mechanism consisting of gears and cams, and often used in mechanical products can ignore the influences of the Coriolis force. VPS employs this property to help quickly calculate the torque applied to the motor shaft.

In an environment where it takes time to prepare for a mechanical simulation, a virtual simulation cannot produce a sufficient effect. Therefore, for the 3D models of parts, 3D CAD data created with the mechanical design is used to easily and intuitively set the mechanical operations. VPS comes with 3D CAD data converters for all major, commercially available 3D-CAD systems and large-scale products assembled in combination with part groups designed using different CAD systems.

5. HIL/SIL simulation technologies

As mentioned in the Introduction, the development of embedded software in mechatronics products is becoming increasingly important. When developing embedded software, engineers create control programs based on mechanical control specifications and timing charts, and then conduct operation tests and make final adjustments in conjunction with prototypes. In the earliest stage of development, however, specifications are often too imperfect to conduct joint tests even after coding, until the prototypes are produced. Moreover, because the initial prototypes that were produced with difficulty are inferior in terms of maturity, it often takes time to investigate the cause of an error occurring in the joint tests. To solve these problems, hardware-in-the-loop (HIL) simulation technology has been developed.[3] This technology allows joint tests to be conducted using a virtual mechanism on VPS instead of actual prototypes (**Figure 6**). The control board on which the embedded software and microcomputer (hardware) are installed is connected to VPS to run the same programs as those used to control the actual prototypes. Moreover, software-in-the-loop (SIL) simulation technology has been developed. In this technology, a software simulator has replaced the control board. Both technologies allow software programmers to not only develop programs while checking the control specifications through the virtual mechanism, but also to upgrade the embedded software without waiting for prototypes to be completed. It is said that recovery programs for such error states as motor or sensor failure, jams, and defective operation account for 70 to 80% of the total embedded software configuration. The virtual mechanism can reproduce the states of errors that rarely occur and verify program operation as many times as needed without destroying the product mechanism.

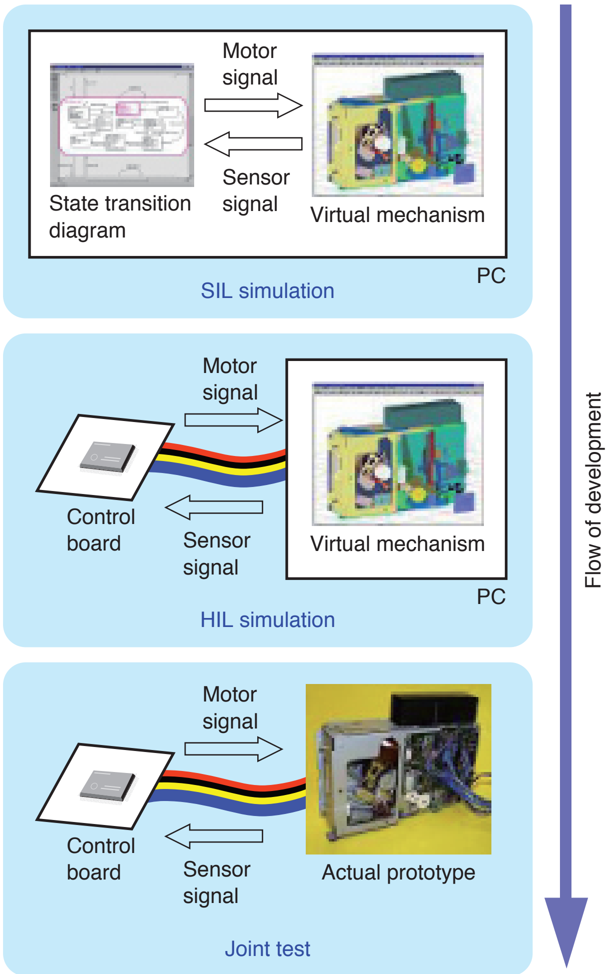

Figure 6
Overview of HIL/SIL simulation technologies.

Figure 7 shows the principle of HIL/SIL simulation technologies. When the motor control signals from the control board are input to VPS, movements of the motor and mechanism are simulated based on those signals. Then a sensor value obtained according to the state of the mechanism is returned to the control board. This simulation gives importance to modeling of the motor and sensor, as well as to the connection interface between the control board and VPS. Also modeled are DC and stepping motors, on/off switches, and the potentiometers frequently used in mechatronics products. Regarding the connection interface, many different connection configurations are considered depending on the product model and method of development. To

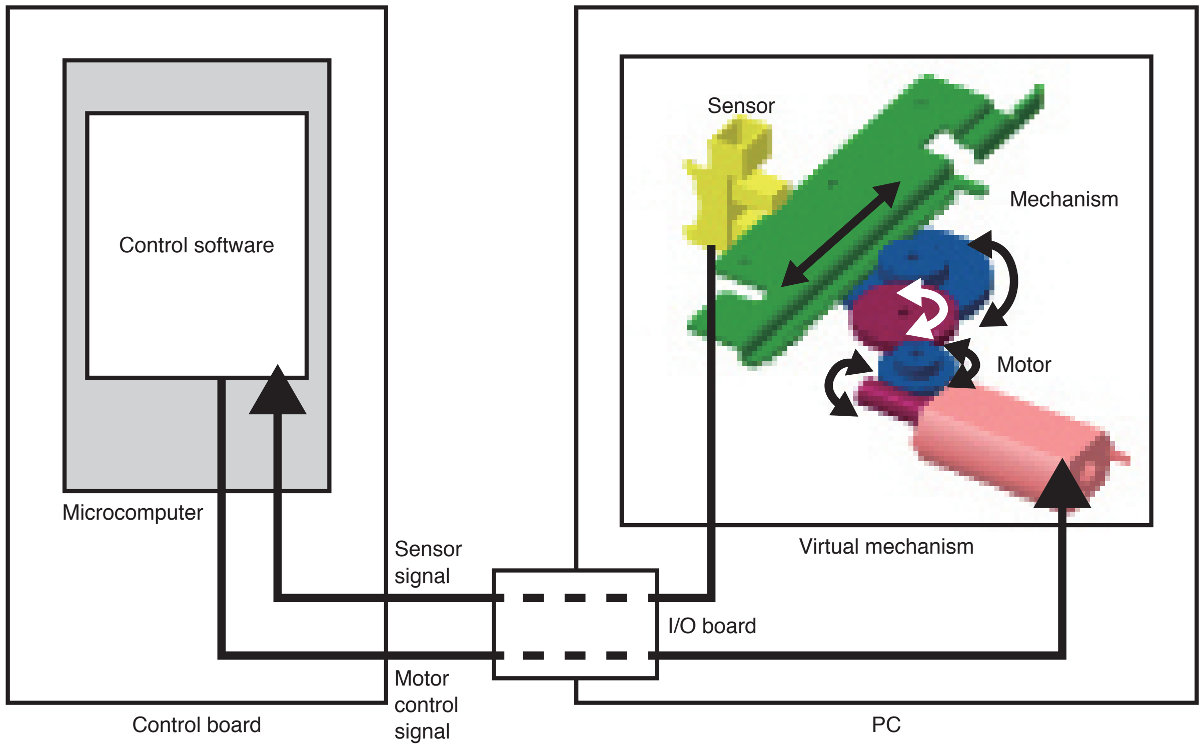

Figure 7
Principle of HIL/SIL simulation technologies.

support these configurations, the basic interface has generalized specifications so that users can easily configure the connection interface.

HIL/SIL simulation technologies based on VPS are currently applied to develop various types of devices such as printers, CD changers, and semiconductor production equipment. Both have brought about very significant effects. As shown in **Figure 8**, when VPS is applied to conventional sequential development, the debugging work for embedded software can be brought forward. Accordingly, a problem that may be found in conjunction with the actual product can be detected at an early stage. A practical example has been reported where the development person-hours could be reduced by 70% with VPS. A lot of problems occur when conducting all verification activities on an actual prototype. However, installing VPS can reduce the number of problems that may occur on an actual prototype because preliminary verification can be performed on VPS by almost 70% of all verification activities. **Figure 9** shows an example of this effect of installing VPS.

It is believed that new approaches will be promoted for developing embedded software, such as abstract model design and hardware-software codesign, to support systems that will grow in scale. Fujitsu is taking these approaches toward developing VPS to integrate the development environments from upper to lower processes, develop cooperative development environments for hardware, software and mechanism, and achieve higher efficiency in verification testing.

6. Modeling of flexible objects

Because digital mockups are based on 3D-CAD systems-shaped data, such mockups

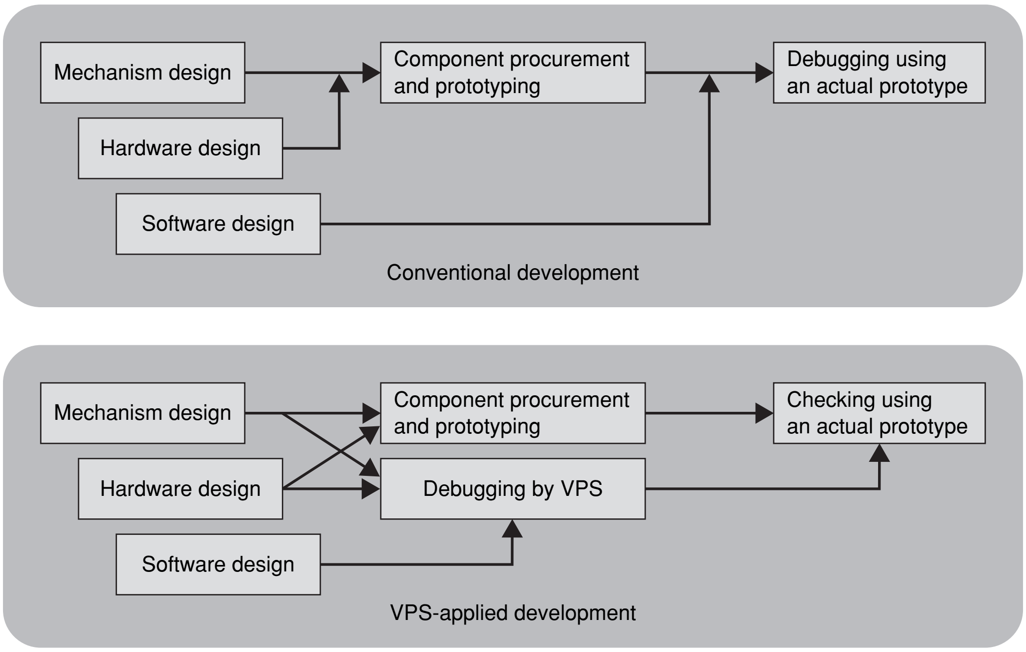

Figure 8
Flow of development process using VPS.

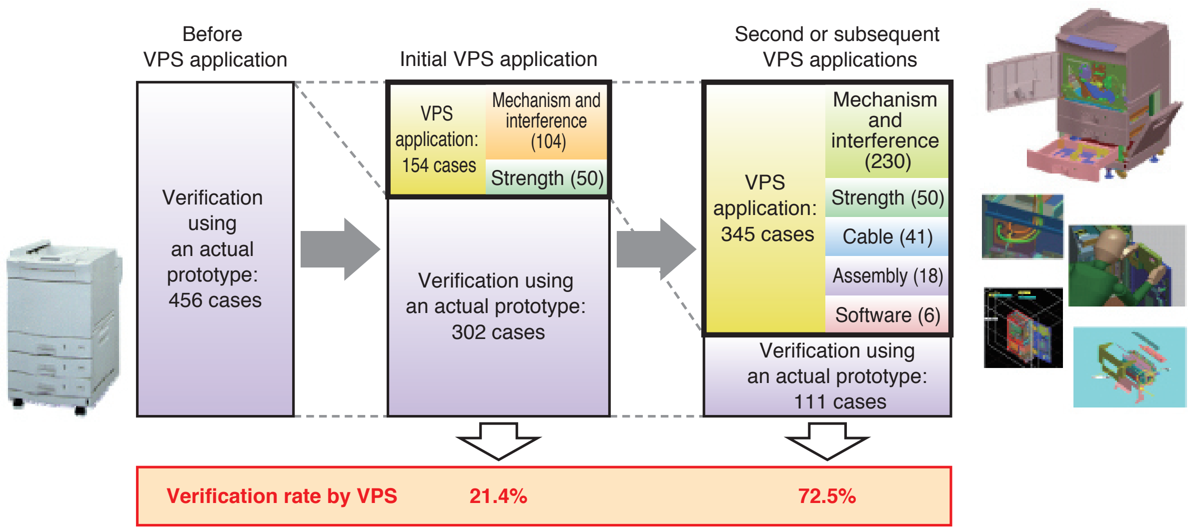

Figure 9
Effects brought about by VPS: Analyzing cases to be improved and verification result.

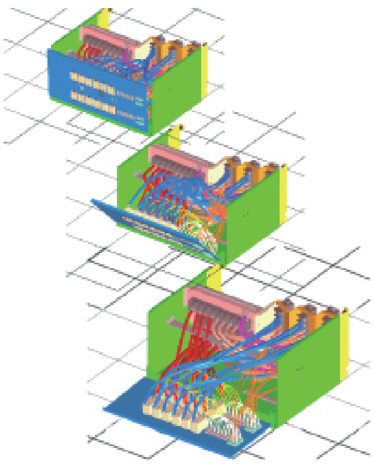

Figure 10
Example of harness layout design.

can generally only handle a rigid body. However, there are growing requests for the modeling of an elastic body due to the widespread use of digital mockups. Because quite a few wire harnesses are built into mechatronics products, it is hoped that the efficiency of layout design to determine wiring routes and lengths in particular will be promoted. Conventional harness layout design tends to get delayed because it requires both mechanical and electrical design specifications. It is much more difficult to design the layout of harnesses allocated to moving parts because the harnesses become deformed with every mechanical operation. To address these problems, Fujitsu developed a harness simulation where harnesses become deformed in real time in conjunction with the mechanism. Fujitsu also developed a design support system for wire harnesses with which harnesses can be allocated and verified virtually on digital mockups.[4)]

To achieve high-speed harness simulation, VPS employs a technique whereby harnesses are regarded as linear flexible objects and approximates these objects by using free curves. It does not employ a structural analysis technique requiring much time to precisely obtain the harnesses shape.

High-speed and high-precision simulation has been achieved by using a curve to indicate a harness. The curve is shaped where both bending elasticity energy and potential energy are minimum values as a result of calculation in view of the rigidity and gravity of the harness. This technique allows engineers to deform the harnesses in real time depending on the movement of connector parts connected to the harnesses.

In addition to the harness simulation, the harness layout and verification functions built into VPS establish a practical design support system for wire harnesses. This system allows engineers to allocate harnesses on a 3D virtual prototype and interactively check the lengths, interference states, and maximum curvatures as if allocated on the actual prototype. **Figure 10** shows an example of the layout design for multiple harnesses on the opening and closing section of a panel. The design support system for wire harnesses facilitates the design of optimum lengths for the harnesses when the panel is being opened and closed. This system has also contributed practically to improving design quality and reducing the design person-hours.

7. Future VPS development

Figure 11 shows the future direction of VPS development. While the basic VPS functionality lies in the modeling and embedded software, strong user demands for VPS include dimensional tolerance, geometric tolerance, exact mechanical dynamics, elastic dynamics, and fatigue analysis. The current stance of VPS relative to these demands is using specialized systems for necessary analysis as the best way. Naturally, it will take an immense amount of time to perform calculations for the demands above. Therefore, VPS will presumably be used as a front-end system, such as to enable seamless data linkage between modeling and analysis or processing, and display the analysis results. The overriding concept is that the VPS front-end system will

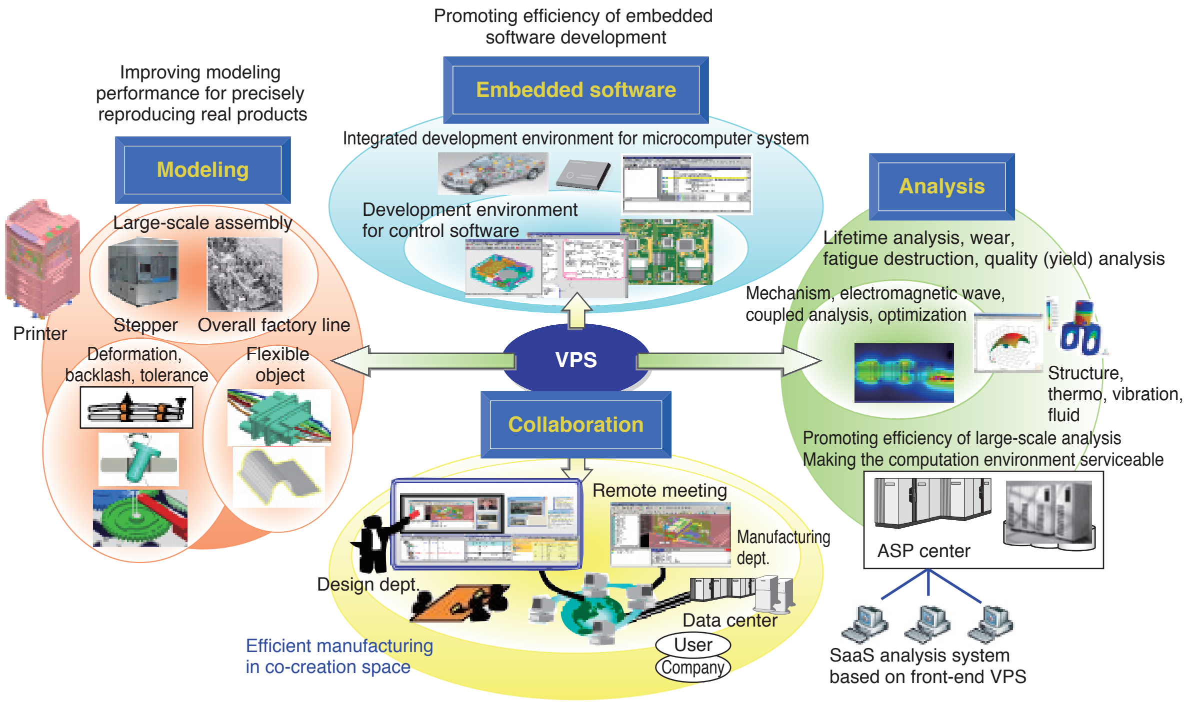

Figure 11
VPS as front-end system for manufacturing.

provide software as a service (SaaS) environment where users receive analysis services from back-end cluster computers without having to create their own analysis environments.

"Collaboration" based on remote design review is also very important. It is becoming increasingly important, particularly for global companies, to create an environment where employees can efficiently promote manufacturing while sharing information with developers including BRICs located worldwide. It is believed that in the future, collaborative spaces will develop into co-creation spaces between manufacturers and the users who will come to these spaces.

The key to the modeling function is developing a technology for easily handling larger volumes of assembly data. Some users are demanding manufacturing plant-wide modeling. Embedded software is expected to operate on a multi-core processor and support a function to estimate total power consumption including the mechanical movement. Accordingly, it will become increasingly important to build a flexible codesign environment for hardware, software and mechanism.

8. Conclusion

Conventionally, several prototypes were inevitably produced in the mechanism development processes. In contrast, VPS-based virtual simulation environment has ensured substantially higher efficiency in this field. Even when prototypes are actually produced, the knowledge obtained can be sequentially reflected in VPS virtual models. It is hoped that VPS will develop into a more useful tool for inheriting manufacturing knowledge. Fujitsu has been continuously improving VPS by correcting inadequacies through the practical use of internal manufacturing worksites. VPS holds an upper hand over competitive products made by CAD system-specified developers that lack manufacturing departments, because the advantages and disadvantages of VPS can be verified through manufacturing. VPS will consequently achieve more remarkable progress as a manufacturing system originating in Japan.

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