Preliminary Comparison of Hybrid Testing Techniques

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Abstract

Hardware-in-the-loop simulation (HILS) and dynamically substructured system (DSS) techniques are generally classified as hybrid methods for performance evaluation of engineering systems, combining both numerical simulation and hardware experiment parts. Principally, HILS techniques are widely applied to testing of power electronics and vehicle systems, while DSS methods emphasise on civil and structural engineering application. Although the two strategies are present in different fields, the similarity and difference between them are briefly discussed in this paper, in order to facilitate cross-literature communication about testing methodologies.

Keywords: dynamically substructured system, hardware-in-the-loop simulation, hybrid testing, actuator

Nomenclature

\[ \Sigma_E \]  emulated system
\[ \Sigma_N \]  numerical parts
\[ \Sigma_P \]  physical parts
\[ G_{TS} \]  transfer system/interface device
\[ z_N \]  numerical part output
\[ z_P \]  physical part output

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doi:10.1016/j.proeng.2014.06.370
1. Introduction

In the dynamic testing field, two hybrid methods for performance evaluation of engineering systems are developed, called dynamically substructured systems (DSS) and hardware-in-the-loop simulation (HILS) techniques. Both DSS and HILS methods involve numerical process and physical experiment parts. Thus, they combine the benefits of numerical computation and full-size experiment strategies, enabling investigation into dynamic behavior of engineering products to become more rapid, economic, focal and flexible, with repeatability and efficiency. Principally, the execution of DSS and HILS tests involves three steps: (i) partition of an entire system into sub-components, (ii) construction of numerical models, full-size physical specimen and associated testing rig, and (iii) implementation and reliability analysis of the testing results.

HILS techniques are widely used in the area of mechanical, electrical and electronic, vehicle, radar and robotic engineering e.g. [3-5], while DSS focuses its application on mechanics, structural and seismic engineering systems, e.g. [6-9]. It is noted that this paper only presents the principal classification, and it would be not possible to include all the cases. As shown in the DSS implementation scheme of Figure 1, at least two sub-components are considered, which are defined as numerical substructure (ΣN) and physical substructure (ΣP), respectively. Usually, critical and nonlinear parts of the entire emulated system (ΣE) are examined physically at full scale in ΣP, and ΣN consists of the remaining components which are well-understood. Actuator systems and sensor devices, which are collectively called the transfer system (GTS), are installed within ΣP, in order to interface the numerical components with physical specimens. However, in the HILS scenario, as shown in Figure 2, the numerical computation part (ΣN) is usually called virtual prototyping or software simulation, while the physical part (ΣP) is called hardware. In addition, the hardware which interfaces ΣN with ΣP is usually called coupling devices. Although DSS and HILS techniques are defined by distinct terminologies, they exhibit similar partition schemes in application.
2. Differences between DSS and HILS methods

This section briefly discusses the major differences between the two hybrid testing methods, which primarily relate to the content of numerical parts $\Sigma_N$ and interface devices $G_{TS}$. First, in terms of the numerical simulation, because DSS is commonly applied to the testing of structural engineering systems, its $\Sigma_N$ usually includes computation of equation of motion associated with ordinary differential equations or lumped large-size state-space matrices; that is modeling of entire dynamic components. In contrast, the software parts within HILS loop are
usually run via a set of look-up tables and visual prototyping machines; see Figure 3 and [5] for example. Therefore, $\Sigma_N$ within HILS tests involves more signal and image processing relating to simulation of realistic environments and loading conditions.

With respect to the $G_{TS}$ part, DSS involves the testing of realistic and large-size structural or mechanical components, and therefore $G_{TS}$ must include mechanical actuators, such as servo motors, in order to transfer mechanical motion and energy between $\Sigma_N$ and $\Sigma_P$. However, it is noted that in some cases, HILS tests do not necessarily include a mechanical actuator. For example, the debugging test of electronic control units using HILS method only requires signal processing between $\Sigma_N$ and $\Sigma_P$, irrespective of transfer of mechanical energy. As a result, different forms of interface devices lead to distinct compensation approaches in the DSS and HILS literature. In the DSS scheme, its control system design aims to compensate for unwanted actuator dynamics that destabilize the tests, whereas in the HILS control problems, instability is often due to pure time delay in signal processing.

Furthermore, in order to assess the reliability of HILS tests, [10] proposes a transparency theory to determine the signal transmission fidelity of coupling system $G_{TS}$. In contrast, there is no a rational technique to quantify the performance of DSS testing results yet. A new perspective in this aspect is the development of substructurability theory [11] in order to fulfill the gap between theory and application.

3. Conclusion

Hybrid HILS and DSS testing techniques are widely considered for performance assessment of critical engineering systems in the early stage of product design. The DSS methods mainly focus application on civil and structural systems, while the HILS techniques are often seen in testing of electrical, aerospace, robotic and automotive components. Both of them incorporate on-line numerical simulation and physical tests of realistic specimens. The signal transmission between numerical and physical parts must be run with high fidelity, in order to achieve reliable and successful tests. Execution of the two methods is complicated by the interface devices which include unwanted dynamics and sensor noises. Therefore, future work in extension to HILS and DSS comparison will consider the control and implementation issues and assessment of testing reliability.

Acknowledgments

The authors gratefully acknowledge the support of the Taiwan National Science Council, under grant 102-2625-M-007-001 ‘Development and Application of Model-Reference Semi-Active Control Methods for Magnetorheological Dampers (I)’, for the support in the pursuance of this work.

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