ABSTRACT

Gao, Xiuyu. Ph.D., Purdue University, December 2012. Development of a Robust Framework for Real-time Hybrid Simulation: from Dynamical System, Motion Control to Experimental Error Verification. Major Professor: Shirley Dyke.

Real time hybrid simulation (RTHS) has increasingly been recognized as a powerful methodology to evaluate structural components and systems under realistic operating conditions. The idea is to explore and combine the advantages of simultaneous numerical analysis with physical lab testing. Furthermore, the enforced real-time condition allows testing on rate-dependent components. Although the concept is very attractive, challenges do exist that require an improved understanding of the methodology. One of the most important challenges in RTHS is to achieve synchronized boundary conditions between the computational and physical substructures. Test stability and accuracy are largely governed by the level of synchronization. The sensitivity of the RTHS system error to the de-synchronization error is analyzed, from which a worst-case substructure scheme is identified and verified experimentally. This de-synchronization error, which is largely associated with the actuator dynamics, is further analyzed, by studying the sensitivity of the actuator dynamics with respect to individual parameters.

The objective of this study is to develop and validate a robust RTHS framework. Hardware development include a reaction system, a servo-hydraulic actuation and control system, a digital signal processing system, and a steel moment resisting frame specimen. An H_∞ loop shaping design strategy is proposed to control the motion of actuator(s). Controller performance is evaluated using the worst-case substructure proportioning scheme. Both system analysis and experimental results show that the proposed H_∞ strategy can significantly improve the stability limit and test accuracy. Another key feature of the proposed strategy is its robust performance in terms of both parametric and non-parametric plant uncertainties, which inevitably exist in any physical system. Extensive validation experiments are performed successfully, including the challenges of multiple actuators dynamically coupled through a continuum frame specimen. These features assure the effectiveness of the proposed framework for more complex RTHS applications.