Thermomechanical Real-Time Hybrid Simulation: Advances and Challenges Towards Creating Resilient Systems

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Abstract: Thermomechanical real-time hybrid simulation (RTHS) provides unique opportunities to observe realistic behaviors and train models for system validation. It is a cost-effective and accessible cyber-physical testing method that combines experimental and computational modeling to study systems under extreme dynamic conditions. This presentation details the development and experimental validation of a novel thermomechanical RTHS method to assess the multi-physics response of lunar habitat systems due to disruptive events. It outlines the framework, modeling approaches, and experimental considerations crucial to establishing the two-way coupling between a numerical and a physical subsystem via an innovative thermal transfer system. The method is experimentally implemented and validated through scenario tests that simulate the cascading thermomechanical effects on a lunar habitat after a micrometeorite impact that damages its structural protective layer. These realistic tests aim to evaluate fault detection and decision-making methods in response to disruptions. Thus, using switching dynamic modeling, the RTHS problem formulation is designed to have numerical damage and repair capabilities, allowing interaction with these fault detection and intervention methods. Through the execution of these scenario case studies, the thermomechanical RTHS method developed is the first of its kind to experimentally execute the effects of damage and repair intervention strategies in real-time on a numerical subsystem while simultaneously imposing the cascading effects on a physical specimen.