Report on the Focused Discussion at NHERI Summit 2022

Multi-hazard Engineering Collaboratory for Hybrid Simulation: Nonlinear Real-time Hybrid Simulation

Focused Discussion at the Natural Hazards Engineering Research Institute (NHERI) Summit 2022

October 6-7, 2022 Washington, DC

Summary

Given the interest and challenges that nonlinear behavior has posed to the hybrid simulation research community, the Multi-hazard Engineering Collaboratory on Hybrid Simulation (MECHS) developed a benchmark control problem statement focused on this topic. To that end, a complete virtual RTHS simulation code package was provided to interested attendees of the NHERI Summit 2022. The scope of the problem was to improve our knowledge of nonlinear controllers by proposing and demonstrating control solutions using a virtual RTHS test that included an unbonded fiber-reinforced elastomeric isolator as the physical specimen and a one-story frame as the numerical substructure. The proposed benchmark control problem was discussed during a focused session at the Summit.

The objectives of the benchmark problem statement were to give the researchers, graduate students, and other interdisciplinary participants with a common framework to discuss the state-of-the-art of RTHS for tackling nonlinear problems. Moreover, it provided the community a space for open discussion on the current trends of RTHS applications, such as multi-physics problems, experiment design, and repeatability challenges.

See the MECHS page for more activities and resources: http://mechs.deignsafe-ci.org

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Introduction

The last MECHS Workshop, "Machine Learning in Hybrid Simulation", was held virtually on March 25th, 2022. The main purpose of the workshop was to show and discuss potential uses that Machine Learning and its related disciplines can have for Hybrid Simulation (HS) applications. An important section of the discussion was devoted to developing experiments for testing specimens with nonlinear behavior. Among the challenges discussed, were the management of nonlinearities and their impact in the HS loop, the computational burden that nonlinear behavior adds to numerical substructures, and the challenges in controlling a nonlinear plant.

Given the interest and challenges that nonlinear behavior has posed to the research community, the Multi-hazard Engineering Collaboratory on Hybrid Simulation (MECHS) developed a benchmark control problem on this topic. Acomplete virtual RTHS simulation code package, based on a real physical setup, was provided to interested attendees that were planning to participate in the NHERI Summit 2022, held at Washington, DC, on October 6-7, 2022. The scope of the problem was to design and assess nonlinear controllers for a RTHS test that included an unbonded fiber-reinforced elastomeric isolator as the physical specimen and a one-story frame as the numerical substructure.

The benchmark control problem statement and proposed solutions were discussed during a focused session at the Summit. The session was divided into three segments. In the first segment, the developers of the benchmark problem statement explained its components and shared a sample PID controller design along with its performances. During the second segment, two participants presented their solutions: the first presentation was based on reinforcement learning; while the second presentation relied on an adaptive model reference control approach.

In the final segment of the session, the attendees were split in three breakout groups. The aim was to gather ideas and suggestions that the RTHS-interested community has on how to further advance this discipline. The three main topics that arose from the discussion were: (1) the challenges for performing HS testing of multi-physics problems, which usually entail nonlinear behavior; (2) approaches to guarantee repeatability or alternative validation methods; and, (3) experiment design, particularly in tackling problems involving distributed loads.

This report is intended to document the aforementioned discussions and is being incorporated into the next Research Agenda on Hybrid Simulation. This report and that research agenda are being posted on the MECHS site for the community: http://mechs.designsafe-ci.org. Testing of nonlinear specimens and phenomena was one of the first motivations of the HS discipline. A benchmark control problem on a nonlinear phenomenon provides an opportunity for the community to test different techniques and creates a discussion on common grounds to identify key development areas. Future advances in our discipline should be able to manage complex nonlinear problems with a reasonable degree of confidence.

Discussion Groups

The attendees were assigned to three discussion groups led by a discussion leader as follows:

Group	Discussion Leader	Note Taker
1	Mohamed Moustafa (*University of Nevada Reno*)	Manuel Salmerón (*Purdue University*)
2	Gaby Ou (*University of Florida*)	Amirali Najafi (*Rutgers University*)
3	Christopher Gill (*Washington University in St. Louis*)	Edwin Patiño (*Purdue University*)

The discussion leaders were provided with suggested questions to guide the discussion, but they were free to conduct their groups at will. Here, the discussed topics were organized around the three major concerns identified from the breakout groups: multi-physics problems, repeatability of experiments, and experiment design.

Multiphysics Problems

Group 1 focused mainly on the fluid-structure interaction problems. They agreed that determining the scaling laws for fluids is the most challenging task for this type of RTHS experiments, especially when interactions are involved. Moreover, scalation complicates further the already intricated validation question.

On their side, members from **Group 2** discussed the possibility of extrapolating HS concepts to applications other than structural ones. For instance, one of the attendees brough the example of transient response in thermal transfer systems. In such systems, the actuator is distributed. Such transfer systems are also used in wind engineering where wind loads are applied in a distributed way.

Finally, **Group 3** discussed geotechnical applications and the particularities they may have. For instance, they brought up the fact that geotechnical problems are mostly force-based rather than displacement-based. Moreover, as opposed to purely structural applications, the inertia forces of the soils do not play a significant role.

The three agreed that expanding the universe of applications of RTHS would have the benefit of getting involved researchers from other disciplines.

Action Items and Future Research Needs

- It is needed to diversify the projects to include more multi-hazards RTHS experiments. Namely, the following applications should be studied further:
    - energy infrastructure;
    - off-shore structures;
    - regular and ultra-high performance concrete elements;
- Getting the stakeholders involved in the field might be a good strategy to get funding for new applications.
- A primer on scalation techniques was proposed for the Fluid-Structure Interaction Workshop to be held on February 8 and 9, 2023, at Florida International University.

Experiment Design

Group 1 discussed on the needed infrastructure to perform wind and fluid-structure interaction experiments. Among the proposed solutions for the distributed loading issue, the possibility of changing the usual actuation system, consisting of several actuators applying point loads in selected locations, for an actuated base, built with rotational springs, was discussed. Another suggestion that arose was to avoid numerically modeling the computational fluid dynamics (CDF) loading and using wind tunnels for testing instead. The problem of sensor distribution and thus that of discretization was also discussed.

The issue of the sensor distribution was also debated by the members of the **Group 2**. On the actuation system side, they agreed that in the current state-of-the-art of HS, the selection of actuators is application-based. Consequently, the experiment design has to be problem-focused.

Group 3 continued their discussion on geotechnical applications by stating that this kind of HS studies has been usually restricted because of the instrumentation limitations inherent to the soil nature. As an alternative to traditional HS techniques, the possibility of using virtual and augmented reality techniques was proposed. Regarding these methods, the group remarked the importance of keeping the time-dimension integrity of the experiments and the proper scaling of the studied systems.

The three groups agreed on the need of further testing with new actuation systems or experimental approaches to reach applications outside earthquake engineering.

Action Items and Future Research Needs

- Further research on new actuation systems configurations is needed to broad the field of application of RTHS.
- Novel sensing techniques should be considered in future RTHS projects.

Repeatability and benchmarking

Group 1 started this portion of the discussion by stating that the wind problems have the difficulty of not being as repeatable as earthquake ones: the flow input has to be generated, as opposed to an earthquake's time-history input. Consequently, several the imposed loadings and the obtained responses should be treated in a statistical sense rather than as a deterministic observation. This stochastic way of generating inputs makes benchmarking a challenging task.

Group 2 stressed the fact that HS applications usually recur to steel due to the reduced uncertainty in its properties, in contrast to, for example, concrete. The latter material has only been tested for few, simple structures in linear-elastic ranges. The question of how can the community move to more complex, geometrically nonlinear problems was discussed. Among the proposed solutions, adaptive, robust and machine learning based controllers were suggested.

Finally, **Group 3** talked about the benefits of benchmarks for engaging the community in open discussions. However, in resonance with **Group 1**, they brought up the fact that geotechnical problems are not as repeatable as structural ones. Monte Carlo and Markov chains techniques were proposed as possible solutions to the non-repeatability problem. Its additional benefit is that they would also help to make predictions on the behavior of the studied structures. Besides, the group agreed that statistical methods are needed to tackle the uncertainty issue that complicates repeatability of geotechnical experiments.

Groups 1 and 3 arrived to the conclusion that stochastic approaches may be needed to work with problems with highly uncertain loads. This same principle can be applied to solve the material uncertainty question posed by Group 2.

Action Items and Future Research Needs

- Create more benchmark problems on diverse applications to engage a broader range of researchers.

- The creation of a library or GitHub folder with the results of different RTHS problems was suggested.

Appendix A: Agenda of the Focused Discussion on Nonlinear Real-Time Hybrid Simulation at the NHERI Summit 2022

Program/Script

- Presentation and problem statement (15 min)
- Participants' Presentations (30 min)
- Discussion: Breakout groups (20 min)
- Conclusion/summary/concluding remarks (6 min)
- Recap and closing (4 min)

Appendix B: Day 2 schedule of the NHERI Summit 2022 where the Focused Discussion was included

DAY 2 SCHEDULE

Session descriptions are available below the schedule. Session times in the schedule table link to the full descriptions below.

7:30 AM	**Breakfast** Grand Foyer			
8:15 AM	**Opening Remarks** *Julio Ramirez* Grand Ballroom			
8:20 AM	**NSF Remarks** *Joy Pauschke* Grand Ballroom			
8:25 AM	**NHERI Decadal Visioning Study for FY 2025–FY 2035** *Jared Kosters* Grand Ballroom			
8:35 AM	**Community Update: NHERI Science Plan** *Ian Robertson* Grand Ballroom			
9:00 AM	**Mini-Workshop: Visioning Session for Future Research Needs and Priorities** Grand Ballroom			
10:15 AM	**Break** Grand Foyer			
10:30 AM	**Focused Discussion Sessions 1**			
	1A – Recent Investments in Large-Scale Testing Facilities for Seismic and Windstorm Hazards Salon K	**1B – MECHS-Nonlinear Real-time Hybrid Simulation** Salon J	**1C – Computational Simulation & Data Analytics in Natural Research - Part 1: Regional Scale** Grand Ballroom	

Appendix C: Pictures from the Focused Session