Development of a Virtual Cyber-Physical Testbed for Resilient Extra-Terrestrial Habitats

Jaewon Park*, Herta Montoya, Yuguang Fu, Amin Meghareh, Shirley J. Dyke, Davide Ziviani
Resilient Extra-Terrestrial Habitats Institute (RETHi), Purdue University
**Presenting author*

Topic Area: Interdisciplinary

Abstract: Establishing permanent and sustainable human settlements outside Earth presents numerous challenges. The Resilient Extra-Terrestrial Habitat Institute (RETHi) has been established to advance the fundamental knowledge needed to enable and design resilient habitats in deep space, that will adapt, absorb, and rapidly recover from expected and unexpected disruptions without fundamental changes in function or sacrifices in safety.

Future extra-terrestrial habitats will rely on several subsystems working synergistically to ensure adequate power supply, life support to crew members, manage extreme environmental conditions, and monitor the health status of the equipment. To study extra-terrestrial habitats, a combination of modeling approaches and experimental validations is necessary, but deep-space conditions cannot be entirely reproduced in a laboratory setting (*e.g.*, micro-gravity effects). To this end, real-time multi-physics cyber-physical testing is a novel approach of simulating and evaluating complex system-of-systems (SoS) that has been applied to investigate the behavior of extra-terrestrial habitats under different scenarios. The developed cyber-physical testbed consists of a real-time computational environment that includes dynamic models of the structural protective layer of the habitat, power generation system, ECLSS and exterior environment, and a physical environment that features a structural dome and a thermal transfer system. Such comprehensive framework that couples virtual and physical aspects will allow the simulation of fault scenarios, emergent behaviors, emergency situations (*e.g.*, meteorite strikes) and actions to be taken to restore a safe state of operation of the habitat. One of most critical features of the cyber-physical testbed is the interface between the two environments. A dedicated thermal transfer system has been designed and constructed to provide realistic thermal boundary conditions to the physical habitat. The extreme temperatures to be found at the interface between the external protective layer of the habitat and the interior structural elements are emulated by means of a low-temperature chiller and an array of cooled panels that cover a dome-style structure. The surface temperatures of the thermal panels are conditioned according to the results of virtual simulation, which take the output heat flux from the physical system as a feedback.

This work will describe the overall architecture of the cyber-physical testbed, the partitioning of the virtual and physical environments, and communication schemes. A meteorite impact and consequent thermal management scenario will be employed as a case scenario to demonstrate the capabilities of the cyber-physical testbed. In addition, preliminary commissioning of the physical thermal transfer system and next steps will be covered.