Design Digital Twinning for Hydro-Structural Optimization: Addressing High-Dimensional Design Spaces with Parametric Model Embedding

Riccardo Pellegrini*, Matteo Diez*, and Frederick Stern†

* CNR-INM, National Research Council-Institute of Marine Engineering
Via di Vallerano 139, Rome, Italy
Email: riccardo.pellegrini@cnr.it

† IIHR—Hydroscience & Engineering, The University of Iowa
Maxwell Stanley Hydraulics Laboratory, 100 C, Iowa City, IA 52242, USA

ABSTRACT

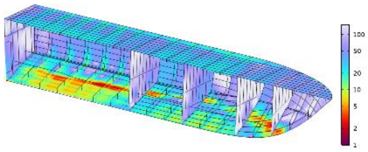

Figure 1: Pareto set (top) and factor of safety during slam (bottom)

Design Digital Twinning (DDT) is the integration of high-fidelity physics-based (HF) models, data-driven methodologies, and real-time sensing to create a virtual replica of a system. Unlike traditional digital twins, which focus on operational monitoring and predictive maintenance of existing assets, DDT is centered on the early-stage design process, enabling multi-disciplinary optimization (MDO). MDO with HF models of innovative, high-performance, and resilient designs, as seek in domains like aerospace and marine engineering, can be affected by the course of dimensionality, especially for global design optimization. A remedy is the use of unsupervised machine learning to reduce the design space dimensionality. Recently, the parametric model embedding (PME) methodology, originally formulated for the design space dimensionality reduction of parametric models in shape optimization [1], was extended for structural optimization problems [2]. Furthermore, the goal-oriented PME was formulated (GO-PME) to further accelerate the convergence of the optimization process. The PME and GO-PME were applied for the multi-fidelity structural optimization of a 40 ft generic prismatic planing hull (GPPH) undergoing realistic hydrodynamic loads from slamming in waves at high speed [3], addressing weight reduction and structural safety increase [4]. A reduction of the (real) design variables from 32 to 13, defining the structural element sizing, was achieved and two solutions were selected from a Pareto set of designs providing, with respect to the original design, 32% and 22% of weight reduction and an acceptable and increased factor of safety, respectively, see Figure 1. The objective of the present work is to extend the structural optimization problem [4] considering an extended design space, yielding a mixed-integer optimization with a larger number of variables, up to O(400), defining structural element number, size, and position; thus involving topological optimization.

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