Minimum Energy Adaptive Structures – All-In-One Problem Implementation

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Abstract

This paper presents new implementations of a design method to obtain minimum energy adaptive structures. The design method was formulated in previous work [1, 2] for reticular structures equipped with sensors (e.g. strain, optical) and linear actuators. The main objective of the design method is the minimization of the structure whole-life energy through reduction of the energy embodied in the material at a small increase in operational energy for structural adaptation. Structural adaptation is employed to counteract the effects of large loading events through control of the shape and of the internal load-path such that the design will not be governed by peak demands that occur rarely. Through balancing material use and operational energy demand, this method explicitly addresses current and future challenges such as material scarcity, energy depletion and reduction of building environmental impacts. This method has been applied to realistic spatial structures of complex layout [3] and it has been successfully tested on a large-scale prototype [4]. The substantial whole-life energy savings obtained through this method (up to 70% for slender structures) and its scalability to structures of complex layout makes it attractive for applications to realistic building scenarios.

The All-in-One problem formulation to obtain minimum energy adaptive structures is stated in [1]. However, the method given in [1] to solve the synthesis process is based on a nested optimization scheme which does not guarantee solution optimality. This paper presents a new implementation of the same synthesis process but based on mixed-integer programming (MIP). Branch-and-bound methods are employed to solve the MIP-based formulation to optimality. Topology, cross-section sizing and actuator layout are treated as binary design variables. Instead, member forces, nodal displacements and actuator control commands (i.e. length changes) are treated as continuous state variables. Geometric compatibility between nodal displacements and element deformations is enforced through adaptation, the actuator length changes modify the internal load-path to homogenize the stresses and change the shape of the structure to keep displacements within serviceability limits. Solutions obtained through the MIP-based method are benchmarked against those obtained using the nested optimization approach given in [1].

References

[1] G. Senatore, P. Duffour and P. Winslow, "Synthesis of Minimum Energy Adaptive Structures," *Structural and Multidisciplinary Optimization,* 2019 (in press).

[2] G. Senatore, P. Duffour, S. Hanna, F. Labbe and P. Winslow, "Adaptive Structures for Whole Life Energy Savings," *International Association for Shell and Spatial Structures (IASS),* vol. 52, no. 4 December n. 170, pp. 233 - 240, 2011.

[3] G. Senatore, P. Duffour and P. Winslow, "Energy and Cost Analysis of Adaptive Structures: Case Studies," *Journal of Structural Engineering (ASCE),* vol. 144, no. 8, p. 04018107, 2018.

[4] G. Senatore, P. Duffour, P. Winslow and C. Wise, "Shape Control and Whole-Life Energy Assessment of an "Infinitely Stiff" Prototype Adaptive Structure," *Smart Materials and Structures,* vol. 27, no. 1, p. 015022, 2018.